Basic Sciences for the Canadian Dental Aptitude Test

A Comprehensive Review

FIRST EDITION



ISBN 9781777105204

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London Press



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[PREPRINT EXCERPT #4112583]

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Published by London Press in Canada
Printed in the United States of America and Canada

ISBN-13: 978-1-7771052-0-4

First Edition

26 25 24 23 22 21 20 / 10 9 8 7 6 5 4 3 2 1

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INTRODUCTION | **WELCOME TO THIS TEXTBOOK**

ABOUT THE CANADIAN DAT

The ***Dental Admissions Test (DAT)*** is a standardized exam required for application to almost all dental schools in Canada and the United States. It is a critical component of your dental school application, since your DAT score is viewed as a predictor of success in future exams. Despite the considerable work you put into GPA and extracurriculars, your DAT score can make or break your application. With that said, it is highly recommended that you start preparing for this test early. The average student will spend four months studying for this exam.

Many Canadian students choose to prepare for the DAT using materials from large test prep companies. This is problematic because almost all DAT textbooks are written for the American DAT, which is a significantly different exam compared to the ***Canadian DAT (cDAT)***. They are administered by two different regulative institutions (American Dental Association vs Canadian Dental Association), and contain sections that do not overlap in content. One section that is unique to the cDAT is the ***Manual Dexterity Test (MDT)***, in which examinees carve a cylinder of soap into a specified shape. The ***Survey of the Natural Sciences (SNS)*** section of the cDAT is more content-heavy and focuses less on application compared to the American DAT. Likewise, the ***Reading Comprehension Test (RCT)*** section of the cDAT is much more fast-paced and contains less critical-thinking type questions compared to the American version. Finally, the ***Perceptual Ability Test (PAT)*** of the cDAT is administered on paper (rather than digitally). Therefore it is critical that your PAT practice takes advantage of key techniques specific to the paper exam. This textbook will guide you through all of the tips and tricks that will help you score high on the cDAT.

DAT FORMAT

The cDAT is composed of the following sections, in the order that they appear:

Section	Number of Questions	Time Provided
Manual Dexterity Test (MDT)	1 carving pattern	30 min
Break	–	10 min
Survey of Natural Sciences (SNS)	70 (40 biology, 30 chemistry)	60 min
Break	–	10 min
Perceptual Ability Test (PAT)	90	60 min
Break	–	10 min
Reading Comprehension Test (RCT)	50	50 min

WHAT DAT SCORE DO I NEED?

The cDAT is a scaled exam, meaning your ***raw score*** will be converted to a ***scaled score*** from 1 to 30. This conversion takes into account how difficult your specific exam was. On exam day, you may write a different exam than your colleagues. However, all scores taken during the same testing period (November or February) are comparable. In addition to scaled scores, a ***composite score*** called an ***Academic Average (AA)*** is calculated. This is simply the average of your SNS and RCT scores. It is recommended that you aim to score above a 20 in each section to increase your chances of acceptance into a dental school.

DAT STUDY STRATEGIES

1. ***Practice, practice, practice.*** You will not improve at all if you neglect doing practice questions and full-length exams. Getting familiar with the type and format of questions asked during the cDAT is the fastest way to bring up your score. This textbook was specifically designed to give you the most practice test exposure. With This textbook, you will get the most realistic simulation experience for the cDAT. Ensure that you take advantage of this by completing most, if not *all* 840 questions from the four hyper-realistic full-length exams included in this book.
2. ***Create a game plan.*** If you are like most students, you will be preparing for the cDAT while juggling university courses, extracurriculars, and even part-time jobs. You need to create a custom study schedule that sets aside protected time for cDAT preparation. Research has shown that 1 to 3 hour study sessions spaced frequently throughout the week is most effective for content retention. Block this time out in your calendar, agenda, planner or whatever scheduling tool you prefer.
3. ***Take content review seriously.*** Do not settle into a false sense of security just because you have taken first and second year university science courses. The amount of content tested in the SNS section is varied and diverse. You may need to review knowledge from as far back as grade nine science. During content review, make sure you focus on material that you struggle with, rather than the concepts you have already mastered.
4. ***Do not waste time on irrelevant content.*** The Canadian Dental Association (CDA) provides a list of topics that will show up in the SNS. These topics are covered in detail by this textbook. Anything that is not on this list is outside the scope of the cDAT. Do not assume that American DAT questions may be relevant.
5. ***Study smart, not hard.*** Psychology researches have shown for decades that our brain is much better at remembering scenes and locations than sentences or paragraphs. Take advantage of memorization strategies such as the method of loci, peg/hook system, and chunking. Also pay attention to the various mnemonics suggested throughout this book. If you have time, work on creating your own mnemonics.
6. ***Train for the cDAT like you would train for a marathon.*** Think of the exam as a challenge, not as a task. Have fun while studying, appreciate the process of learning, and most importantly, take breaks to avoid burnout. However, make sure to slowly develop your stamina and focus such that you are prepared to write a four-hour exam.
7. ***Disengage with social media.*** According to many pedagogical journals, it takes up to 10 minutes for your brain to fully re-engage in a cognitively intensive activity after being distracted. Furthermore, social media consumption has been correlated with poor mental health and increased anxiety. Focus on developing and investing in face-to-face relationships.

TEST DAY RULES

The CDA website always has the most up-to-date information on test centres and rules. Analogue watches are now banned, despite being allowed prior to 2019. A timer will usually be projected onto the front of your exam room. The only items you will need to bring are your photo ID and a printed copy of your confirmation letter. Pencils and erasers will be provided. Note that water bottles and calculators are not allowed. There is no penalty for guessing questions, so ensure that all questions on your bubble sheet are answered.

HOW TO USE THIS BOOK

Unlike other texts, this book is specifically written and formatted for the Canadian DAT. The ***biology*** and ***chemistry*** sections are presented in a high-yield bullet note format designed to maximize information density and readability. Each bullet point presents a new concept or unit of information. The ***reading comprehension*** and ***perceptual ability*** sections are presented in a more traditional paragraph format. As your progress, you will encounter the following icons throughout the text:



→ Presents information or suggestions that are extra-relevant for the Canadian DAT



→ Suggests a mnemonic or memory aid to help memorize important content



→ Presents a robust technique for solving a specific type of problem



→ Information that is very likely to appear on the actual exam

SECTION 1 MANUAL DEXTERITY



CHAPTER 1 | **PRINCIPLES OF MDT**

MINDSET

The Manual Dexterity Test is designed to evaluate your fine motor skills. This is a skill that can only be improved with practice. When studying for the MDT, it is important that you first learn the proper soap carving technique before attempting a practice test. Carving using a poor technique will only engrain bad habits into your muscle memory.

You will be given only 30 minutes to turn a solid cylinder of soap into a given pattern. This is not a lot of time, so you must move in a precise and purposeful manner. Many students will experience anxiety during the test, which is a significant detriment to your fine motor skills. The more you practice, the more comfortable you will become with the test format. In order to simulate test conditions as close as possible, it is recommended that you practice in the mornings (when the cDAT is held), in a quiet setting, and under timed conditions.

To practice the MDT, you will need to buy your own knife and pack of soaps. These kits are available from the CDA and various third-party suppliers online. Keep in mind that the soap you are given on test day is likely to be slightly different in texture, even compared to the official CDA kit. Be prepared to work with soap that is more or less crumbly, since texture is difficult for manufacturers to standardize. Soaps can be expensive, so try to limit your carving to one or two soaps per day in the weeks leading up to the DAT. To make the most out of every practice, grade your carvings using the official CDA rubric. Record any mistakes and areas of potential improvement in a journal.

TEST REGULATIONS

During the MDT, you will be supplied with pencils, a pencil sharpener, a permanent marker, standardized ruler (flexible), a soap, and a knife. Gloves are optional, meaning you must bring them yourself. Gloves are highly recommended to increase grip. The soaps are very slippery, and may become even more so if your hands get sweaty during carving. Bandages are also optional but recommended, in case you cut yourself. Keep in mind that watches are no longer allowed as of 2019.

EVALUATION OF CARVINGS

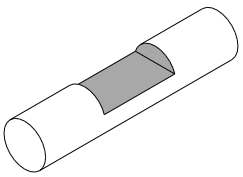
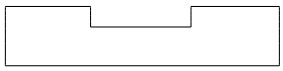
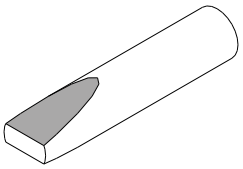
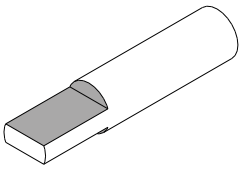
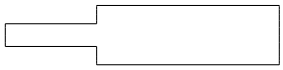
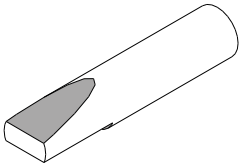
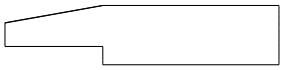
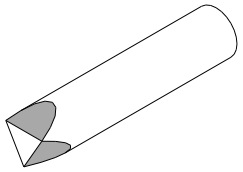
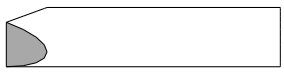
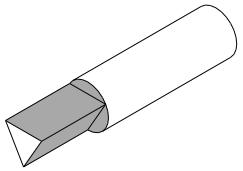
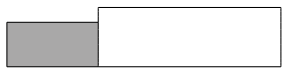
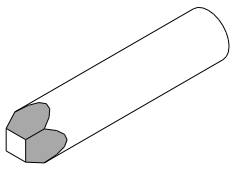
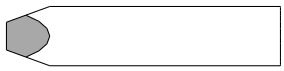
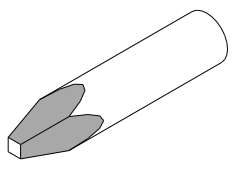
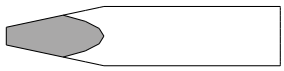
Your carving will be evaluated based on four criteria. Each of the following criteria are graded on a scale of 0 to 3.

- ***Pattern Reproduction*** – Does the carving accurately reflect the patterns illustrated in the instructions? To avoid an automatic deduction, you must carve the correct patterns
- ***Measurements*** – Does the dimensions of your soap match the instructions? To score high, you must ensure less than 0.5 mm of deviation from the instructed dimensions
- ***Planar Surfaces*** – Are your carved surfaces completely flat and smooth? To score high, you must avoid any slight curvature or roughness of surfaces that should be flat
- ***Angles*** – Are your carved angles sharp and accurate? To score high, you must ensure that right angles are extremely close to 90 degrees and not rounded
- ***Symmetry*** – Does your soap have the same symmetry as depicted in the instructions? To score high, you must ensure that longitudinally (lengthwise), the left side of the soap appears as the mirror image of the right side

It is highly recommended that you reference the official evaluation rubric provided by the CDA. Use this document to grade every practice soap that you carve.

CARVING PATTERNS

There are only eight possible patterns that you will be asked to carve. Each test will contain three of these patterns in combination. Note that some of these patterns may appear on the test incomplete (missing a cut).

Pattern Name	Isometric View	Side View	Front View
Saddle			
Flute			
Notch			
Flute-Notch			
Fluted Triangle			
Notched Triangle			
Fluted Square			
Narrow Fluted Square			

CHAPTER 2 | **TECHNIQUE**

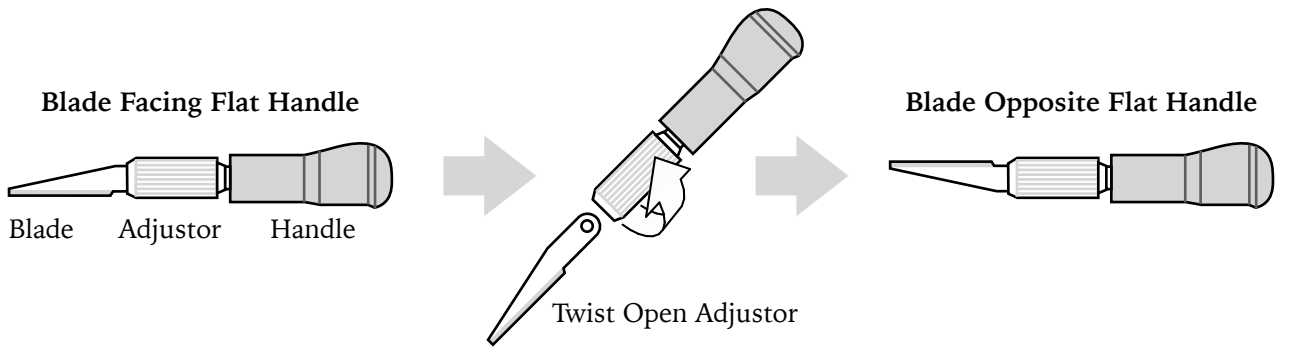
Now that we are familiar with the basic patterns that you may be asked to carve on the cDAT, let us discuss proper technique. Your 30 minutes of carving time should be divided into the following phases:

Phase	Description	Time Allotted
Interpretation	Read the carving instructions and ensure you understand	1 minute
Drafting	Use the pencil and ruler to lightly etch the required dimensions onto the soap	9 minutes
Rough Carving	Use the blade to roughly carve out the patterns, leaving an adequate margin for fine carving	10 minutes
Fine Carving	Use the blade and ruler to refine your rough carving, ensuring perfect dimensions, angles, and flatness	10 minutes

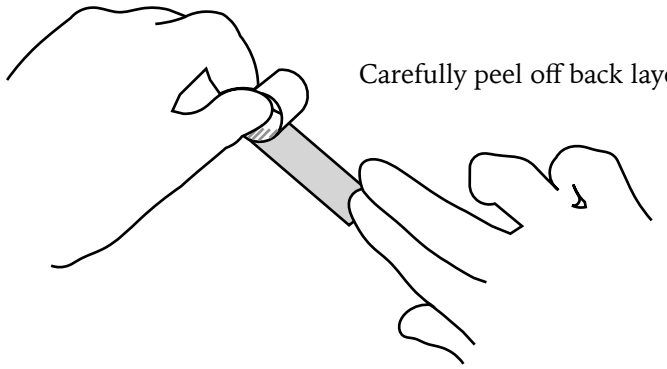
In the next few paragraphs, we will discuss in detail how to approach each of these phases.

PHASE 1: INTERPRETATION

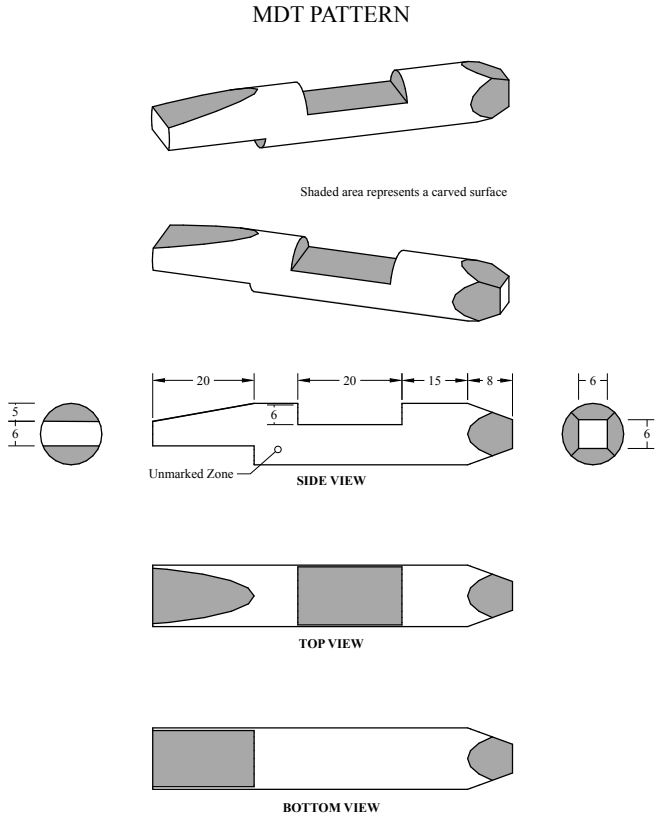
In the couple of minutes that you have before the test begins, ensure that the supplied HB pencils are as sharp as possible and adjust the blade of your knife to the orientation that is most comfortable to you.



Many students also find it helpful to peel off the stiff paper backing of the supplied ruler. This makes your ruler more flexible and easier to wrap circumferentially around the soap.



Once the test begins, open the MDT booklet and examine the instruction page, which will look like this:



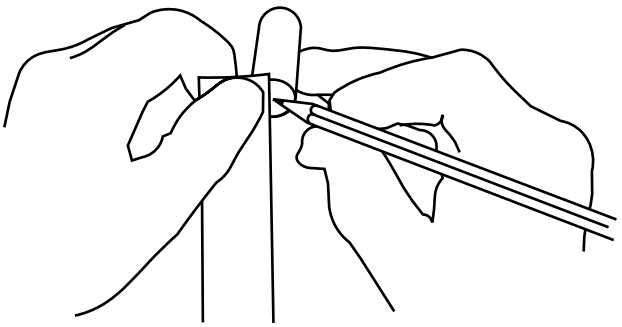
All dimensions are in millimetres. With every set of instructions, there will be a special area called the ***unmarked zone***. This area will not be evaluated during scoring, and exists to account for the variability in length between each cylinder of soap. However, the diameter of each soap should be exactly 16 mm.

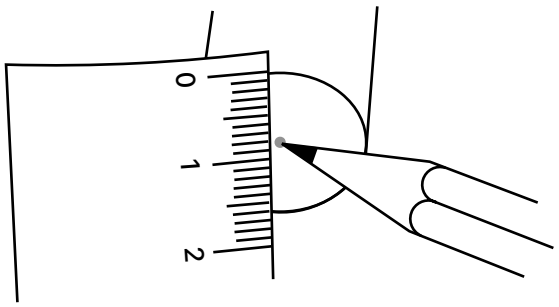
The isometric 3D views may not be shown. However, the side, top, and bottom projections will always be presented. You should practice visualizing the 3D pattern given only the 2D projections.

Be sure that you understand exactly what the instructions are asking for, since carving the wrong pattern will result in an automatic deduction to your score (0/3 in the measurement category of the CDA rubric).

PHASE 2: DRAFTING

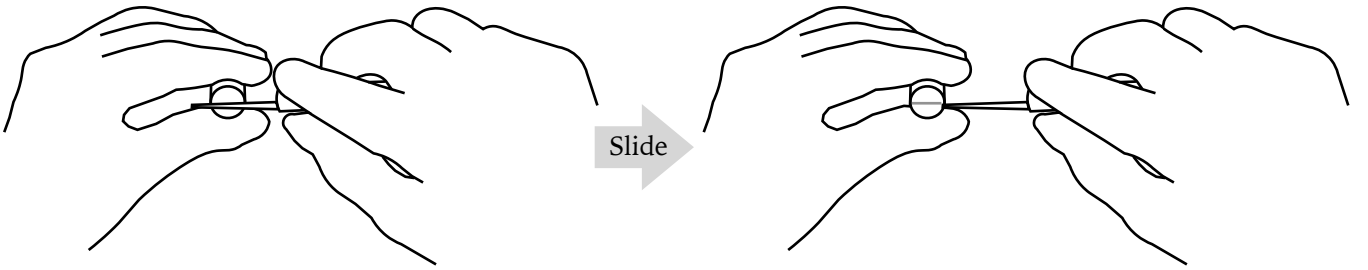
This phase involves using our pencil and ruler to etch out ***guidelines*** that will help us carve symmetrical and accurate patterns. To start, position your ruler over one end of the soap such that it covers the entire diameter of 16 mm. Next, use your pencil to mark the ***centre point*** (at 8 mm). Keep in mind that there is an extra millimetre of paper between the edge of the ruler and the beginning of the markings.



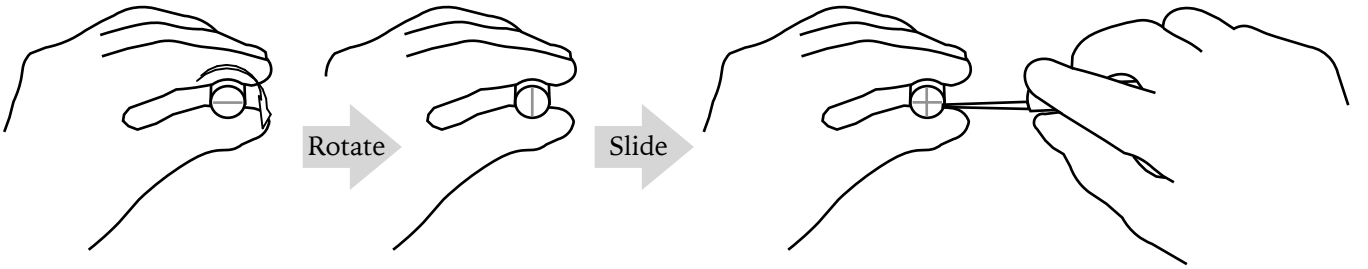


Zoomed View

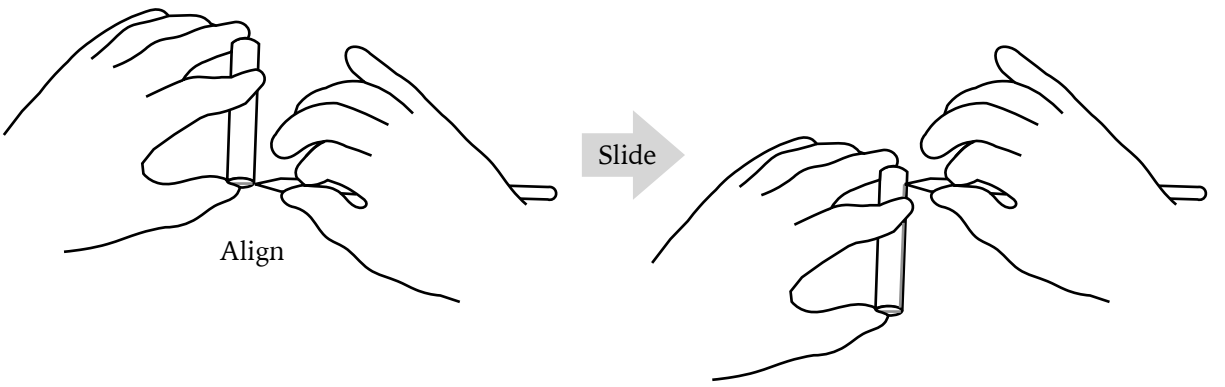
After marking the centre point, use your blade to etch a horizontal line that runs through it. To do this, place the blade onto the soap and pull the knife straight back while applying gentle force.



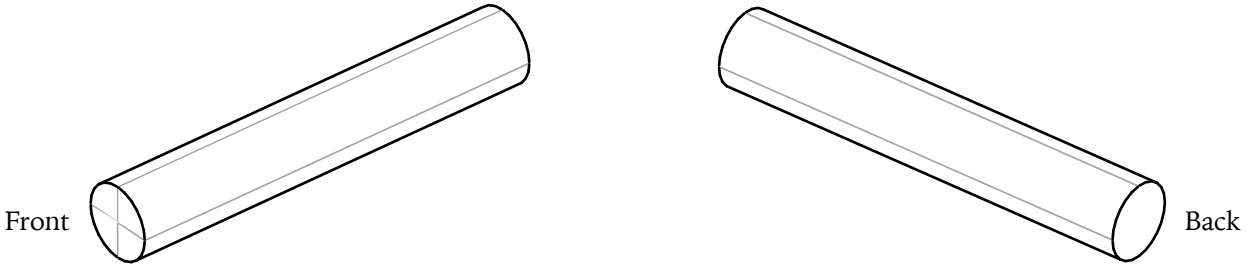
Next, rotate the soap 90 degrees and etch another line that runs through the centre point. Make sure your blade is as close to a right angle as possible.



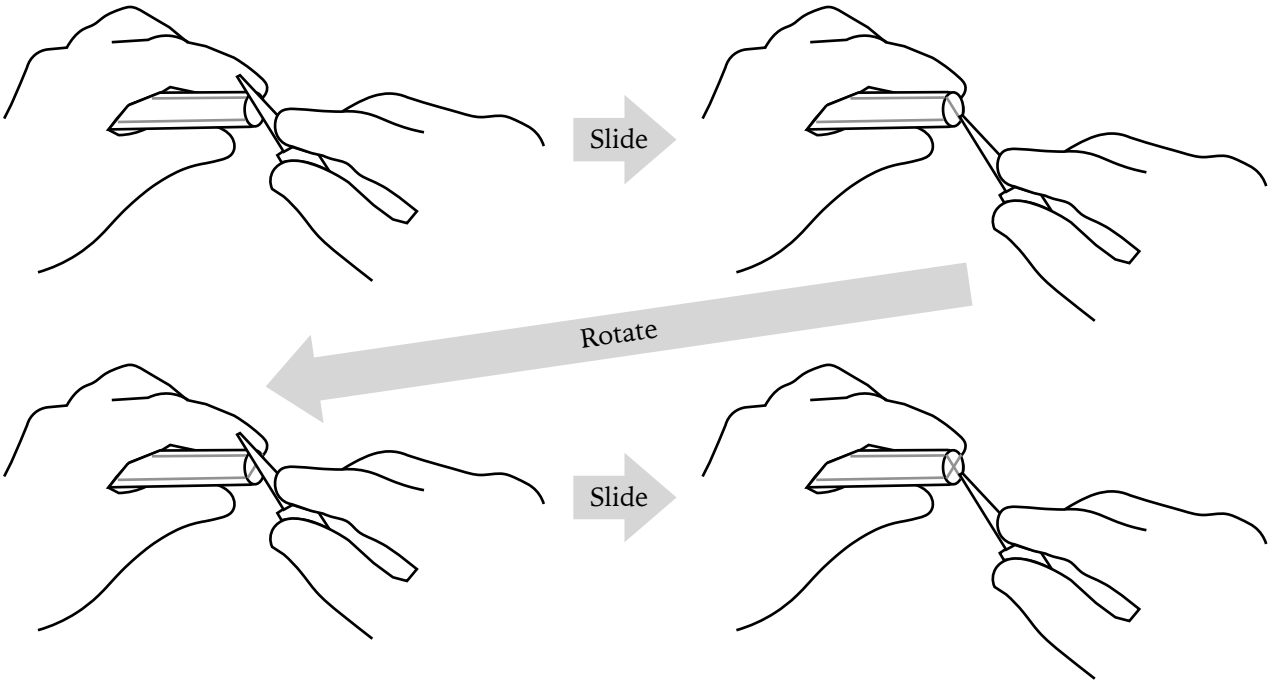
Now we need to extend these two guidelines across the entire length of the soap. The level of precision in which you execute the next step is critical. Using one hand, grip the soap using your thumb and middle finger and rest it on the table. Using your other hand, hold the pencil at the same hight as one of the two guidelines. In one fluid motion, move the soap towards you such that the pencil etches out a perfectly straight line. It is important that your wrist and fingers do not move at all. This will cause the etched line to curve or be shaky. Only your elbow and arms should be in motion.



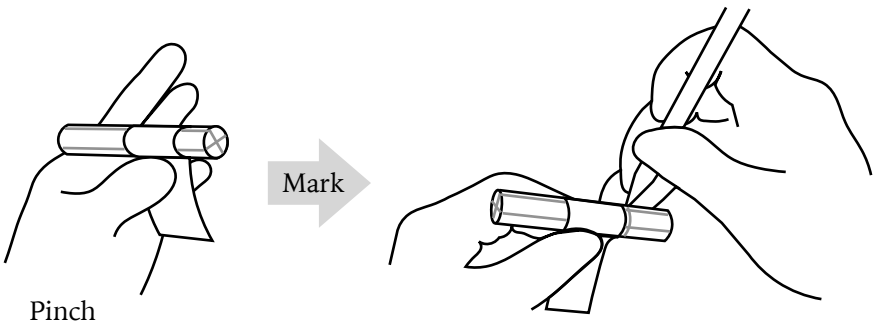
Repeat this until four ***lateral guidelines*** exist along the top, bottom, left, and right sides of the soap. Your soap should now look like the following:



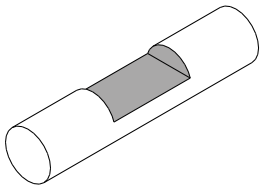
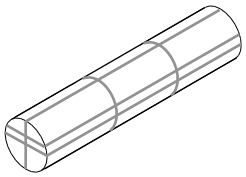
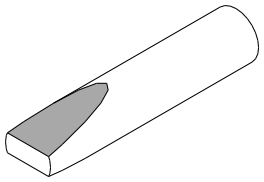
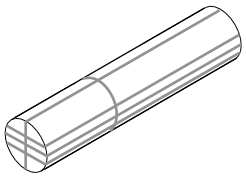
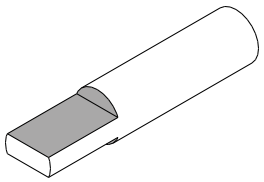
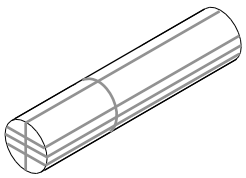
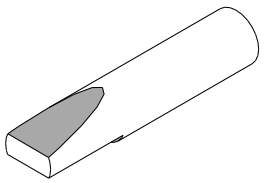
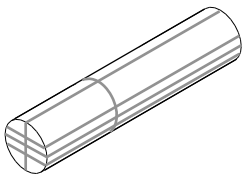
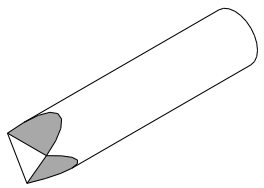
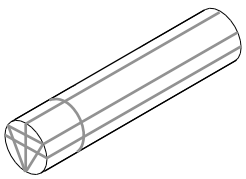
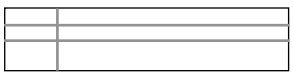
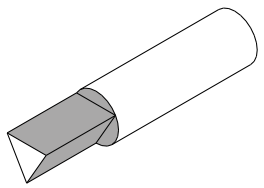
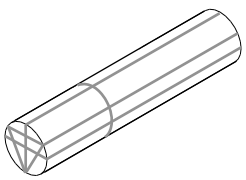
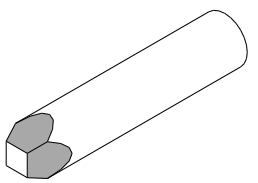
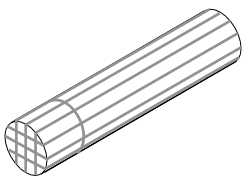
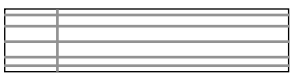
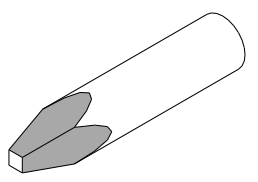
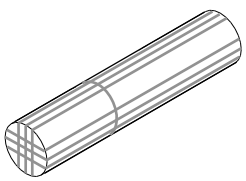
Next, use your blade to connect the lateral guidelines on the remaining non-etched surface (back side).



Now we need to create guidelines that delineate the edges of the actual patterns to be carved. Using the technique we just presented, create a pair of lateral guidelines representing the *depth* of the carved pattern (the distance towards the cylinder's centre). Next, create ***circumferential guidelines*** by measuring and etching the *length* of the carved pattern (the distance from one end of the cylinder) along *all four* lateral guidelines. Then, wrap your ruler around the soap, pinching it tight between your thumb and index finger. Make sure the ends of the ruler are aligned with each other, and that there is no space between the soap and ruler. Finally, take your pencil and etch along the ruler until a ring is marked out. You may need to rotate and reposition the soap occasionally while marking.



Once the circumferential guidelines are complete, you have completed phase 1 of soap carving! The next page contains a summary of all the guidelines you should end up with for each pattern.

Pattern Name	Illustration	Guidelines	Side View	Front View
Saddle				
Flute				
Notch				
Flute-Notch				
Fluted Triangle				
Notched Triangle				
Fluted Square				
Narrow Fluted Square				

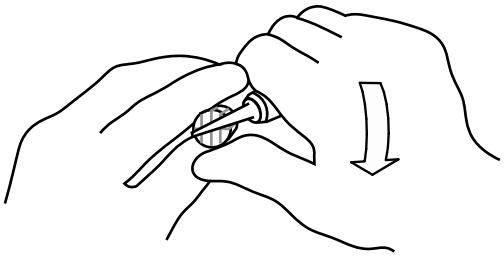
PHASE 3: ROUGH CARVING

Before beginning rough carving, take a few seconds to double-check that you have drafted the correct pattern guidelines onto the soap. Starting to carve with wrong guidelines would be a significant and unrecoverable mistake. If you find an error at this stage, do not panic – only the actual carvings are marked, not your lines. Simply re-draft the erroneous guideline(s) and continue to rough carving. After double-checking the accuracy of your guidelines, use the provided permanent marker to shade in the areas which need to be carved out. This reduces the chance of accidentally carving out the wrong portion.

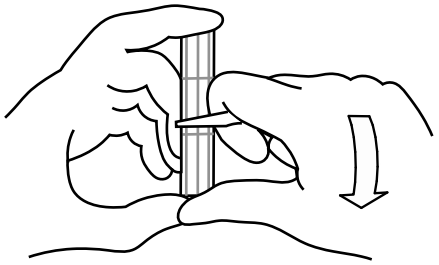
Hand placement is very important when making cuts. The knife should be grasped in the palm, with the fingers wrapped around and positioned close to the blade. The thumb should make contact with the soap for stability. Avoid carving in a direction that obscures the blade's path from your point of view.



Correct Knife Grip



Hand Placement When Carving the Ends of the Soap

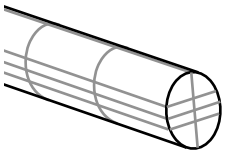


Hand Placement When Carving the Sides of the Soap

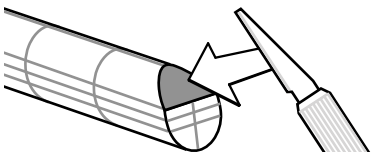
Ensure that your strokes are always directed away from other guidelines to avoid accidentally crossing them. As you carve, you should be using the ruler around every two minutes to check how close you are to the instructed dimensions.

When rough carving notches, follow the steps shown below:

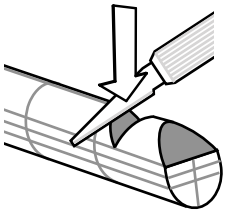
Before Rough Carving



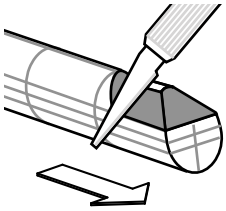
① Carve Along End Guidelines (Leaving a 1 mm Margin)



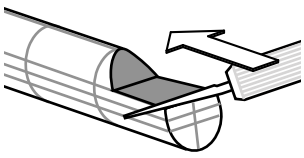
② Create an Angled Notch



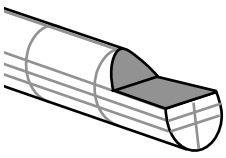
③ Carve Along Longitudinal Guidelines (Leaving a 1 mm Margin)



④ Remove Remaining Material With Horizontal Strokes



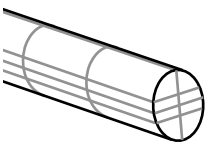
After Rough Carving



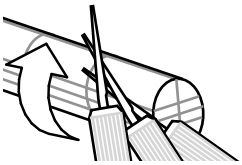
The angled notch forms a "barrier" to protect the un-carved portions of soap from the blade's horizontal strokes.

When rough carving flutes, follow the steps shown below:

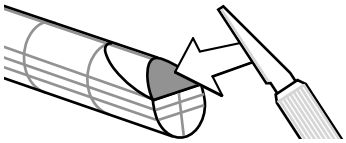
Before Rough Carving



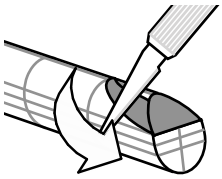
① Use a Rolling Motion to Lightly Carve the Proper Flute Angle



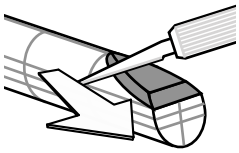
② Carve the End Steeper Than the Flute Angle (Leaving a 1 mm Margin)



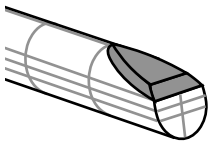
③ Carve Both Sides Along the Flute Angle (Leaving a 1 mm Margin)



④ Remove Protruding Material With Angled Strokes



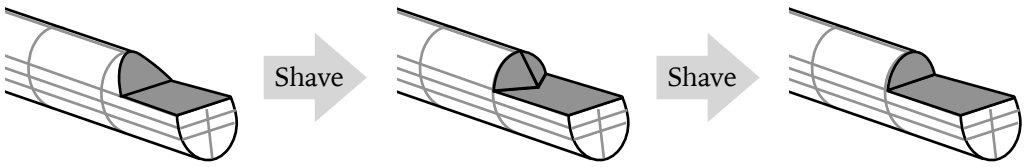
After Rough Carving



Always leave a 1 mm margin around your guidelines. This is because over-carving the soap is an irreversible mistake – you can always carve soap off but you can never add it back on. Thus, avoid carving past the guidelines at all costs. By leaving a margin, you can also ensure that flat surfaces are completely level by using the shaving techniques that we will discuss in phase 4 (fine carving). During fine carving, this 1 mm margin will be used to perfect the "fit and finish" of the soap.

PHASE 4: FINE CARVING

All cuts for this phase must be done in a gradual and accurate manner. It is recommended that you use the base of your blade instead of the tip because it supplies finer control and is less prone to shaky movements. During fine carving, all we are doing is shaving off excess soap layer by layer until we hit our original guidelines. The fragments of soap removed should appear whiter and thinner than the fragments removed during rough carving. For notches, you can carve a precise 90 degree angle by following this shaving pattern:



For flutes, simply shave down the angled surface, using your thumb or index finger to stop the blade from chipping the end's edge and two corners:

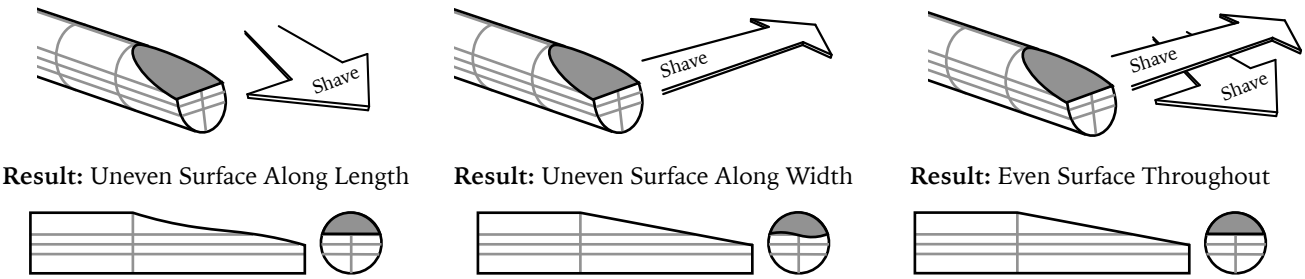


Thumb Stops Blade or Index Finger Stops Blade

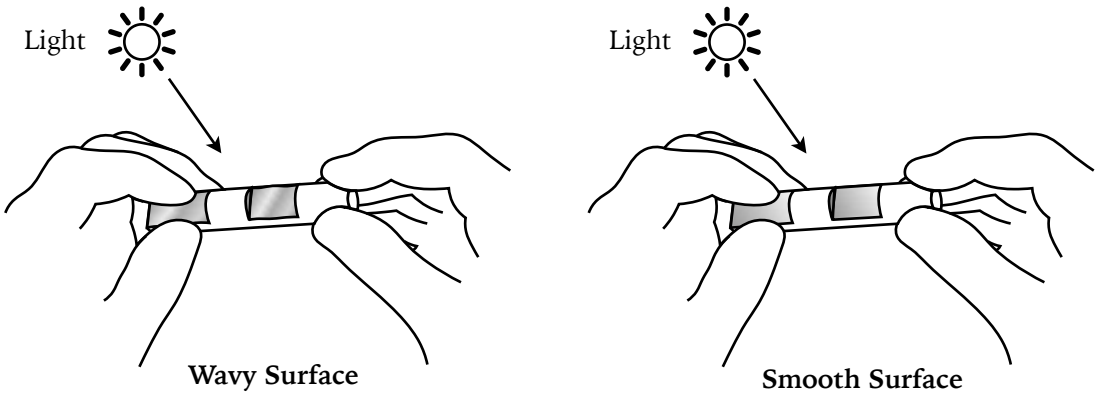
When shaving soap, make sure to angle the blade slightly such that the beveled edge is coplanar (on the same plane) as the surface being shaved. This will help prevent the blade from catching on the rough surface and chipping your soap.



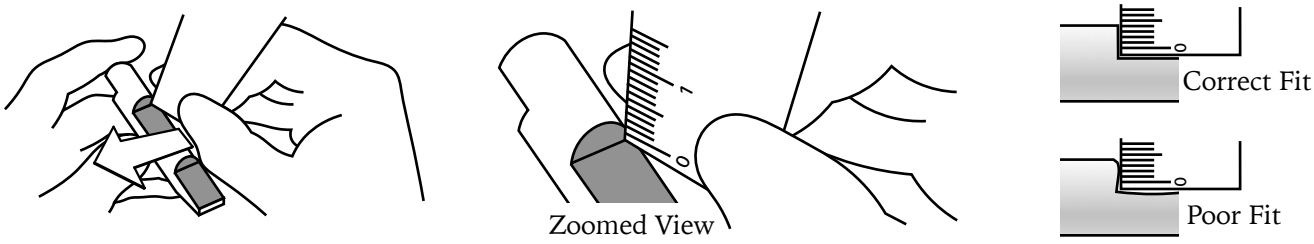
To make your surfaces truly flat, you need to shave in more than one direction. This will eliminate any bumps that may occur when shaving along only one axis.



You can check the smoothness of your surfaces by holding the soap up to a light source and checking for any wavy reflections, which indicate a bumpy surface. When you observe the surface to produce accurate mirror-like reflections, then it is perfectly smooth.

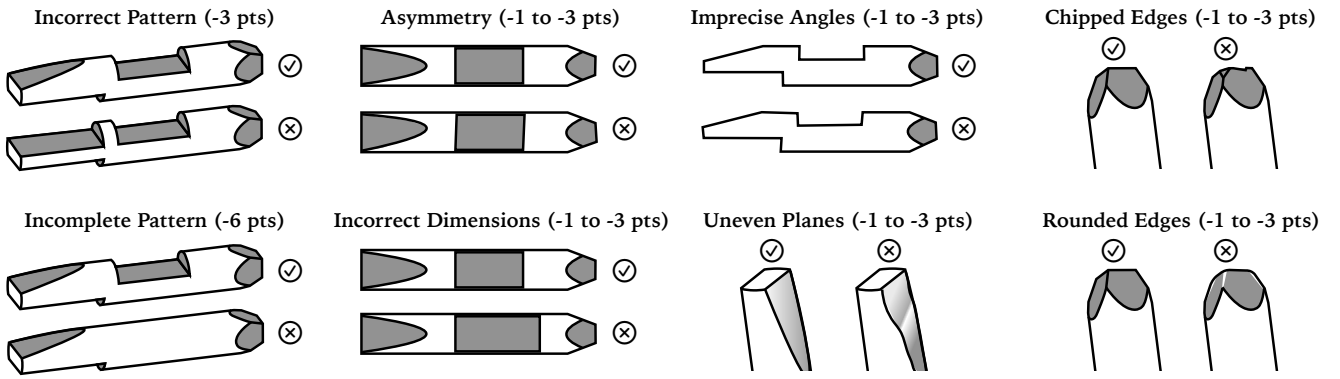


Finally, check your right angles using a corner of your ruler. Swipe the rule from one side of the notch to the other. The carved soap should precisely fit the ruler corner throughout the entire width.



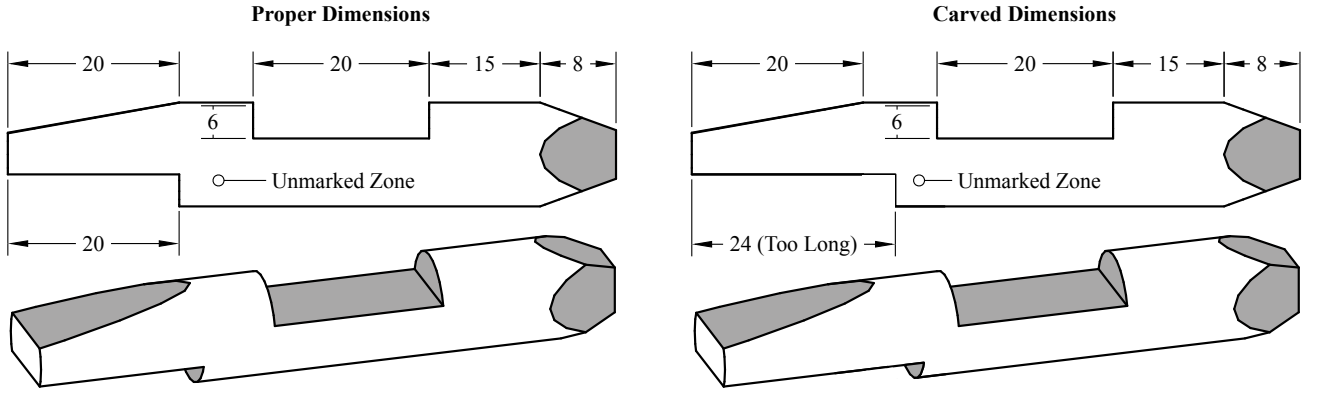
In the last few minutes of the MDT, check your carving for symmetry, smoothness, and correctness of angles. You may also use your gloved fingers to gently wipe off excess shavings from the soap.

COMMON MISTAKES

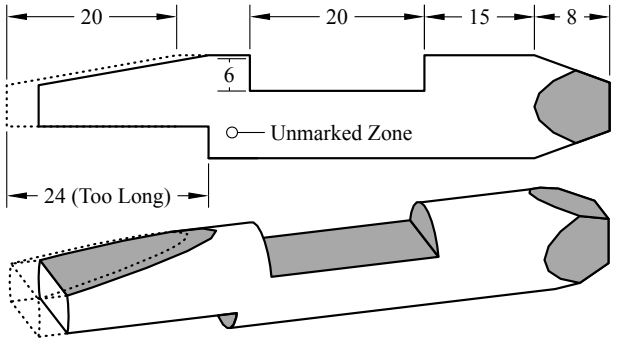


FIXING OVER-CARVING

In most cases of accidentally carving beyond your guidelines, the mistake is irrecoverable. However, if this occurs on the same side as the unmarked zone, you may be able to fix your dimensions by "shifting" the pattern. For example, notice how in the following carving, the notch is 4 mm longer than the proper dimensions:



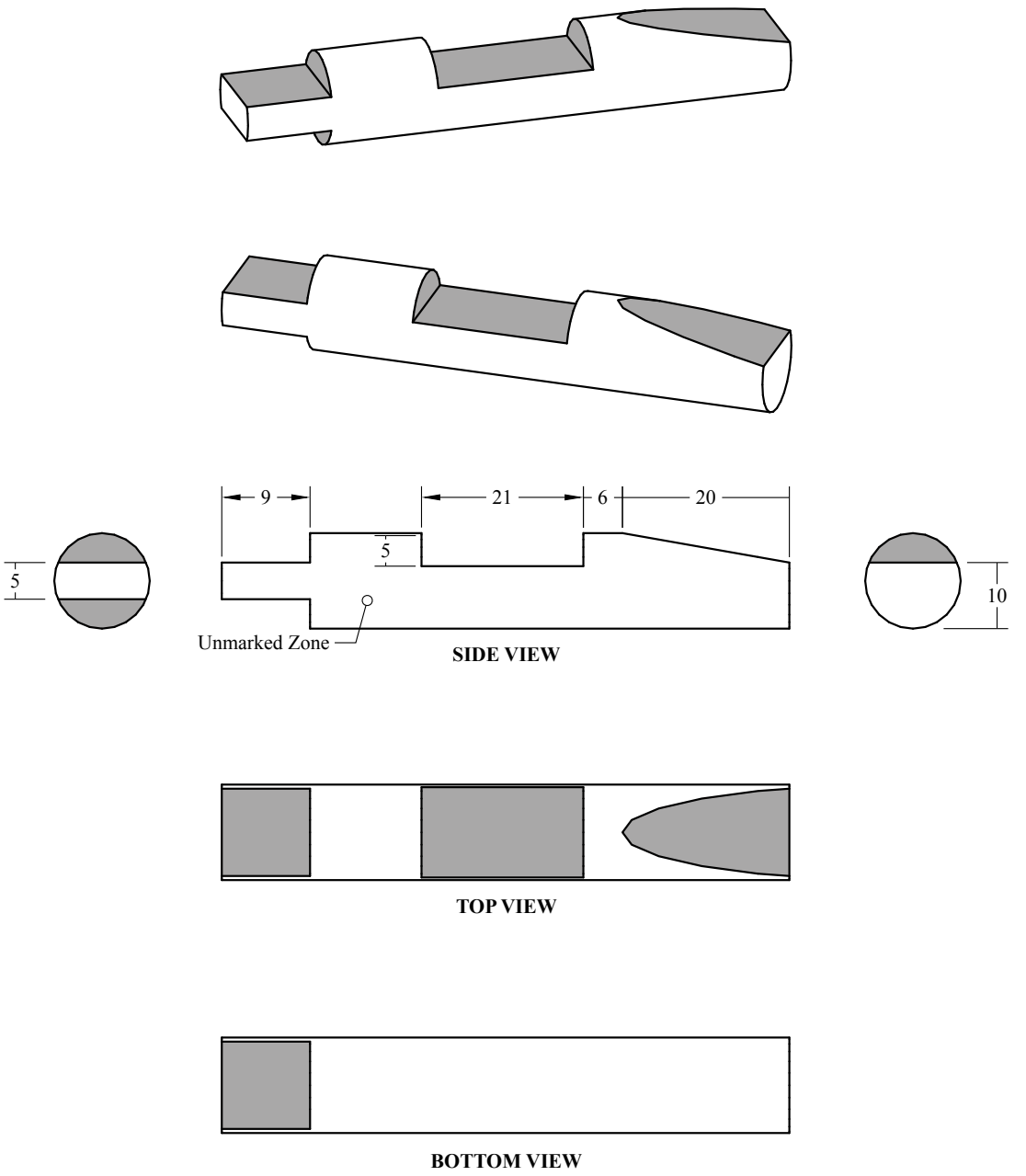
We can fix this mistake by cutting 4 mm of soap off the left end and shifting the flute 4 mm to the right:



Now, the notch has the proper dimensions (20 mm), and the flute dimensions are unchanged. The only thing that differs is that the unmarked zone has shrunken 4 mm, the same distance the notch was over-carved.

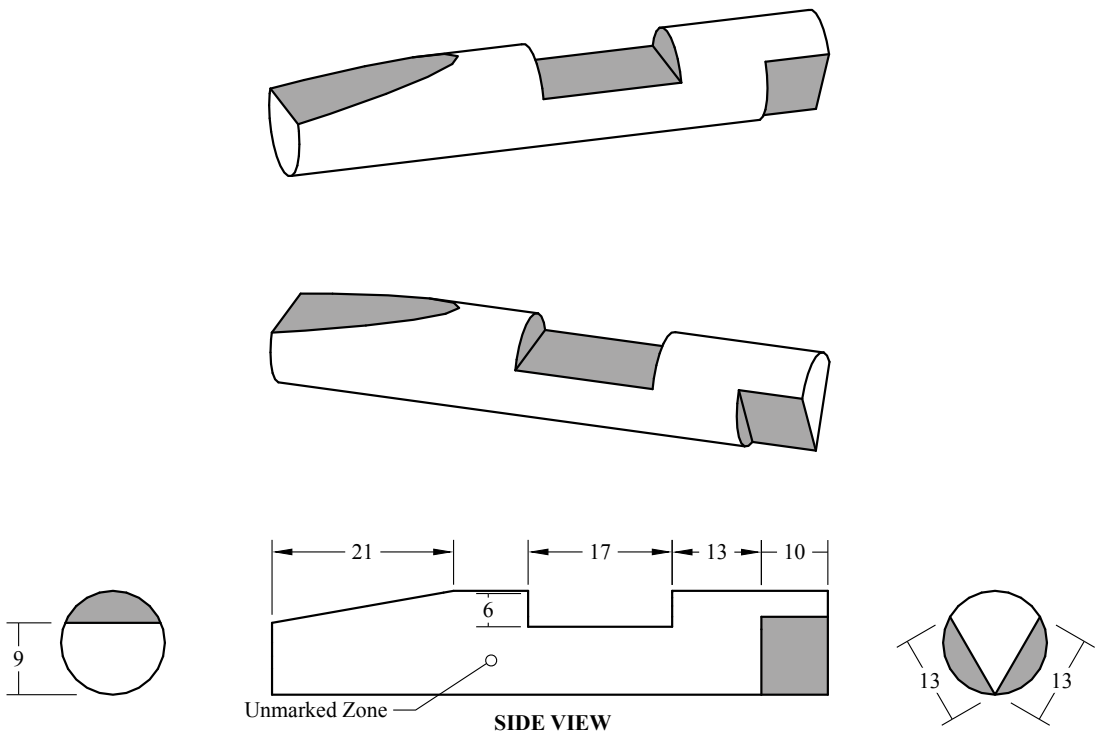
CHAPTER 3 | **PRACTICE PATTERNS**

SIMULATED MANUAL DEXTERITY TEST – PATTERN 1



Shaded area represents a carved surface. All measurements are shown in millimetres.

SIMULATED MANUAL DEXTERITY TEST – PATTERN 2



SIDE VIEW



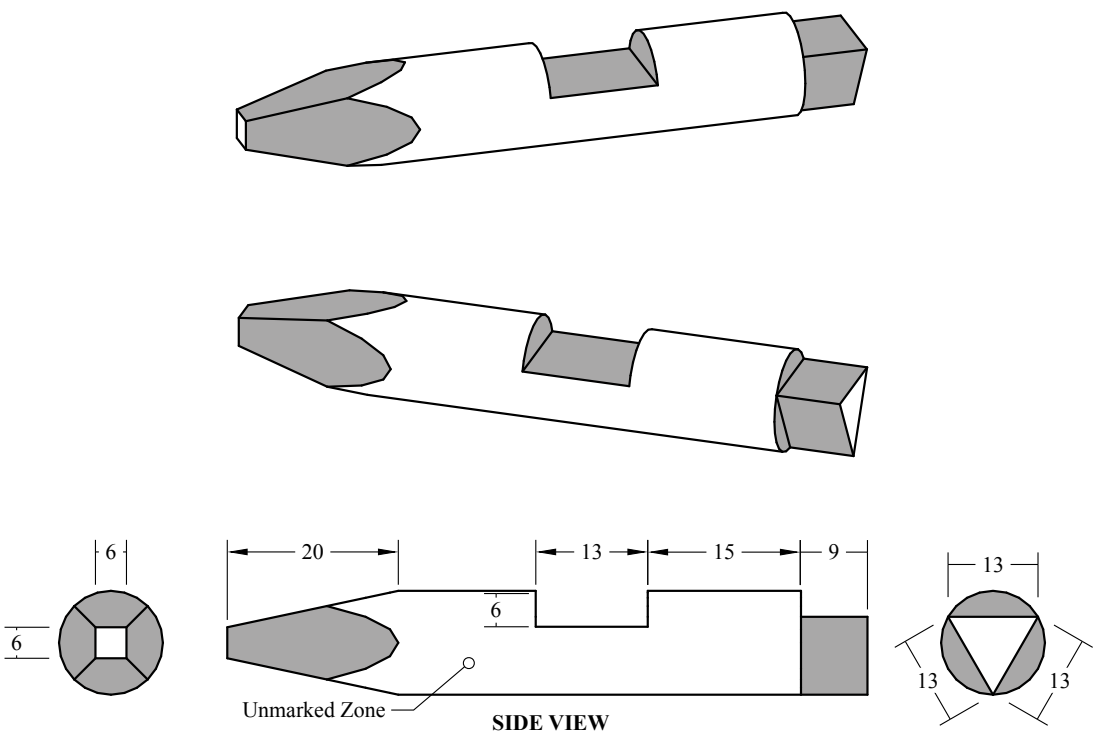
TOP VIEW



BOTTOM VIEW

Shaded area represents a carved surface. All measurements are shown in millimetres.

SIMULATED MANUAL DEXTERITY TEST – PATTERN 3



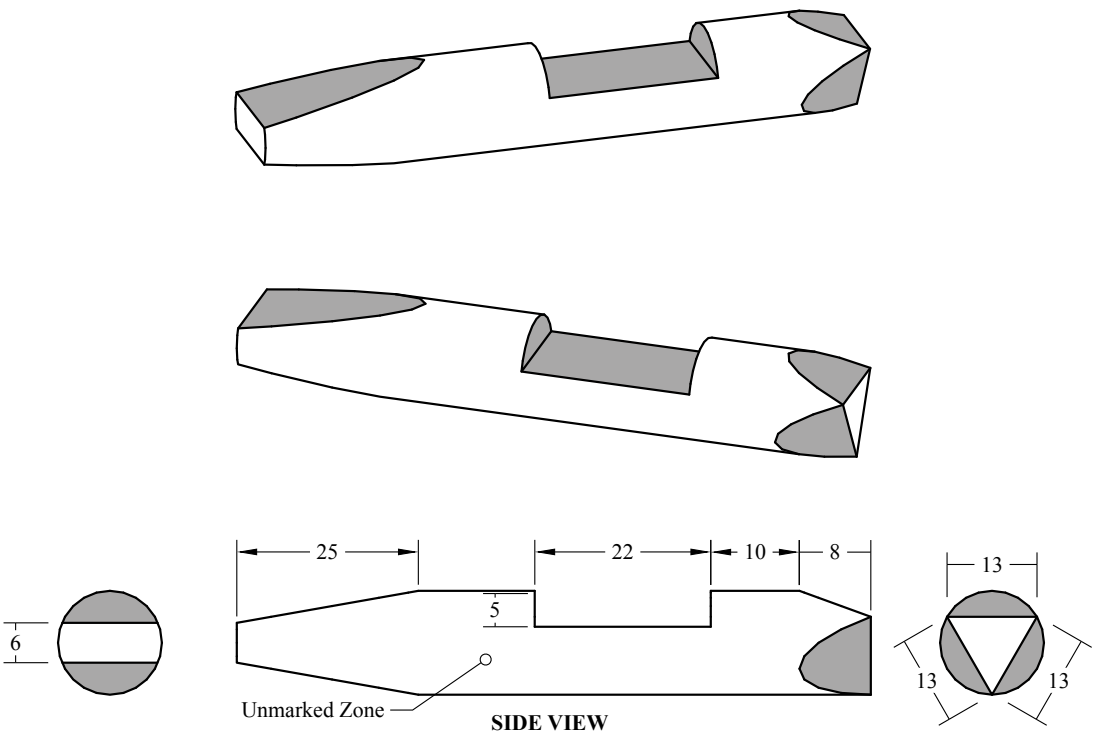
SIDE VIEW

TOP VIEW

BOTTOM VIEW

Shaded area represents a carved surface. All measurements are shown in millimetres.

SIMULATED MANUAL DEXTERITY TEST – PATTERN 4



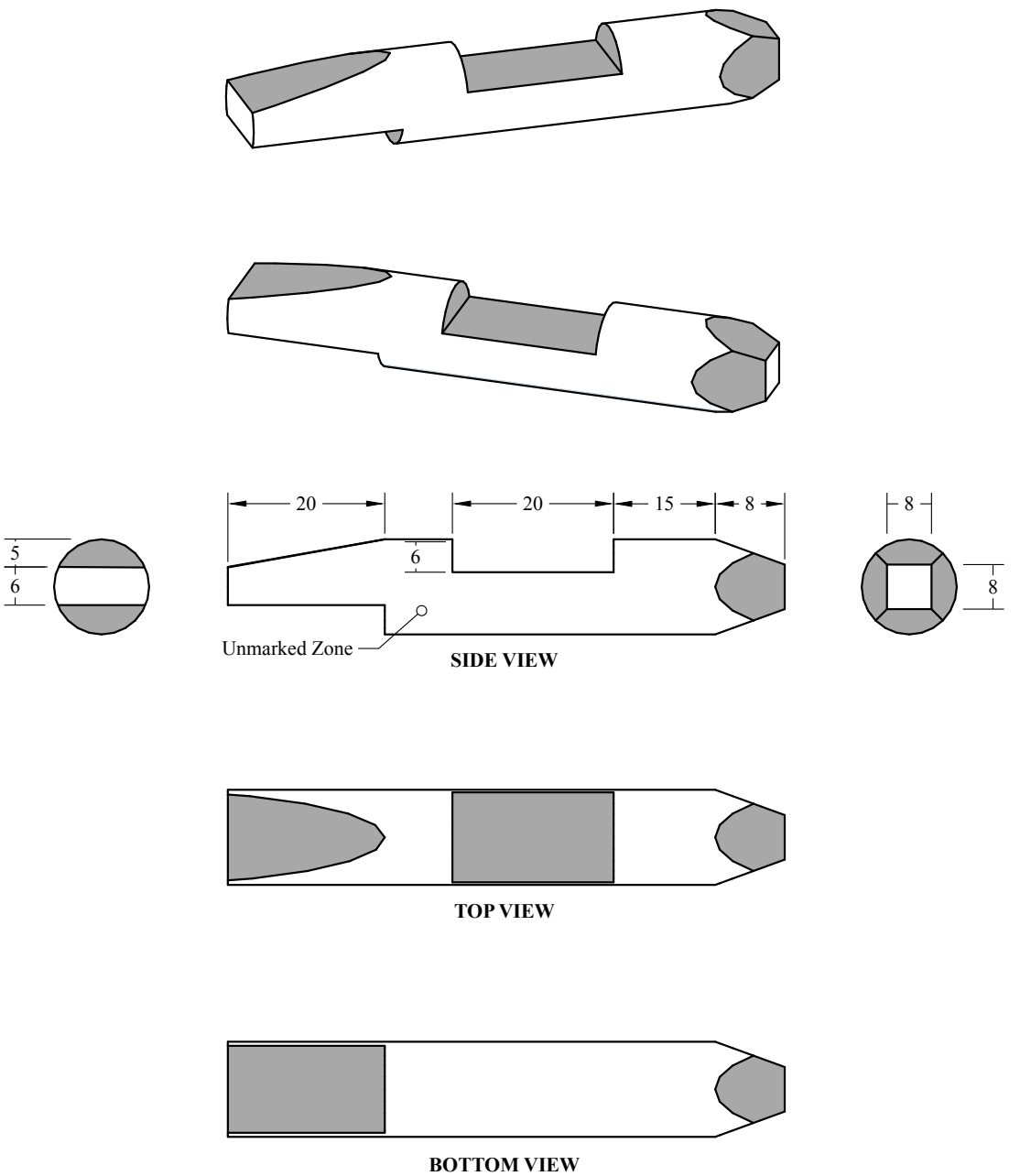
SIDE VIEW

TOP VIEW

BOTTOM VIEW

Shaded area represents a carved surface. All measurements are shown in millimetres.

SIMULATED MANUAL DEXTERITY TEST – PATTERN 5



Shaded area represents a carved surface. All measurements are shown in millimetres.

SECTION 2 BIOLOGY



CHAPTER 1 | **PRINCIPLES OF DAT BIOLOGY**

MINDSET

Biology makes up the majority of the cDAT Survey of Natural Sciences (SNS) section. Because the chemistry questions that follow the biology section can be time-consuming, it is recommended that you budget less than half of your SNS time (<30 min) to complete the 40 biology questions. This means that you should be moving at a relatively high pace (roughly 40 seconds/question). Unlike the American DAT, the cDAT focuses less on depth of knowledge and more on breadth. This means the questions tend to cover a wide variety of topics but rarely ask about details such as specific enzymes or mechanism steps.

STUDY STRATEGY

Focus on learning ***high-yield*** content that is most likely to show up on the SNS. In this section, such concepts will be labeled with the ☆ HIGH-YIELD tag. Since the cDAT covers material from grade nine science to second year university, start content review as early as possible (ideally 3 months before test day). Once you feel that you have covered 80% of the topics in content review, begin practicing with the full-length exams at the end of this textbook. Try to complete 1 exam per week, reviewing the written solutions to the questions that you answer incorrectly and referencing back to the textbook throughout.

Since most cDAT biology questions are relatively straightforward recall-type problems, having good memorization skills is an asset. Therefore, supplement your content review by testing yourself with flashcards. If you handwrite flashcards, try to organize them into "confident", "needs review", and "no idea" piles, so you know where to prioritize your review. This technique is called ***spaced repetition***, and is scientifically proven to enhance recall by taking advantage of the psychological spacing effect. Many online flashcard applications automate this process. If you find it difficult to focus during content memorization, try setting a timer to 25 minutes and isolating yourself from all distractions during the allotted time. If your mind wanders, write the thought down on paper and return to focus. After the 25 minutes, take a 5 minute break and repeat the process. This is called the ***Pomodoro technique***, and is widely popular among students and professionals alike. Finally, make sure you take advantage of the various memorization techniques mentioned in the preface of this book. This includes ***mnemonics***, which are presented throughout the chapter and denoted with the MNEMONIC tag.

CHAPTER 2 | **THE ORIGIN OF LIFE**

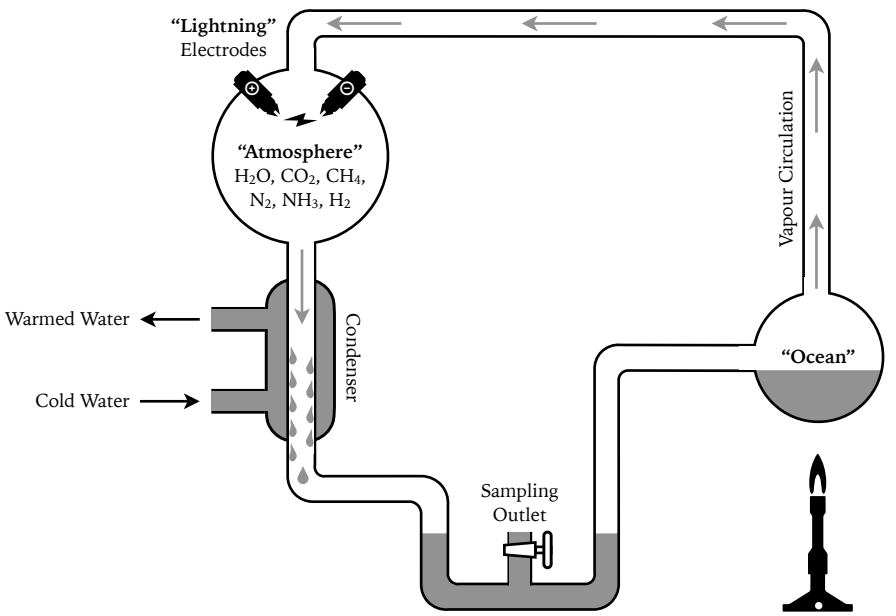
- The Earth was formed around 4.5 billion years ago and contained a ***reducing atmosphere*** containing carbon monoxide (CO), carbon dioxide (CO_2), hydrogen gas (H_2), nitrogen gas (N_2), water vapour (H_2O), sulphur (S), hydrochloric acid (HCl), and hydrogen cyanide (HCN)
- Oxygen was not part of the atmosphere until the advent of photosynthesis billions of years later, which generated enough oxygen gas to transform the reducing atmosphere into an oxidative one
- ***Abiogenesis*** is the idea that life emerges from inorganic, non-living substances
- Scientists agree that life on Earth arose sometime between 4.5 and 3.5 billion years ago

HYPOTHESES OF EARLY LIFE

- ***Panspermia*** – States that life on Earth was seeded by asteroids containing organisms or organic molecules from other planets
- ***Oparin-Haldane Hypothesis*** – States that simple organic molecules arose from abiotic molecules, eventually becoming more complex organic macromolecules in an environment called the ***primordial soup***
- ***Heterotroph Hypothesis*** – States that the first forms of life lacked the ability to make their own food, instead relying on organic molecules in the primordial soup
- ***RNA world Hypothesis*** – States that self-replicating RNA molecules and ribozymes (enzymes made of folded RNA) was the first to arise, leading to more complex organic molecules and metabolic pathways
- ***Metabolism-First Hypothesis*** – States that metabolic networks were the first to arise, leading to the formation of RNA and DNA later on

MILLER-UREY EXPERIMENT

- The Miller-Urey experiment was designed to test the "primordial soup" theory proposed by Oparin and Haldane. Miller and Urey provided evidence that life may have originated from the spontaneous synthesis of organic molecules in the ancient Earth's reducing atmosphere
- The experiment consisted of water (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrogen (N_2), ammonia (NH_3), and hydrogen (H_2) sealed inside a sterile circuit:



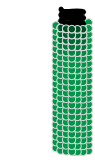
- The mixture was heated with a bunsen burner and cooled with a water condenser to mimic the evaporation and condensation cycles of the ancient atmosphere
- Sparks were fired between electrodes to mimic lightning and other sources of energy on ancient Earth
- After running the experiment for one week, organic compounds such as urea, formaldehyde, hydrogen cyanide, acetic acid, lactic acid, and amino acids were discovered

THE PRIMITIVE CELL

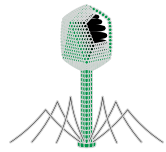
- ***Protobionts/protocells*** were the first compartmentalized living units, precursors to the cell
  - ***Coacervates*** are protocells composed of lipids
  - ***Microspheres*** are protocells composed of polypeptides
- All early cells were prokaryotes. Eukaryotes evolved when a heterotrophic prokaryote engulfed an autotrophic prokaryote and developed a mutualistic relationship. This is called ***endosymbiosis***
- Mitochondria and chloroplasts are believed to be endosymbionts, since they have a double lipid bilayer, independent chromosomes, and reproduce via binary fission

VIRUSES AND PRIONS

- ***Viruses*** are not considered to be living because they rely on a host for reproduction and do not show signs of metabolism or cellular organization. However, it is believed that they existed before any terrestrial life due to their simplicity and use of an RNA genome
- Viruses can vary greatly in size, host, and replication mechanism. Their genome can consist of single-stranded RNA, single-stranded DNA, or double-stranded DNA
- The ***capsid*** of a virus is a protective protein shell. They can be ***filamentous***, ***icosahedral,*** or ***head-tail***:


Filamentous Capsid


Icosahedral Capsid


Head-Tail Capsid

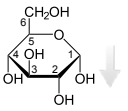
- The capsid may be surrounded by a lipid ***envelope***, which facilitates host binding and penetration. This envelope is often picked up from the cell membrane of a previous host during cell lysis
- The lifecycle of a virus can either be ***lysogenic*** or ***lytic***:
  - ***Lysogenic Cycle*** – The viral genome is integrated into the host genome and replicated whenever the host divides. The host cell continues to function normally for many generations as the virus lies dormant. When the cell is exposed to particular stimuli (stress, UV radiation, etc.), the virus is reactivated and enters the lytic cycle
  - ***Lytic Cycle*** – The virus multiplies rapidly and causes lysis of the host cell, resulting in the release of viral progeny to infect nearby cells
- ***Prions*** are infectious, misfolded proteins that are able to cause normal proteins to also fold abnormally. Like viruses, prions are not considered to be living because they require a host to reproduce
- Prions are responsible for many neurodegenerative diseases such as bovine spongiform encephalopathy in cows and Creutzfeldt–Jakob disease in humans

CHAPTER 3 | **BIOMOLECULES**

CARBOHYDRATES

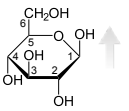
- Carbohydrates are "sugars" that have functions in the energy storage and structure of organisms
- All carbohydrates have the empirical formula $C_nH_{2n}O_n$, where n is an integer
- As a monomer, carbohydrates can exist in an alpha (α) or beta (β) form:

Alpha (α) Glucose



Hydroxyl group on carbon 1 faces down

Beta (β) Glucose

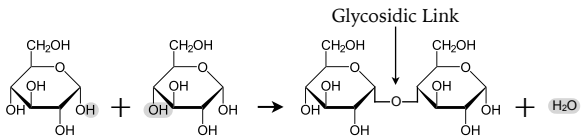


Hydroxyl group on carbon 1 faces up

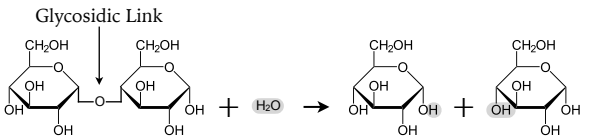
DAT TIP You do not need to memorize the chemical structure of glucose

- ***Carbohydrates*** can also exist as polymers of repeating sugar units linked via glycosidic bonds/links
- ***Glycosidic links*** contain an oxygen that holds the carbons of two sugar units together via covalent bonds
- ***Dehydration synthesis/condensation reactions*** create glycosidic links by removing a water molecule from two sugars, joining them covalently. On the other hand, ***hydrolysis reactions*** break glycosidic links by introducing a water molecule:

Dehydration Synthesis/Condensation Reaction

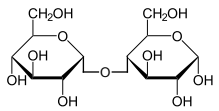


Hydrolysis Reaction



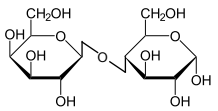
- A glycosidic linkage can be classified based on the stereochemistry of each carbon involved:
  - ***Alpha (α) Glycosidic Bond*** – The two carbons involved have the same stereochemistry. In other words, the hydroxyl groups face the same direction
  - ***Beta (β) Glycosidic Bond*** – The two carbons involved have different stereochemistry. The hydroxyl groups face opposite directions

Alpha (α) Glycosidic Bond



Maltose

Beta (β) Glycosidic Bond



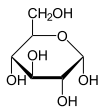
Lactose

DAT TIP Make sure you understand the difference between carbohydrate α/β forms vs glycosidic bond α/β forms

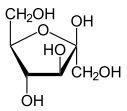
- Carbohydrates are often referred to as mono-, di-, and polysaccharides. These names refer to the number of sugar units involved in the carbohydrate structure

- ***Monosaccharides*** – Consist of one sugar unit
  - Can have three to seven carbon atoms. ***Pentoses*** (five carbon sugars) and ***hexoses*** (six carbon sugars) are the most common. Important monosaccharides to know for the DAT are:
    - ***Glucose*** – Six-carbon sugar (hexose) usually with a six-carbon ring (pyranose)
    - ***Fructose*** – Six-carbon sugar (hexose) with a five-carbon ring (furanose)
    - ***Galactose*** – Six-carbon sugar (hexose) usually with a six-carbon ring (pyranose)
  - Note that glucose, fructose, and galactose all have the same molecular formula ($C_6H_{12}O_6$). This means they are ***isomers***

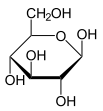
Glucose



Fructose

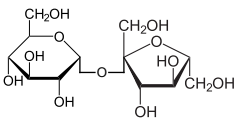


Galactose



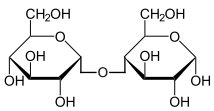
- ***Disaccharides*** – Consist of two sugar units
  - ***Sucrose*** – α-Glucose + α-Fructose, connected via an $\alpha(1,5)$ glycosidic bond
  - ***Maltose*** – α-Glucose + α-Glucose, connected via an $\alpha(1,4)$ glycosidic bond
  - ***Lactose*** – α-Glucose + β-Galactose, connected via a $\beta(1,4)$ glycosidic bond

Sucrose



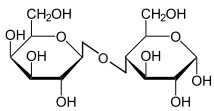
Glucose + Fructose

Maltose



Glucose + Glucose

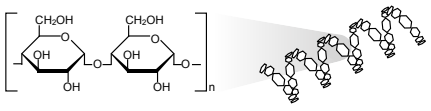
Lactose



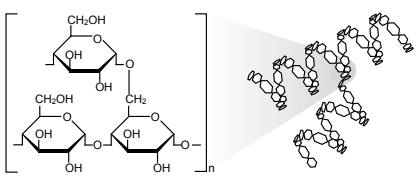
Galactose + Glucose

- ***Polysaccharides*** – Consist of more than two sugar units
  - ***Amylose*** – A form of starch used by plants to store energy. Composed of glucose joined by α-1,4-glycosidic bonds
  - ***Amylopectin*** – A more branched form of starch used by plants to store energy. Composed of glucose joined by α-1,4-glycosidic bonds and some α-1,6-glycosidic bonds
  - ***Glycogen*** – An even more branched polysaccharide used in humans to store energy. Composed of glucose joined by α-1,4-glycosidic bonds and many α-1,6-glycosidic bonds. Glycogen is mainly stored in the liver
  - ***Cellulose*** – A structural polysaccharide used in plants. Composed of glucose joined by β-1,4-glycosidic bonds, which allow it to form a linear sheets.
- ***Chitin*** – A structural polysaccharide used in fungi and insects. Composed of N-acetylglucosamine joined by β-1,4-glycosidic bonds and is almost identical to cellulose except that it contains nitrogen

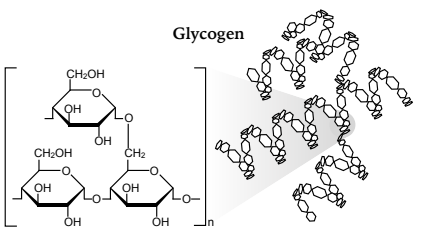
Amylose



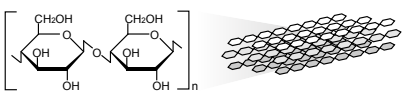
Amylopectin



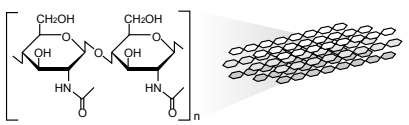
Glycogen



Cellulose

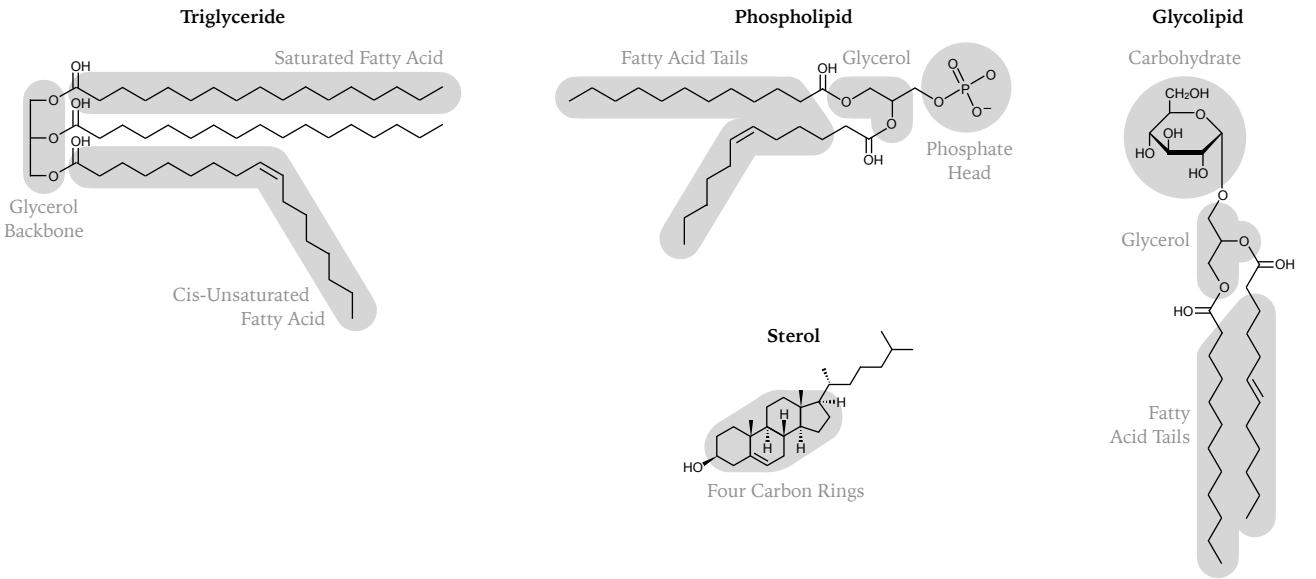


Chitin



LIPIDS

- Lipids are biomolecules that are solvable in non-polar solvents. They have functions in the energy storage, structure, insulation, and biochemical pathways of organisms
- ***Triglycerides*** are lipids that form the main component of fat and oil. It consists of:
  - ***1 Glycerol Backbone*** – A three carbon compound with a hydroxyl group on each carbon, which forms ester bonds with fatty acids
  - ***3 Fatty Acid Chains*** – A non-polar hydrocarbon chain that ends in a carboxyl group. This causes lipids to be hydrophobic (does not mix with water)
    - ***Saturated*** – Fatty acid contains only single bonds between carbons
    - ***Unsaturated*** – Fatty acid contains one or more double bonds between carbons
      - ***Trans-unsaturated*** – Double bond is in the *trans* orientation, resulting in a straight chain
      - ***Cis-unsaturated*** – Double bond is in the *cis* orientation, resulting in a kinked chain
- ***Phospholipids*** are special lipids that consist of two non-polar hydrocarbon tails and a polar phosphate head. This combination makes phospholipids ***amphipathic***, meaning they demonstrate both hydrophobicity and hydrophilicity. Phospholipids are found in cell membranes
- ***Glycolipids*** are lipids that have carbohydrate groups attached. They are found on the outside of the cell membrane and facilitate intercellular recognition
- ***Sterols*** are lipids that have a structure involving four carbon rings. ***Cholesterol*** is a sterol and a common precursor to many steroid hormones, which play an important role in the endocrine system. Cholesterol also helps regulate cell membrane fluidity

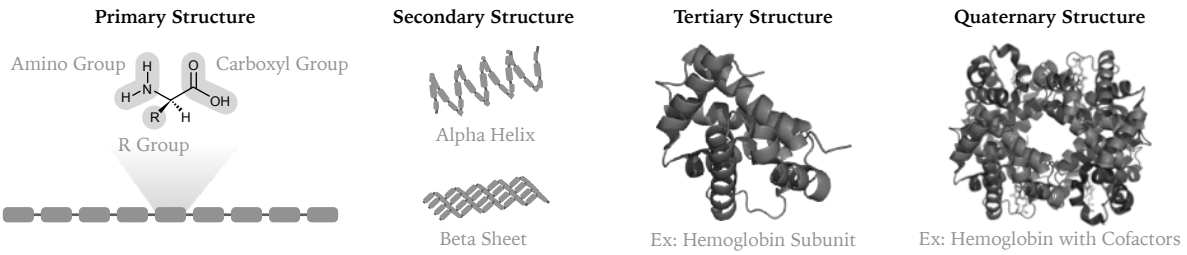


PROTEINS

- Proteins are folded versions of ***polypeptides***, polymers of amino acids linked together via ***peptide bonds***
- Amino acids are composed of a central carbon bonded to an ***amino group*** (NH_3), ***carboxyl group*** (COOH), ***hydrogen*** (H), and a variable ***R group***

DAT TIP Unlike the MCAT, the cDAT does not require the memorization of amino acids

- Proteins have four levels of structure:
  - ***Primary Structure*** – The order of ***amino acids*** in the polypeptide chain
  - ***Secondary Structure*** – Hydrogen bonding of the ***polypeptide backbone***, forming ***alpha helices*** or ***beta sheets***
  - ***Tertiary Structure*** – Further folding due to ionic bonds, disulphide bridges, hydrophobic interactions, and hydrogen bonds. Mostly due to interactions between ***R groups***
  - ***Quaternary Structure*** – Multiple polypeptide chains organizing together via hydrogen bonding. Includes ***cofactors***, which are non-protein molecules that contribute to the protein's function



- All four levels of structure give the protein its proper shape, which is required for function. Thus proteins must be completely folded in order to function properly
- Proteins can unfold or ***denature*** when exposed to changes in environmental conditions. These are the most common external stressors:
  - ***Enzymes*** – Destroys primary, secondary, tertiary, and quaternary structure by breaking peptide bonds
  - ***High Temperature*** – Destroys secondary, tertiary, and quaternary structure by disrupting hydrogen bonds
  - ***Chemicals*** – Destroys secondary, tertiary, and quaternary structure by disrupting hydrogen bonds
  - ***Low pH*** – Destroys tertiary and quaternary structure by disrupting ionic bonds
- Denaturation may be permanent or temporary depending on the severity of the environmental change
- All the information needed for protein folding and re-folding are coded in the primary structure

NUCLEIC ACIDS

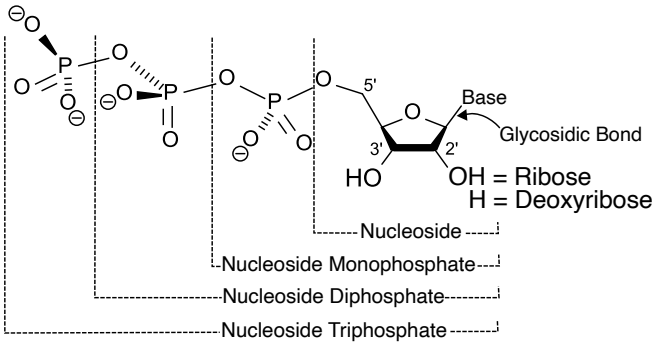
- Nucleic acids are nucleotide polymers that encode hereditary information
- A ***nucleotide*** contains the following components:
  - ***Pentose (five carbon) Sugar*** – In DNA, this sugar is deoxyribose. In RNA, this sugar is ribose
  - ***Nitrogenous Base*** – May be pyrimidines or purines. ***Pyrimidines*** have one carbon ring (cytosine and thymine), while ***purines*** have two rings (adenine and guanine). Uracil is a pyrimidine derivative that is only found in RNA. Nitrogenous bases form hydrogen bonds with its complement pair, which will be discussed further in Chapter 5 (Molecular Genetics)
  - ***Phosphate Group*** – Gives DNA and RNA a negative overall charge

MNEMONIC "Pure As Gold" → Purine Adenine Guanine

MNEMONIC "CUT the Pie" → Cytosine Uracil Thymine Pyrimidine

- Nucleotides are connected to each other via ***phosphodiester bonds*** between the ***5' carbon*** and the ***3' carbon***. The 3' end of a nucleic acid has a free hydroxyl group, while the 5' end does not. This gives DNA and RNA ***directionality***. In double-stranded DNA, the two sugar-phosphate backbones are arranged in an ***antiparallel*** fashion, meaning the 5' and 3' carbons point in opposite directions

- A ***nucleoside*** is similar to a nucleotide, except it does not contain a phosphate group



- Note that "DNA" stands for deoxyribonucleic acid. "Deoxyribo-" indicates that the ribose sugar component of its nucleotides has a hydrogen instead of a hydroxyl group on the 2' carbon
- "RNA" stands for ribonucleic acid. Unlike DNA, RNA does have a hydroxyl group on the 2' carbon

DAT TIP You do not need to memorize the chemical structure of any nitrogenous base

WATER

- Unlike all the other molecules in this chapter, water is inorganic. However, it has unique properties that are necessary to sustain life on Earth
- Water has a high surface tension, which enables some insects to walk on its surface. This occurs due to ***cohesion***, which is caused by hydrogen bonding between water molecules
- Capillary action causes water to flow up the xylem in vascular plants. This occurs due to ***adhesion***, which is cased by hydrogen bonding between water and other polar molecules
- The high ***heat capacity*** of water helps moderate the temperature of freshwater ecosystems. This also allows organisms to distribute body heat uniformly
- The high ***specific heat of vaporization*** allows animals to dissipate excess heat through the evaporation of sweat
- Finally, water is less dense in the solid state compared to the liquid state, unlike many other compounds. This is due to crystal lattice formation in ice, which spreads the water molecules apart. Because of this, many aquatic organisms are able to survive in the winter because floating surface ice insulates the rest of the water

CHAPTER 4 | **THE CELL**

PROKARYOTES VS EUKARYOTES ☆ HIGH-YIELD

• This chapter discusses animal eukaryotic cells. For plant and bacterial cells, see Chapter 16 and 15, respectively
DAT TIP Prokaryotic cells are very different from eukaryotic cells, these differences are important for the DAT

	Prokaryote	**Eukaryote**
Membrane-Bound Organelles	No	Yes
Ribosomes	Yes, small	Yes, large
Centrioles	No	Yes
Cytoskeleton	No	Yes
Nuclear Organization	Nucleoid region	Double membrane-bound nucleus
Genome Organization	Circular chromosome	Linear chromosome containing telomeres and histones

MEMBRANE-BOUND ORGANELLES ☆ HIGH-YIELD

- This chapter will only discuss the basic cell organelles. For plant cells, review Chapter 16
- ***Nucleus*** – A double membrane-bound organelle containing chromosomes. Consists of the:
  - ***Nuclear Envelope*** – A double lipid bilayer membrane containing perforations called nuclear pores, which allows mRNA and proteins in/out of the nucleus. The space in between the inner and outer nuclear membrane is called the ***perinuclear space***
  - ***Nuclear Lamina*** – A network of intermediate filaments and proteins located underneath the nuclear envelope. Provides mechanical support and regulates cell division
  - ***Nucleoplasm*** – The fluid inside the nucleus
  - ***Nucleolus*** – The part of the nucleus that contains chromosomes. Also the site of rRNA synthesis
- ***Mitochondria*** – A double membrane-bound organelle that is the site of ATP synthesis (TCA cycle and oxidative phosphorylation) and beta oxidation. Contains its own circular chromosome and ribosomes, evidence supporting the theory of endosymbiosis
- ***Endoplasmic Reticulum (ER)*** – An interconnected network of membrane-bound sacs called ***cisternae***. It is continuous with the nuclear envelope. There are two types of endoplasmic reticulum:
  - ***Rough Endoplasmic Reticulum (RER)*** – Contains ribosomes embedded on the membrane, which synthesizes polypeptides directly into the RER, destined for the secretory pathway or plasma membrane
  - ***Smooth Endoplasmic Reticulum (SER)*** – Does not contain ribosomes. Synthesizes lipids, phospholipids, and steroid hormones. Also detoxifies metabolic waste, drugs, and alcohol. In muscle cells, the SER is called the ***sarcoplasmic reticulum*** and stores Ca^{2+} to trigger contractions
- ***Golgi Apparatus*** – Located between the RER and plasma membrane. It receives vesicles from the RER and modifies the encapsulated proteins via glycosylation, sulfation, or phosphorylation. The modified proteins are then directed to the plasma membrane (to be secreted) or lysosome (to be degraded)
- ***Lysosomes*** – Contain hydrolytic enzymes that are active at low pH and break down proteins, waste products, and pathogens. Also participates in ***autophagy***, the recycling of cellular components
- ***Peroxisomes*** – Contain ***catalase***, an enzyme that breaks down hydrogen peroxide (H_2O_2) into water (H_2O) and oxygen (O_2)
- ***Flagella*** – Large whip-like organelle that protrudes from the cell body and functions in motility

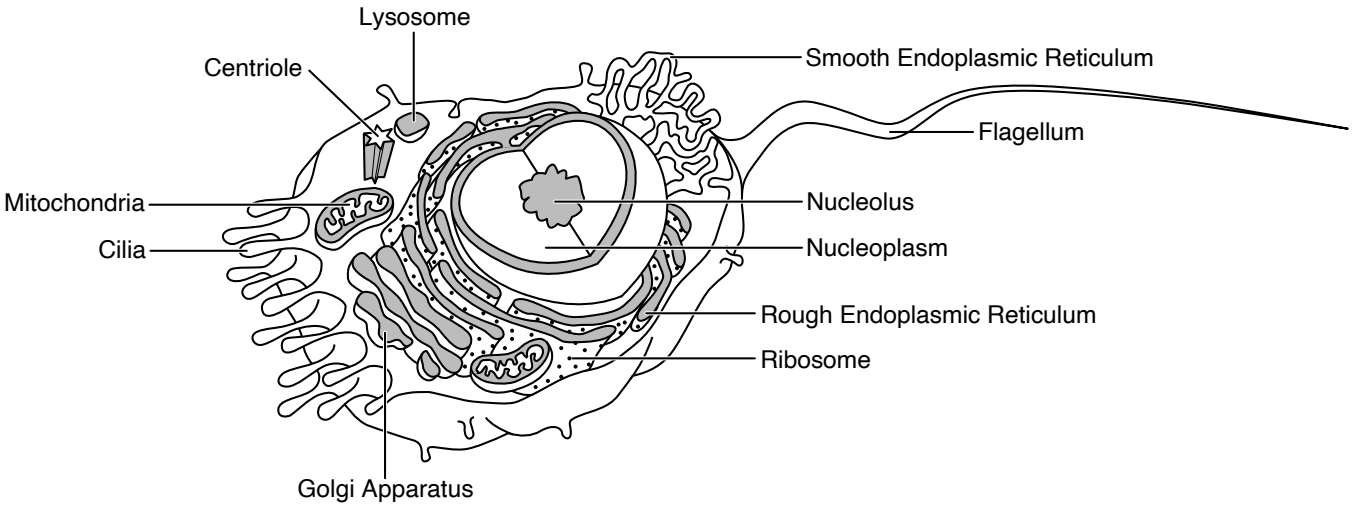
- ***Cilia*** – Small hair-like organelle that protrudes from the cell body and is often found in large-numbered clusters. They function in moving fluids or substances across a surface. Specialized cilia also function in sensation (ex: stereocilia of the inner ear)
- Both the flagella and cilia are made of ***microtubule doublets*** (polymers of tubulin protein) arranged in a patter called the ***9+2 axoneme***
- Cilia and flagella both use the motor protein ***dynein*** instead of myosin, which is found in muscle

OTHER CELLULAR COMPONENTS (NO MEMBRANE) ☆ HIGH-YIELD

- ***Ribosomes*** – They are technically not organelles, but rather macromolecules composed of rRNA and proteins. They translate mRNA into polypeptides (protein). They are located on the surface of the rough endoplasmic reticulum (RER) or free-floating in the cytoplasm
- ***Centrioles*** – Found in pairs arranged at 90 degrees to each other, they are cylinder-shaped and located at the poles of a cell. They are composed of ***microtubule triplets*** and function to separate the sister chromatids during mitosis. The centrioles are surrounded by dense material celled the pericentriolar material (PCM). A ***centrosome*** is composed of a pair of centrioles plus the PCM

MNEMONIC The terms "centrosome", "centriole", and "centromere" are easily confused. Remember that a centrosome contains some centrioles (a pair), while a centromere merely joins sister chromatids

- ***Cytoskeleton*** – Not organelles. Functions in cell division, motility, and organelle transport. Consists of:
  - ***Microfilaments*** – Smallest diameter (7 nm), composed of actin protein. Functions in cytoplasm motility. Examples include the contractile ring during cytokinesis and pseudopods in amoeba
  - ***Intermediate Filaments*** – Intermediate diameter (10 nm). Provides structural support. Examples include keratin filaments and nuclear lamins
  - ***Microtubules*** – Largest diameter (25 nm), composed of tubulin protein. Acts as a cellular "highway" for organelle transport. Also functions in cell division and cellular motility. Examples include the mitotic spindle, flagella, and cilia



THE INTERCELLULAR BUFFER

- Cells use an intercellular buffer system, which is different from the extracellular buffer system used in blood
- Instead of bicarbonate and carbonic acid (which is found in blood), the intracellular buffer consists of monohydrogen phosphate and dihydrogen phosphate:

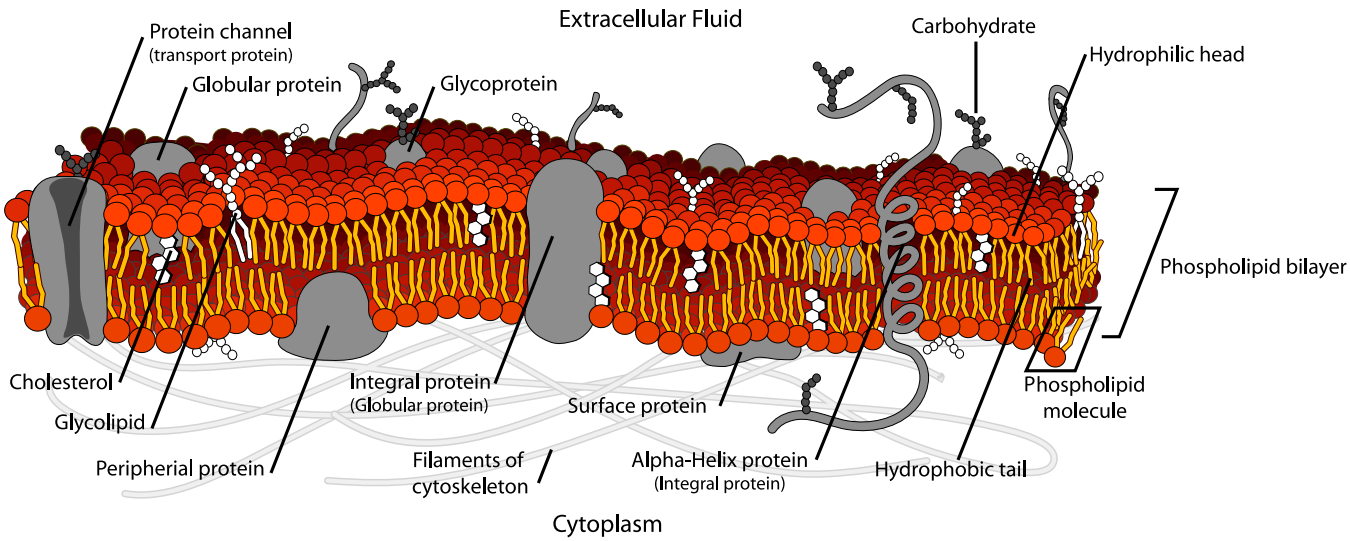
$$HPO_4^{2-} + H^+ \rightleftharpoons H_2PO_4^-$$

THE EXTRACELLULAR MATRIX

- The ***extracellular matrix (ECM)*** is a three-dimensional network of structural proteins, adhesion proteins, proteoglycans, and other materials
- ***Structural Proteins*** – Provide strength to bones, tendons, and cartilage. Examples include collagen and elastin. Collagen is the most abundant protein in the ECM
- ***Adhesion Proteins*** – Bind the ECM components to the cell membrane. Examples include fibronectin, laminin, and integrin
- ***Proteoglycans*** – Formed from proteins plus glycosaminoglycans (GAGs), which are carbohydrate polymers. Have a net negative charge that attracts Na^+ and water. Functions to hydrate and maintain osmotic pressure of the ECM and resident cells

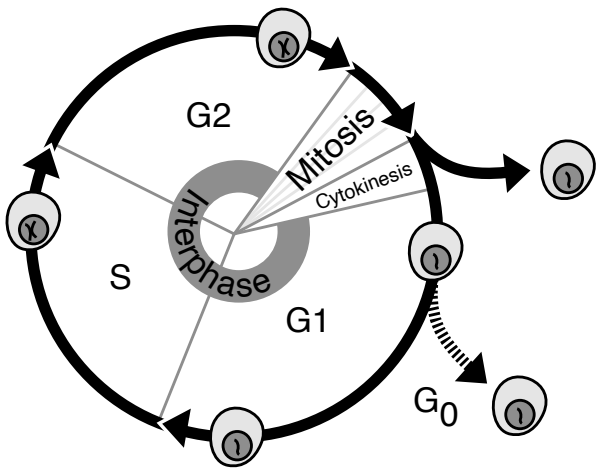
THE FLUID MOSAIC MODEL ☆ HIGH-YIELD

- The plasma membrane is a phospholipid bilayer that encloses a cell
- The hydrophilic phosphate heads face outwards, while the hydrophobic lipid tails face inwards
- The fluid mosaic model states that the plasma membrane is a "fluid" phospholipid bilayer with a "mosaic" of membrane proteins, which can be integral (transmembrane) or peripheral (surface) proteins
- ***Peripheral proteins*** are attached to the lipid bilayer via non-covalent interactions (hydrogen bonding, hydrophobic interactions, electrostatic interactions) and can be removed by changing pH or salt concentrations
- ***Integral proteins*** are embedded within the lipid bilayer and can only be removed by adding detergents
- Membrane proteins can move laterally (side to side), but cannot flip or invert within the phospholipid bilayer
- ***Cholesterol*** acts as a membrane fluidity buffer. When temperature is high, cholesterol's intermolecular interactions makes the membrane less fluid. When temperature is low, cholesterol's steric hinderance makes the membrane more fluid. Cholesterol is present only in eukaryotic cell membranes. Prokaryotes contain sterol-like molecules called ***hopanoids***, which have a similar function to cholesterol



THE CELL CYCLE

- ***Interphase*** – The cells spends 90% of its time in interphase, during which chromosomal replication occurs to produce ***sister chromatids***. The sister chromatids are held together by a ***kinetochore*** proteins at the ***centromere***. During interphase, chromosomes exist in an uncoiled form called ***chromatin***, which is not visible under a light microscope. Specialized cellular functions such as nutrient absorption or signal transmission occur during this stage. Interphase is composed of three sub-phases:
  - ***G1 Phase*** – Also known as the first "gap" or "growth" phase. During G1 phase, the quantity of proteins, organelles, and cytoplasm inside the cell increases
  - ***S Phase*** – Also known as the "synthesis" phase. During S phase, DNA synthesis occurs and the chromosomes are replicated
  - ***G2 Phase*** – Also known as the second "gap" or "growth" phase. During G2 phase, the quantity of proteins, organelles, and cytoplasm inside the cell further increases in preparation for mitosis
  - ***G_0 Phase*** – Also known as the "resting" phase. G_0 is entered when the cell is deprived of the resources necessary for proliferation
- ***Mitosis*** – A series of steps that leads to the separation of sister chromatids in preparation for cytokinesis. We will discuss this further in the next paragraph
- ***Cytokinesis*** – Cell membrane cleaves off and divides the cytoplasm and organelles, forming two identical cells
- The entire cell cycle is regulated by ***cyclin*** and ***cyclin-dependent kinase (CDK)*** proteins



MITOSIS ☆ HIGH-YIELD

- A form of cell division that occurs in somatic cells to produce two genetically identical diploid cells
- A ***chromosome*** refers to any cohesive unit of genetic information that make up an organism's genome. Thus, when the 46 chromosomes of a human cell duplicate, it results in 46 chromosomes (*not* 92) because each of the sister chromatids are joined via the centromere, so the pair considered as "one" chromosome

MNEMONIC "PMAT" → Prophase Metaphase Anaphase Telophase

- ***Prophase*** – Chromosomes condense; centrioles move to poles; mitotic spindle forms; nuclear membrane dissolves
- ***Metaphase*** – Spindle fibres attach to chromatids via the kinetochore; formation of the metaphase plate. When the mitotic spindle attaches to the kinetochore, it is called the kinetochore microtubule
- ***Anaphase*** – Centromeres split and chromatids get pulled towards the poles
- ***Telophase*** – Spindle dissolves; nuclear membrane reforms; chromosomes uncoil. Cytokinesis occurs simultaneously. A cleavage furrow forms in animal cells and a cell plate forms in plant cells to divide the organelles and cytoplasm into two daughter cells

MEIOSIS ☆ HIGH-YIELD

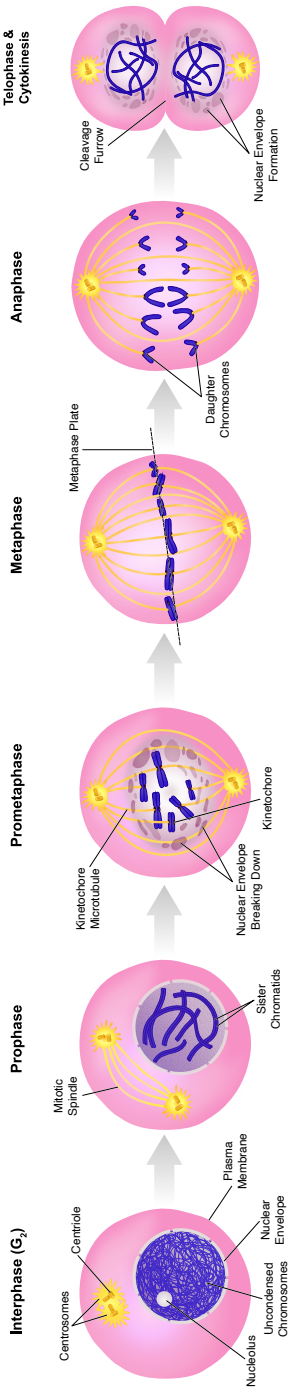
- A form of cell division that occurs in germline cells to produce four genetically non-identical haploid cells
- Meiosis consists of the same steps as mitosis (PMAT), except it occurs twice
- ***First (I) Meiotic Division*** – Called the "reductional division" because the copy number is reduced from 2 to 1
  - ***Prophase I*** – Same as in mitosis except the homologous chromosomes undergo ***synapsis***, where segments of genetic information cross over and are exchanged at the ***chiasmata***. This arrangement of four connected chromatids is called a ***tetrad***
  - ***Metaphase I*** – Same as in mitosis except homologous chromosomes align at the metaphase plate, rather than sister chromatids
  - ***Anaphase I*** – Same as in mitosis except the homologous chromosomes are pulled apart, and there is no splitting of the centromeres
  - ***Telophase I*** – Exactly the same as in mitosis
- ***Second (II) Meiotic Division*** – Called the "equatorial division" because the sister chromatids are divided in half
  - The steps are exactly the same as in mitosis

SUMMARY OF DIFFERENCES ☆ HIGH-YIELD

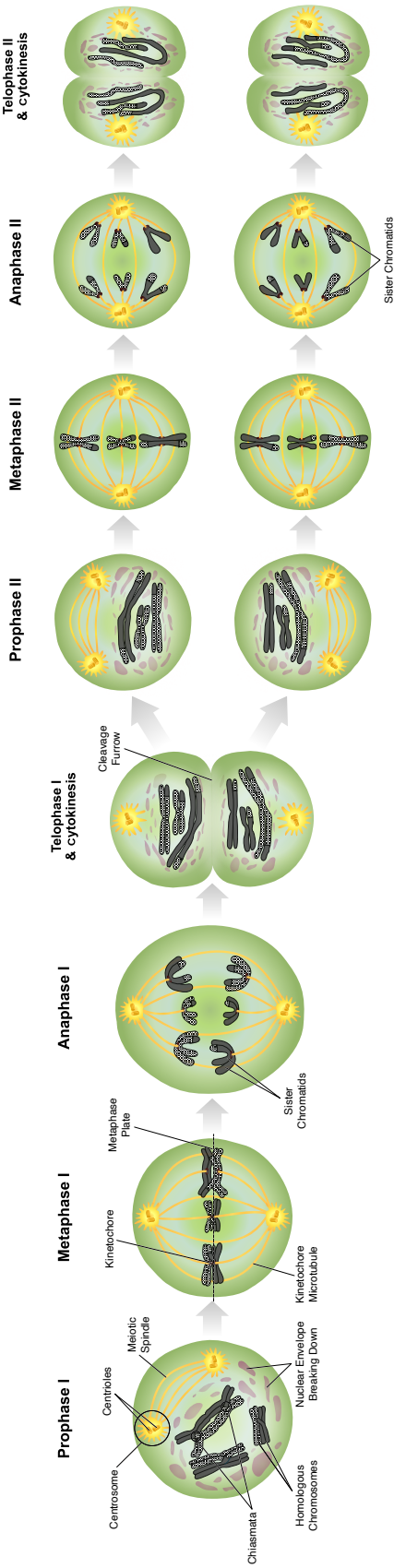
Phase	Mitosis	Meiosis
Prophase	No crossing over	Homologous chromosomes undergo synapsis, crossing over and forming a tetrad
Metaphase	Sister chromatids align	Homologous chromosomes align
Anaphase	Centromeres split Sister chromatids are pulled apart	Centromeres do not split Homologous chromosomes are pulled apart
Telophase	No difference	No difference
Result	Two genetically identical and diploid cells	Four genetically different and haploid cells

NONDISJUNCTION PATHOLOGIES

- ***Nondisjunction*** is the failure of sister chromatids or homologous chromosomes to separate during mitosis or meiosis. This results in ***aneuploidy*** (an abnormal number of chromosomes) and can cause a variety of diseases:
  - ***Turner Syndrome*** – Female is missing an X chromosome (XO). Symptoms include infertility, webbed neck, low-set ears, and short stature
  - ***Klinefelter Syndrome*** – Male has two or more X chromosomes (XXY). Symptoms include infertility, small testes, breast growth, less body hair, and weaker muscles
  - ***Jacob's Syndrome*** – Male has an extra Y chromosome (XYY). Symptoms include taller than average hight, increased acne, learning disorders, and behavioural problems. Fertility remains normal
  - ***Downs Syndrome*** – Trisomy (three copies) of chromosome 21. Symptoms include infertility, growth delays, intellectual disability, flat head and nose, increased separation between toes, and shortened neck
  - ***Edwards Syndrome*** – Trisomy of chromosome 18. Symptoms include infertility, premature death, clenched fists, small head, congenital defects, and severe intellectual disability
  - ***Patau Syndrome*** – Trisomy of chromosome 13. Symptoms include infertility, premature death, intellectual disability, motor disorders, small head, congenital defects, and severe intellectual disability
  - ***Cri du Chat Syndrome*** – Monosomy (one copy) of chromosome 5. Symptoms include a characteristic cat-like cry, infertility, severe intellectual disability, small head, and behavioural problems



Mitosis



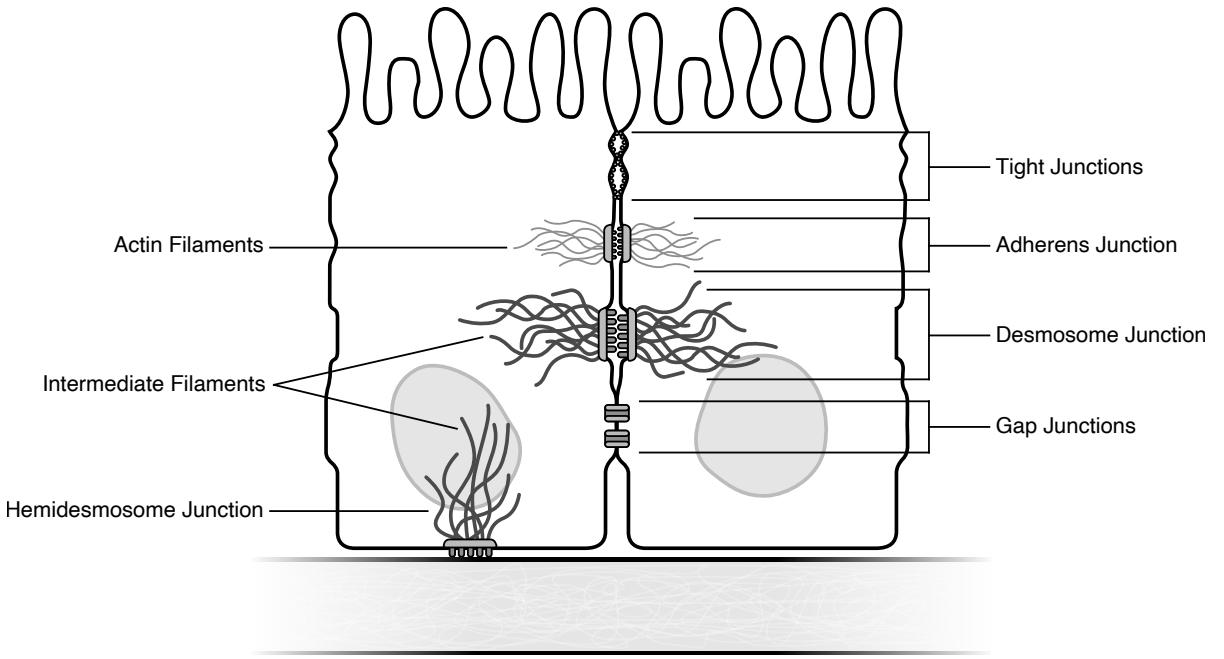
Meiosis

CELL JUNCTIONS

- ***Tight Junctions*** – Continuous, water-tight seal between cells, found in the bladder, intestine, kidney
- ***Adherens Junctions*** – Dot shaped seals between cells, linking actin filaments. Found in cardiomyocytes

  MNEMONIC Adherens junctions link Actin filaments

- ***Desmosomes*** – Dot shaped seals between cells, linking intermediate filaments. Found in the skin and intestines
- ***Hemidesmosomes*** – Same thing as desmosomes, except they form between a cell and the extracellular matrix (ECM) instead of between cells
- ***Gap Junctions*** – Tunnels between cells, allowing the free flow of water and ions. Found in neurons and cardiomyocytes
- ***Plasmodesmata*** – A special type of gap junction found only in plant cells. Directly joins the cytoplasm of adjacent plant cells, similar to a gap junction



ENDOSYMBIOTIC THEORY

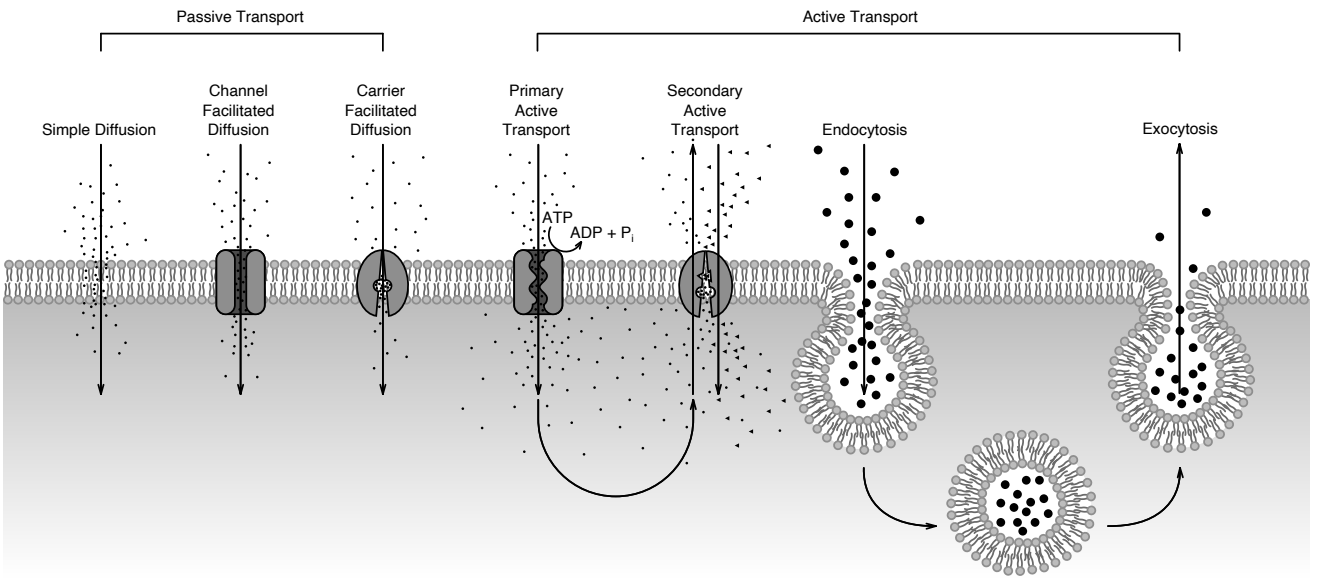
- States that all early cells were prokaryotes. Eukaryotes evolved when a heterotrophic prokaryote engulfed an autotrophic prokaryote and developed a mutualistic relationship
- Mitochondria and chloroplasts are believed to be endosymbionts, since they have a double lipid bilayer, independent chromosomes, and reproduce via binary fission
- Mitochondria are derived from ancient aerobic bacteria, while chloroplasts are derived from ancient cyanobacteria

APOPTOSIS AND NECROSIS

- ***Apoptosis*** is a form of programmed/controlled cell death where the cell membrane, cytoplasm, and organelles are systematically broken down and recycled by the body
  - Too much apoptosis may lead to autoimmune disease, while too little apoptosis may lead to cancer
  - During embryonic development, humans have webbed fingers and toes. Apoptosis normally occurs to eliminate this webbing before birth
- In contrast to apoptosis, ***necrosis*** is an uncontrolled cell death resulting from physical or chemical disruption

CELLULAR TRANSPORT ☆ HIGH-YIELD

- ***Active Transport*** – Occurs against a concentration gradient; requires ATP
  - ***Primary Active Transport*** – ATP is directly used to pump a substance across the membrane. For example, the Na^+/K^+ pump moves three Na^+ ions out of the cell for every two K^+ ions moved in
  - ***Secondary Active Transport*** – ATP is used to generate a concentration gradient, which another transporter relies on to pump a substance across the membrane. For example, the Na^+/glucose symporter in the proximal tubule of the kidney relies on the cell's Na^+ gradient to resorb glucose
  - ***Exocytosis*** – Substances brought out of the cell in bulk via secretory vesicles. For example, neurotransmitters such as acetylcholine are exocytosed from the axon terminal of neurons
  - ***Endocytosis*** – Substances brought into the cell in bulk via invaginations of the cell membrane to form special vesicles (early endosome, late endosome, and lysosomes). For example, iodinated thyroglobulin is brought into follicle cells of the thyroid via endocytosis
    - ***Receptor-Mediated Endocytosis*** – Substances bind to receptors on the membrane, which then causes the formation of ***clathrin-coated vesicles***. For example, low-density lipoprotein (LDL, aka "bad cholesterol") is absorbed by cells via receptor-mediated endocytosis
    - ***Phagocytosis*** – Cell engulfs a large solid particle, forming a phagosome. For example, pathogens are phagocytosed by macrophages
    - ***Pinocytosis*** – Cell engulfs small particles (usually fluids). For example, lipid particles are absorbed by human cells through this process
- ***Passive Transport*** – Occurs along a concentration gradient; does not require ATP
  - ***Osmosis*** – Movement of water across the membrane. For example, water is resorbed in the nephron and collecting duct of the kidneys through osmosis
  - ***Simple Diffusion*** – Movement of small, uncharged, or non-polar substances across the membrane. For example, oxygen is absorbed into the capillaries of alveoli through simple diffusion
  - ***Facilitated Diffusion*** – Movement of large, charged, or polar substances across the membrane with the help of integral membrane proteins. For example, glucose is absorbed by most cells via facilitated diffusion
    - ***Channel Proteins*** – Form a "tunnel" for the substance to cross the membrane
    - ***Carrier Proteins*** – Binds to the substance and changes conformation to release it on the other side
- Types of transport proteins:
  - ***Uniporter*** – Moves one molecule across the membrane in one direction
  - ***Symporter*** – Moves two molecules across the membrane in the same direction
  - ***Antiporter*** – Moves two molecules across the membrane in opposite directions

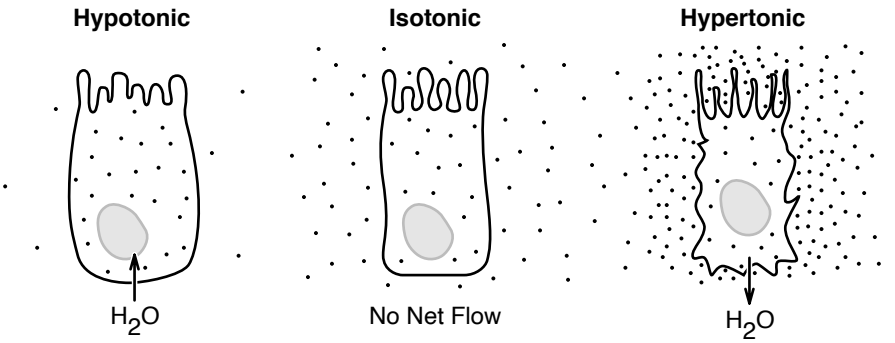


CELLULAR COMMUNICATION

- ***Quorum Sensing*** – Populations of bacteria release a signalling molecule to obtain information about population density, which they can then use to coordinate synchronized, large-scale changes in behaviour
- ***Autocrine Signalling*** – Cell releases signalling molecules that act on itself
- ***Paracrine Signalling*** – Cell releasing signalling molecules that act regionally or on cells nearby
- ***Endocrine Signalling*** – Cell releasing signalling molecules that act at great distances from the source

TONICITY ☆ HIGH-YIELD

- Tonicity is a property of the aqueous environment or solution that the cell is in
- ***Hypotonic*** – Concentration of the environment is lower than that of the cell. The cell will absorb water through osmosis, and may burst (cytolysis)
- ***Isotonic*** – Concentration of the environment is equal to that of the cell
- ***Hypertonic*** – Concentration of the environment is higher than that of the cell. The environment will absorb water from the cell through osmosis, and the cell may shrivel up (plasmolysis)
- Marine fish must constantly drink water and excrete highly concentrated, salty urine in order to survive in a hypertonic environment (salt water)
- Freshwater fish must drink very little water and excrete really dilute urine in order to survive in a hypotonic environment



CHAPTER 5 | **MOLECULAR GENETICS**

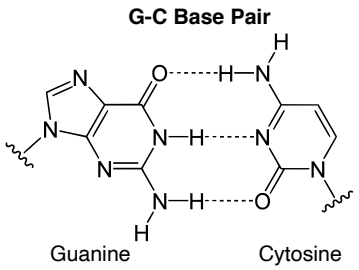
- The ***central dogma*** of genetics is the flow of information from DNA to RNA to protein:

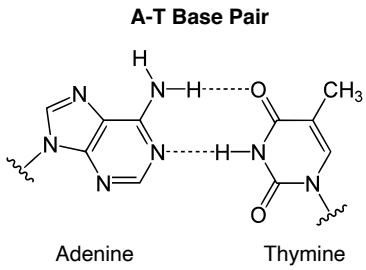
$$\text{DNA} \xrightarrow{Transcription} \text{RNA} \xrightarrow{Translation} \text{Protein}$$

- DNA and RNA are nucleic acids. We learned about the chemical composition of nucleic acids in chapter three while discussing macromolecules. In this chapter, we will review the molecular properties of DNA and RNA, as well as the mechanism through which information contained in DNA is converted to protein, an essential macromolecule for all living organisms

DNA STRUCTURE ☆ HIGH-YIELD

- Unlike RNA, DNA is usually double-stranded. The two antiparallel sugar-phosphate backbones form a right-handed helix structure, with the nitrogenous bases in the centre
- The nitrogenous bases are held together via ***hydrogen bonds***, formed between ***complementary*** base pairs:





- G-C pairs are stronger than A-T pairs because they consist of three hydrogen bonds instead of two. Therefore double-stranded DNA with a high ***G-C content*** also has a high ***melting temperature (T_m)***, the temperature at which 50% of the DNA becomes single-stranded
- Due to complementary bonding, ***Chargaff's rule*** states that DNA from all organisms should have a 1:1 ratio of purines and pyrimidines, and that %A = %T and %G = %C

Example

A strand of DNA is composed of 35% adenine. What is the percentage of cytosine?

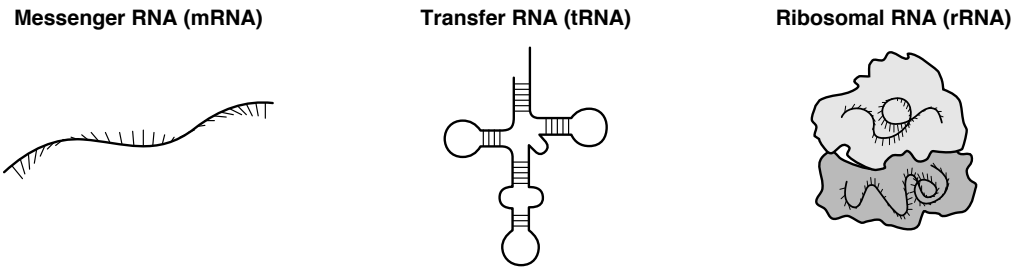
A) 35% B) 70% C) 15% D)30%

Worked Solution

$\%A = 35$, therefore $\%T = 35$	Using Chargaff's rule, we know that the percentage of adenine equals the percentage of thymine
$\%CG = 100 - \%AT = 100 - 70 = 30$	Since all DNA has a 1:1 ratio of purines and pyrimidines, we know that $\%CG = 100 - \%AT$
$\%C = \%G = \frac{1}{2}\%CG = \frac{1}{2}(30) = 15$	Using Chargaff's rule, we know that the percentage of cytosine equals the percentage of guanine
$\%C = 15$	Therefore the answer is C)

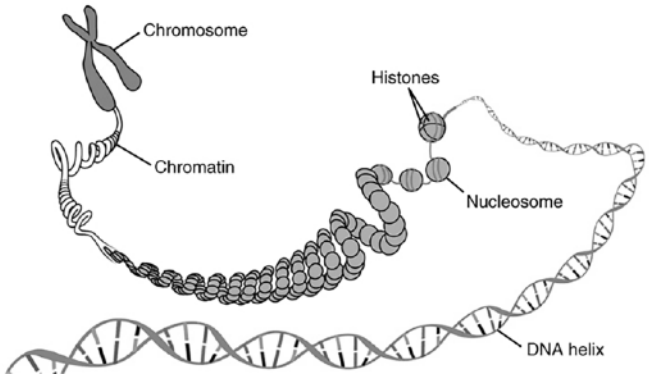
RNA STRUCTURE ☆ HIGH-YIELD

- RNA contains the same nitrogenous bases as DNA, except thymine is replaced by uracil, another pyrimidine. Like thymine, uracil pairs with adenine via two hydrogen bonds
- Unlike DNA, RNA is single-stranded. However, base pair hydrogen bonding still occurs via folding of the sugar-phosphate backbone. This enables RNA to adopt a secondary structure, in addition to its primary structure (the order of nucleotides)
- ***Transfer RNA (tRNA)*** brings amino acids to the ribosome during translation and has a cloverleaf structure
- ***Ribosomal RNA (rRNA)*** is interwoven with proteins, forming the ribosomal subunits
- ***Messenger RNA (mRNA)*** brings genetic information out of the nucleus after transcription and has a free-floating, single-stranded structure



EUKARYOTIC CHROMOSOMES

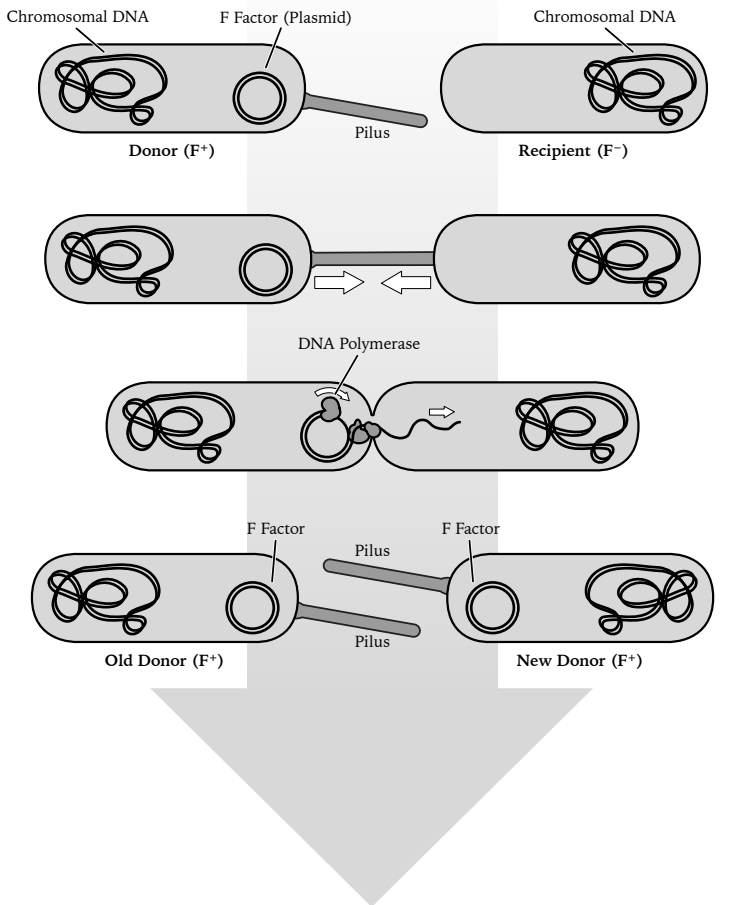
- In order to effective store DNA within the relatively small volume of the nucleus, it must be wrapped around ***histone proteins***. When eight histone proteins are surrounded by DNA, it resembles "beads on a string" and is referred to as a ***nucleosome***. This "beads on a string" structure is further wrapped around ***scaffold proteins*** to produce ***chromatin***. Finally, one or more strands of chromatin are called ***chromosomes***



- Chromatin is classified into two forms, depending on how tightly it is bound to histones and other scaffolds:
  - ***Euchromatin*** – Loosely packed DNA that is transcriptionally active and appears lighter under microscopy
  - ***Heterochromatin*** – Tightly packed DNA that is transcriptionally inactive and appears darker under microscopy

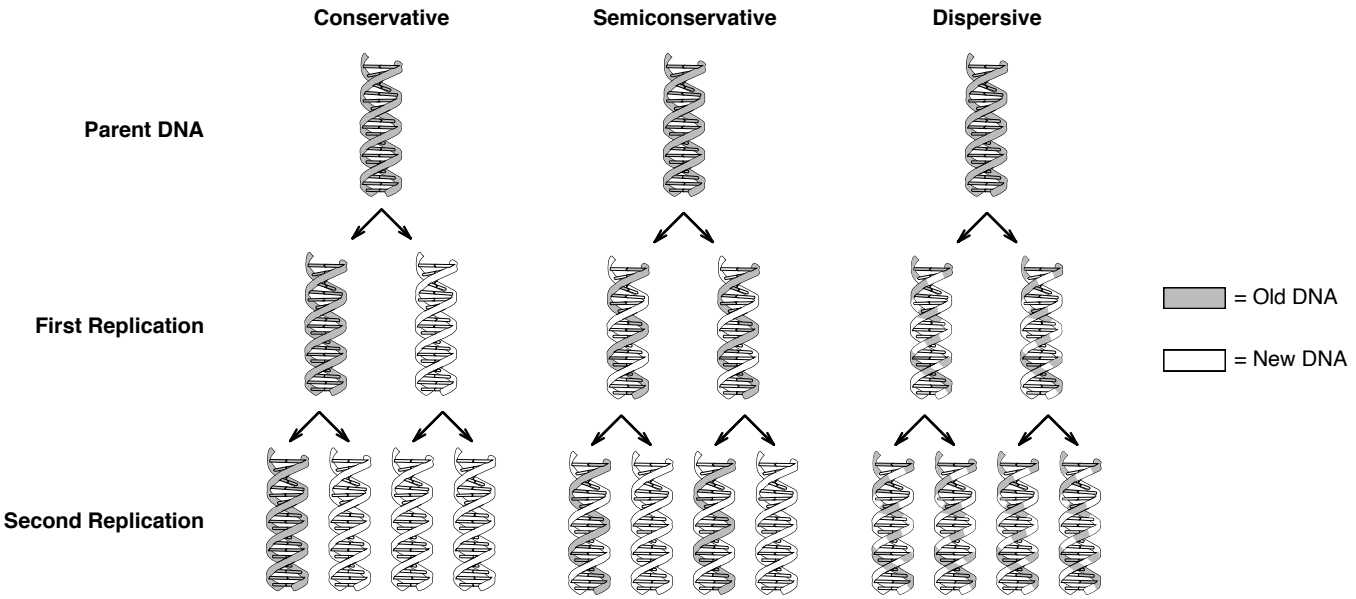
PROKARYOTIC CHROMOSOMES

- Prokaryotes do not contain a nucleus and thus their DNA is housed within a free-floating region of the cytoplasm called the ***nucleoid***. Their chromosomes are circular and much smaller than eukaryotic genomes. Instead of histones, prokaryotes use ***supercoiling*** to compact their DNA
- In addition to their chromosome, prokaryotes often also have a secondary ring of extra-chromosomal DNA called a ***plasmid***. The genes contained on plasmids are non-essential for survival but may encode additional traits for reproduction and antibiotic resistance
- Since bacteria reproduce via ***binary fission*** and do not exchange genetic material via gametes, there are other mechanisms through which genetic variation is generated:
  - ***Transformation*** – Bacteria picks up DNA (usually a plasmid) from its environment. The plasmid is then integrated into its extra-chromosomal genome and passed to daughter cells
  - ***Transduction*** – A bacteriophage virus moves segments of chromosomal DNA from one bacteria to another. The DNA is integrated into the bacteria genome and passed to daughter cells
  - ***Transposable Elements*** – Sequences of DNA that "jump" from one location to another within a genome. They can move via "cut and paste" or "copy and paste" mechanisms. In bacteria, transposable elements carry genes responsible for pathogenicity and antibiotic resistance
  - ***Conjugation*** – DNA (usually a plasmid) is transferred between two bacteria through a tube called the ***pilus***. The bacteria with the pilus is called the donor, while the bacteria receiving the DNA is called the recipient. Only bacteria with a special plasmid called the ***fertility factor (F factor)*** can form a pilus and be donors. Usually the F factor is transferred to the recipient, along with other plasmids such as the ***resistance transfer factor (R factor)***. The R factor encodes multiple antibiotic resistance genes



DNA REPLICATION ☆ HIGH-YIELD

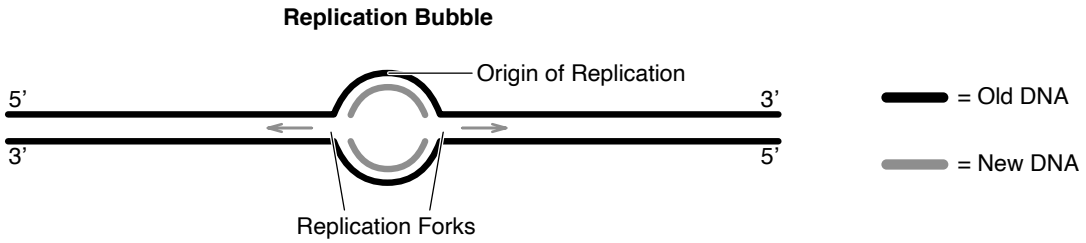
- DNA replication is the process of duplicating double-stranded DNA in preparation for mitosis or meiosis
- The process of DNA replication is ***semiconservative***, as opposed to fully conservative or dispersive:



- Experimentation by Meselson and Stahl eventually proved the semiconservative model to be correct. This means that each strand of the double helix acts as a template for the synthesis of a new, complementary strand
- There are three phases in DNA replication: initiation, elongation, and termination

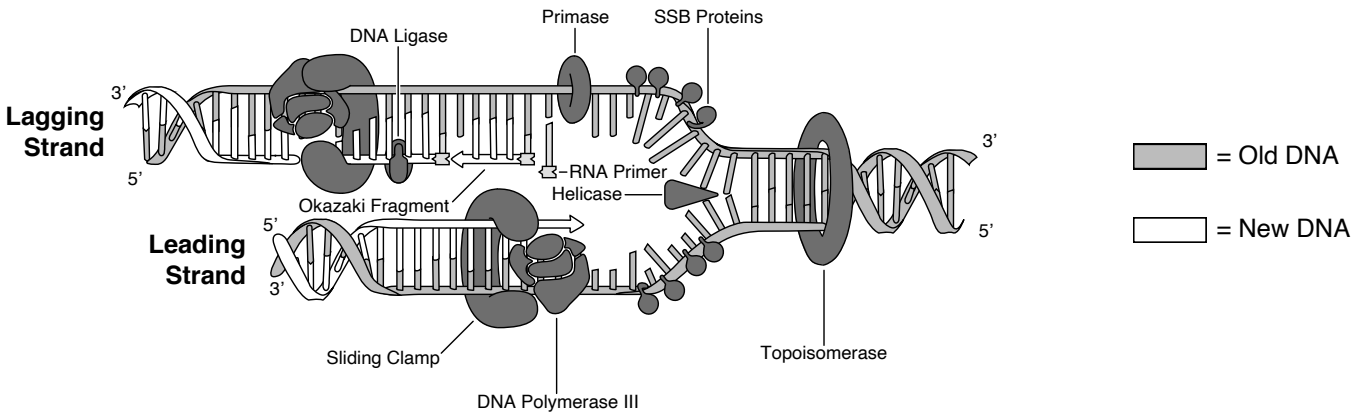
1. Initiation

- During this phase, ***initiator proteins*** separate the two strand of DNA, creating an ***origin of replication (ORI)***. This tends to occur in regions of high A-T content because A-T pairs are weaker than G-C pairs
- The separating strands of DNA form a ***replication bubble***, which consists of two ***replication forks*** on either side travelling in opposite directions:



2. Elongation

- The majority of the time during DNA replication is spent in this phase
- During elongation, several proteins help synthesize a new DNA strand, using the old one as a template
- ***Primase*** is an enzyme that synthesizes a ***primer***, a short stretch of complementary RNA that provides a 3' hydroxyl group for DNA polymerase to extend
- ***DNA polymerase III*** adds complementary nucleotides one-by-one onto the 3' end of the growing DNA strand. Since DNA polymerase can only add nucleotides to the 3' end, one daughter strand must be elongated continuously (called the ***leading strand***), and the other must be elongated in fragments (called the ***lagging strand***). The lagging strand consists of many RNA primers with short stretches of DNA called ***Okazaki fragments***. ***DNA polymerase I*** eventually replaces the RNA primers with DNA, and the gaps between Okazaki fragments are sealed by ***DNA ligase***
- ***Helicase*** is a protein that separates or "unzips" the double-stranded DNA at the replication fork
- ***Single-strand binding (SSB) proteins*** "clamp" onto the unzipped DNA strands to prevent them from annealing (sticking back together)
- ***Topoisomerase*** creates temporary double-stranded breaks in the DNA to prevent supercoiling
- ***Sliding clamp*** is a protein that binds DNA polymerase III to the strand being copied



3. Termination

- When the replication fork nears the end of the chromosome, DNA polymerase dissociates and replication is terminated
- In eukaryotes, DNA replication is unable to reach the ends of the linear chromosome. As a result, a short segment of DNA is lost after each replication cycle
- Telomeres are sequences of repetitive DNA at the ends of linear chromosomes that helps prevent the loss of important genetic information. ***Telomerase*** is an enzyme that extends telomeres, counteracting the shortening of telomeres from DNA replication. The shortening of telomeres is what causes a ***Hayflick limit***, which describes the limited number of times a cell can divide before cellular senescence

DNA TRANSCRIPTION ☆ HIGH-YIELD

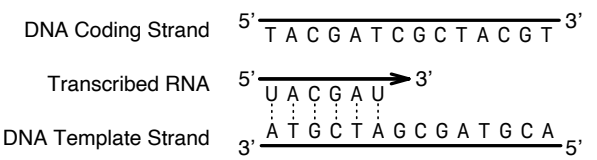
- Transcription is the fist step in the central dogma of genetics. During transcription, DNA is converted to mRNA, which will later be translated by a ribosome into a polypeptide
- The main enzyme involved is ***RNA polymerase***, which uses a single strand of DNA (called the ***template strand***) to synthesize a single strand of mRNA
- Transcription is broken down into the same three phases as in DNA replication: initiation, elongation, and termination

1. Initiation

- RNA polymerase binds to the ***promoter***, which is a sequence of DNA located upstream (5' direction) relative to a gene. In eukaryotes, RNA polymerase recognizes part of the promotor called the ***TATA box***
- After binding, RNA polymerase separates the double-stranded DNA and begins adding RNA nucleotides one-by-one. Unlike DNA polymerase, RNA polymerase is able to begin elongation without a primer

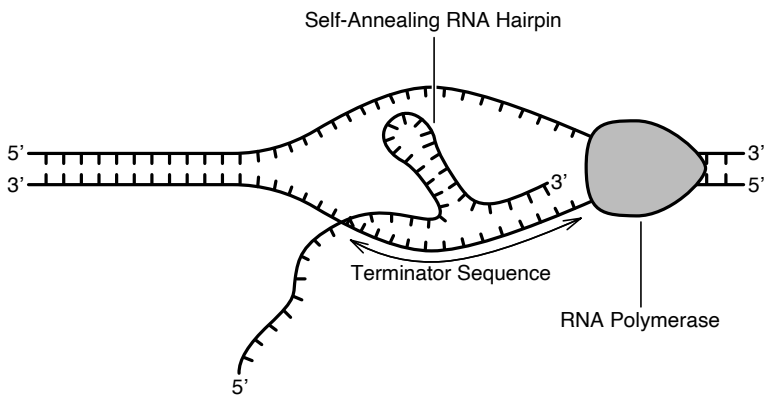
2. Elongation

- RNA polymerase adds complementary nucleotides to the 3' end of the growing strand. Note that the RNA strand is nearly identical to the ***coding strand*** of the parent DNA, except thymine is replaced with uracil

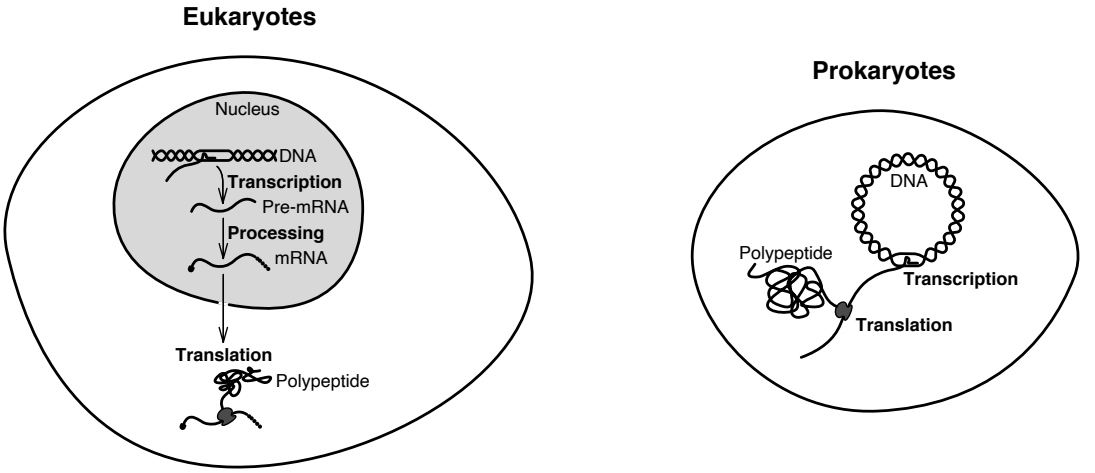


3. Termination

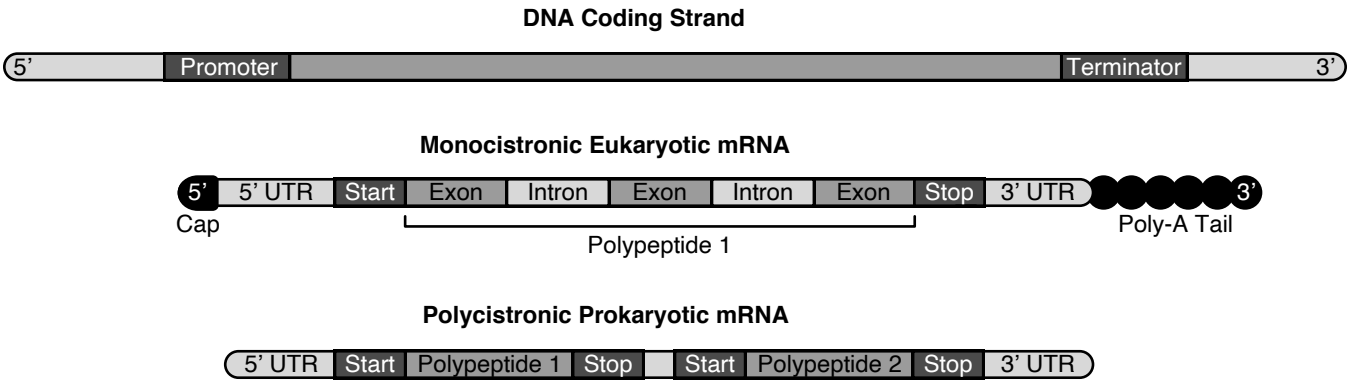
- Once the ***terminator sequence*** is reached, RNA polymerase dissociates from the DNA and the completed mRNA strand (called the ***transcript***) is released
- An example of a prokaryotic terminator sequence is the ***self-annealing RNA hairpin***. An example of a eukaryotic terminator sequence is the ***polyadenylation signal***. Transcription terminators can also be proteins, such as ***Rho factor***



- There are differences between eukaryotes and prokaryotes in terms of how transcription occurs. In eukaryotes, transcription occurs in the nucleus and the mRNA must migrate through nuclear pores and into the cytosol for translation. In prokaryotes transcription and translation occur simultaneously



- The mRNA transcript produced in eukaryotes is called ***pre-mRNA*** because it is not immediately ready for translation, and must undergo an extra step called ***post-translational processing*** in which the following modifications are made:
  - ***5' Cap Addition*** – A sequence of modified guanine nucleotides is added to the pre-mRNA to increase stability and protect the mRNA from enzymes in the cytosol
  - ***Poly-A Tail Addition*** – Multiple adenosine nucleotides are added to the pre-mRNA. This is important for both stability and nuclear export
  - ***Intron Splicing*** – ***Introns*** are nucleotide sequences that are not expressed (translated). They are cut (spliced) out of the RNA by a protein complex called a ***spliceosome***. The remaining nucleotide sequences (called ***exons***) are ligated back together prior to translation. The same mRNA sequence can be spliced in more than one pattern. This is called ***alternative splicing*** and allows eukaryotes to encode more than one protein structure in a single gene
- Eukaryotic and prokaryotic mRNA also differ in terms of how many polypeptides can be coded on a single transcript. mRNA that encodes for more than one polypeptide are called ***polycistronic***, while mRNA that encodes only one polypeptide are ***monocistronic***. Eukaryotic genes are mostly monocistronic while prokaryotic genes are polycistronic
- In both eukaryotic and prokaryotic mRNA, there is a stretch of nucleotides located between the promotor and the start of translation called the ***5' untranslated region (UTR)***. There is also a stretch located between the end of translation and the end of the mRNA, called the ***3' untranslated region (UTR)***



RNA TRANSLATION ☆ HIGH-YIELD

- During translation, mRNA is "read" three nucleotides at a time by a ***ribosome***. Each sequence of three nucleotides is called a ***codon***, and corresponds to a specific amino acid. By reading the order of codons in the mRNA, the ribosome knows which amino acids are needed to synthesize a polypeptide chain
- There are a total of 61 codons that correspond to 20 amino acids. The reason why there are more codons than amino acids is because only the first two nucleotides encode information about which amino acid is needed. The last nucleotide is allowed to vary. This is called the ***wobble hypothesis***:

Second Nucleotide

First Nucleotide	U	C	A	G
U	UUU, UUC: Phenylalanine UUA, UUG: Leucine	UCU, UCC, UCA, UCG: Serine	UAU, UAC: Tyrosine **UAA**, **UAG**: Stop	UGU, UGC: Cysteine **UGA**: Stop UGG: Tryptophan
C	CUU, CUC, CUA, CUG: Leucine	CCU, CCC, CCA, CCG: Proline	CAU, CAC: Histidine CAA, CAG: Glutamine	CGU, CGC, CGA, CGG: Arginine
A	AUU, AUC, AUA: Isoleucine **AUG**: Methionine (Start)	ACU, ACC, ACA, ACG: Threonine	AAU, AAC: Asparagine AAA, AAG: Lysine	AGU, AGC: Serine AGA, AGG: Arginine
G	GUU, GUC, GUA, GUG: Valine	GCU, GCC, GCA, GCG: Alanine	GAU, GAC: Aspartic Acid GAA, GAG: Glutamic Acid	GGU, GGC, GGA, GGG: Glycine

DAT TIP You are not required to memorize the codon table except for the start and stop codons

- Since there are three base pairs per codon, a sequence of nucleotides can be read three different ways depending on the starting point. The start codon (AUG) ensures the ribosome is in the proper ***reading frame***
- Note that the start codon codes for methionine. Therefore, all nascent polypeptides begin with this amino acid. However, not all proteins begin with methionine because in eukaryotes, it is usually removed during post-translational processing before the polypeptide is folded into a protein
- Unlike the start codon, the three stop codons (UAA, UAG, UGA) do not code for an amino acid
- Ribosomes recognize each codon through transient hydrogen bonding with the complementary anticodon of a ***transfer RNA (tRNA)*** molecule. tRNA also carry the individual amino acids that correspond with each codon. A tRNA that is "loaded" with its corresponding amino acid is called an ***aminoacyl-tRNA***
- Each ribosome consists of one large and one small subunit. Each subunit is made of protein and ***ribosomal RNA (rRNA)***. The ribosome contains three sites: the ***aminoacyl site (A)***, ***peptidyl site (P)***, and ***exit site (E)***

MNEMONIC "APE" → Aminoacyl Peptidyl Exit

- The translation mechanism has three phases:

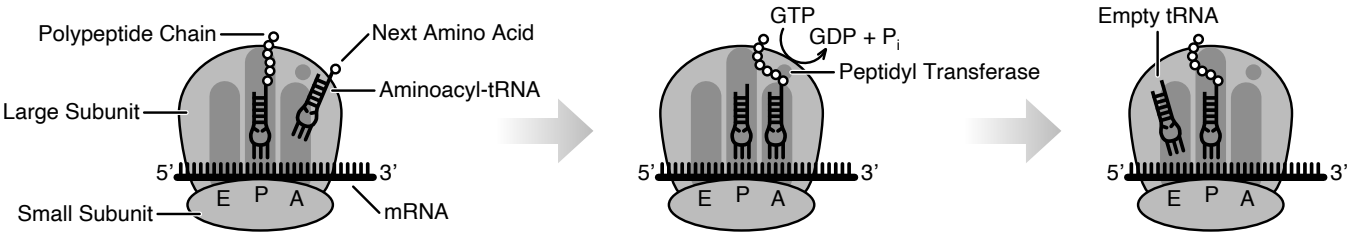
1. Initiation

- In eukaryotes, the small ribosomal subunit and an aminoacyl-tRNA assemble around the mRNA and start scanning for a start codon. Once "AUG" is reached, the large ribosomal subunit binds. This is called the ***initiation complex***. In prokaryotes, small ribosomal subunit attaches directly to a stretch of mRNA called the ***Shine-Dalgarno*** sequence, which is located right before the start codon

2. Elongation

- An aminoacyl-tRNA corresponding to the next codon occupies the A site. GTP is hydrolysed to provide energy for the ribosome to create a new polypeptide bond between the amino acids at the P and A sites. The enzymatic component of the ribosome that catalyses this reaction is called ***peptidyl transferase***

- After the formation of a new peptide bond, the ribosome shifts forward by one codon (three bases), allowing the next aminoacyl-tRNA to bind at the A site. At the same time, the empty tRNA at the E site is released. This resets the ribosome, and the process repeats until the stop codon is reached



3. Termination

- When the ribosome arrives at one of the three stop codons (UAA, UAG, UGA), release factor proteins bind at the P site and releases the polypeptide chain
- The large and small subunits dissociate and can be reused to translate another mRNA
- In eukaryotes, the nascent polypeptide may undergo ***post-translational modifications*** such as the removal of amino acids. Additionally, ***chaperone proteins*** help the polypeptide fold into its proper protein structure

EUKARYOTIC GENE REGULATION

- All cells in an organism have the same chromosomal DNA. However, our cells have different phenotypes because the way in which the DNA is expressed differs from cell to cell
- In eukaryotes, gene regulation can occur at many steps in the flow from DNA to RNA to protein. All of these regulatory steps contribute to how much or how little a gene is expressed (turned into protein) at a given time

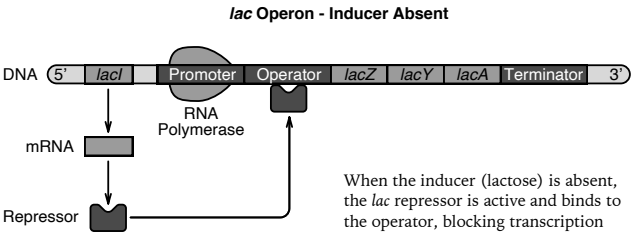
- **Transcriptional Regulation**
  - This type of gene regulation occurs before transcription
  - ***Chromatin accessibility*** is a major factor that determines how frequently genes are transcribed. DNA that is tightly wrapped around histones (heterochromatin) does not allow the binding of RNA polymerase, and thus is transcribed less. DNA that is partially unwound (euchromatin) allow polymerase binding and thus are more actively transcribed
  - The ***chromatin remodelling complex*** displaces histones to increase the transcription of certain genes
  - The addition of an acetyl group to histones (called ***histone acetylation***) leads to uncoiling of DNA and increases transcription
  - The addition of a methyl group to DNA (called ***DNA methylation***) will decrease transcription, effectively silencing the gene. Methylation tends to occur at sites called ***CpG islands***
  - Histone acetylation and DNA methylation produce heritable phenotype changes without altering the DNA sequence itself. This is called ***epigenetic regulation***
  - External signals such as growth hormones can also trigger proteins called ***transcription factors*** to bind to the nuclear DNA and influence transcription rate. ***Activators*** are transcription factors that promote transcription, while ***repressors*** inhibit transcription

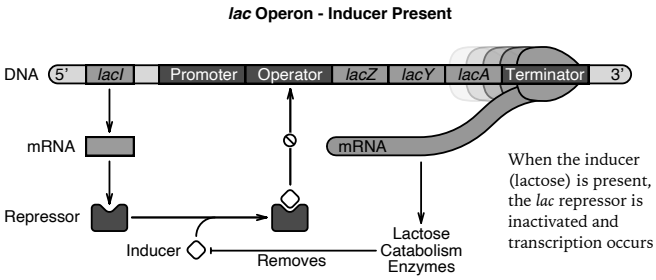
- **Post-Transcriptional Regulation**
  - This type of gene regulation occurs after transcription and before translation. It influences gene expression by changing the way pre-mRNA is processed
  - ***Alternative splicing*** allows the production of different mRNAs from the same pre-mRNA
  - The addition of the ***5' cap*** and ***poly-A tail*** can be regulated to increase or decrease mRNA stability in the cytosol prior to translation
  - Small single-stranded regulatory RNAs called ***microRNA (miRNA)*** can bind to a complementary sequence in a RNA transcript and block translation or cause RNA degradation

- **Post-Translational Regulation**
  - This type of gene regulation occurs after translation. It is much faster than chromosomal or post-transcriptional regulation because the time-consuming process of producing a polypeptide has already occurred. Thus post-translational regulation allows the cell to alter protein levels rapidly
  - ***Protein folding*** and ***processing*** turns nascent polypeptides into functional proteins. This process may involve trimming amino acids, adding cofactors, and combining multiple polypeptides to form a quaternary structure. These mechanisms can all be regulated to increase or decrease the amount of active proteins
  - ***Protein degradation*** can be regulated by changing the amount of ***ubiquitin tagging***. Ubiquitin is a protein that marks a target for destruction via a ***proteasome***. Proteins tagged with a polyubiquitin chain are degraded earlier than non-tagged proteins

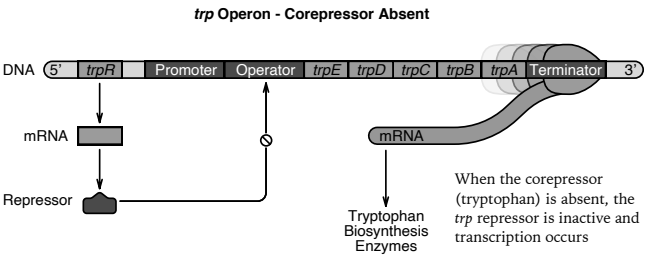
PROKARYOTIC GENE REGULATION

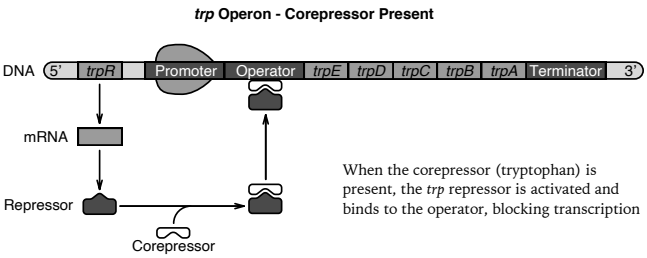
- Gene regulation in prokaryotes are regulated by ***operon*** systems that use negative feedback cycles
- Operons are DNA sequences that consist of the following components:
  - ***Enhancer*** – Binding site for a special protein called an ***activator***
  - ***Promotor*** – Binding site for RNA polymerase to start transcription
  - ***Operator*** – Binding site for a special protein called the ***repressor***
  - ***Genes*** – Operons usually contain several genes which are transcribed together, sharing the same mRNA
  - ***Terminator*** – Signals RNA polymerase to stop transcription
  - ***Activator*** – A protein that helps RNA polymerase bind to the promotor, increasing transcription
  - ***Repressor*** – A protein that binds to the operator and blocks RNA polymerase, inhibiting transcription
- ***Inducible operons*** are usually off (not transcribed) but can be turned on by an ***inducer***, a small molecule that binds to and inactivates the repressor. The ***lac operon*** is an example of an inducible operon:





- ***Repressible operons*** are usually on (transcribed) but can be turned off by a ***corepressor***, a small molecule that binds to and activates the repressor. The ***trp operon*** is an example of a repressible operon:





MOLECULAR GENETICS LAB TECHNIQUES

- ***Centrifugation*** – Used to separate substances with different densities from a mixture. The sample is placed in a tube that is spun at high velocities. The resulting centrifugal force will cause dense substances to migrate to the bottom of the tube, while less dense components migrate towards the top. The result is the formation of a solid mass called the ***pellet***, and a liquid layer on top called the ***supernatant***
  - ***Density/Gradient Centrifugation*** – Sample is spun once and substances are separated along a continuous density gradient from the top to bottom of the tube
  - ***Differential Centrifugation*** – Sample is spun and the supernatant is isolated and spun again at higher speeds. This process is repeated a number of times. This technique is used to separate the organelles and membranes of cells

- ***Polymerase Chain Reaction*** – Used to exponentially increase the quantity of a specific DNA sequence for use in forensics or genetic engineering. Complementary DNA ***primers*** are used to delineate the sequence to be amplified, and a heat-stable ***Taq polymerase*** is used in combination with a ***thermal cycler*** to produce an ***amplicon***

- ***Gel Electrophoresis*** – Used to separate DNA, RNA, or proteins based on size and charge. The sample is pipetted into individual wells in an ***agarose*** or ***polyacrylamide*** gel soaked in an electrolyte solution. When an electrical charge is supplied, DNA and RNA molecules migrate towards the cathode due to the overall negative charge from phosphate groups, while proteins can migrate towards the cathode or anode depending on their overall charge and isoelectric point. Smaller molecules are better able to move through the gel matrix, so they migrate farther from the wells than larger molecules. In DNA and RNA electrophoresis, a ***ladder*** containing nucleic acids of standardized length is usually used so comparisons can be made between gels
  - There are many techniques based on electrophoresis that are named according to the substance being separated: ***southern blot*** for DNA, ***northern blot*** for RNA, and ***western blot*** for protein

  MNEMONIC "SNOW, DROP" → Southern Northern Western, DNA RNA Protein

- ***Restriction Digest*** – Used to cut DNA so it can be ligated (joined) with other sequences to create ***recombinant constructs***. Bacterial ***restriction enzymes*** are used to make double-stranded breaks at specific sequences. These breaks can have a single-stranded overhang (called a ***sticky end***) or no overhang (called a ***blunt end***)

- ***DNA Sequencing*** – Used to determine the primary structure (order of nucleotides) of a DNA sequence. In ***Sanger sequencing***, DNA is elongated with fluorescent dideoxynucleotides that terminate the growing chain once they are incorporated. A laser is used to read the last nucleotide of every DNA fragment through ***capillary gel electrophoresis***. In ***next-generation sequencing***, nano-chips seeded with DNA oligonucleotides allow for parallel sequencing, which can produce faster and cheaper results

- ***Karyotyping*** – Used to visualize an organism's complete set of chromosomes. Cells are arrested in metaphase and dyed with Giemsa stain. A digital image is acquired under light microscopy, and chromosomal pairs are identified and arranged according to chromosome number

- ***Reverse Transcription*** – Used to generate complementary DNA (cDNA) from single-stranded mRNA. This allows eukaryotic genes to be ***cloned*** (reproduced) in prokaryotes. cDNA does not contain any introns because it is derived from eukaryotic mRNA that has already been processed by spliceosomes

PATHOLOGIES

- ***Mutations*** result from errors in the DNA sequence that are the result of DNA replication, environmental mutagens, or spontaneous damage. There are various types of mutations:
  - ***Point Mutations*** – Only a single nucleotide is affected
  - ***Frameshift Mutations*** – The reading frame is shifted such that the ribosome reads the wrong codons. This can occur by inserting or deleting nucleotides in any multiple except three
  - ***Substitutions*** – The correct base is exchanged for an incorrect base
  - ***Insertions/Deletions*** – Extra base pairs are added, or existing base pairs are removed
  - ***Chromosomal Mutations*** – Large segments of DNA are rearranged. Chromatin can be deleted, inserted, transposed (from one chromosome to another), or even inverted (reversed in directionality)
  - ***Somatic Mutations*** – A mutation affecting only somatic tissue. Can be passed to daughter cells via mitosis
  - ***Germline Mutations*** – A mutation affecting cells that become the sperm and egg when fully developed. Unlike somatic mutations, germline mutations are heritable and can be passed to progeny
- Mutations can also be categorized based on their effect on translation:
  - ***Silent Mutation*** – Has no effect on translation and the resulting polypeptide. This can occur if the mutation occurs at the last nucleotide of the codon (wobble base pair) or in a regulatory sequence
  - ***Missense Mutation*** – Causes the resulting polypeptide to have an incorrect amino acid. This may cause protein misfolding
  - ***Nonsense Mutation*** – Causes the resulting polypeptide to be prematurely terminated due to the creation of an early stop codon
- ***Single nucleotide polymorphisms (SNPs)*** are point mutations that occur in more than 1% of the population. Not all SNPs are pathological because the average individual has roughly ten million SNPs in their genome, many of which are silent

DNA REPAIR

- DNA repair describes several mechanisms through which a cell identifies and corrects damage to DNA:
  - ***Proofreading*** – DNA polymerase checks that the right nucleotide is added during replication. If an error is detected, the polymerase will replace the nucleotide before continuing replication
  - ***Mismatch Repair*** – Shortly after DNA replication is complete, a protein complex scans the strand for mismatched bases. If one is detected, a second complex excises a sequence of DNA near the mismatch and DNA polymerase replaces the segment with the correct nucleotides. Finally, DNA ligase seals the single-stranded breaks. The protein complex is able to distinguish the incorrect strand from the correct strand because old DNA is methylated, while new DNA is not
  - ***Excision Repair*** – DNA damage is excised and replaced. There are many forms of excision repair:
    - ***Base Excision Repair*** – An enzyme called ***glycosylase*** detects and excises a specific base. Different glycosylase enzymes exist for each base. The single-stranded breaks are then sealed with DNA ligase
    - ***Nucleotide Excision Repair*** – Detects and excises damaged DNA that distorts the double helix. The most common form of this damage is a ***thymine dimer***, caused by UV radiation. DNA helicase is required to unwind the segment of DNA that needs to be excised. The segment is replaced and ligase seals the single-stranded breaks
  - ***Double-stranded Break Repair*** – The detection and repair of large-scale, chromosomal damage:
    - ***Non-Homologous End Joining*** – The two ends of a damaged chromosome are joined back together without any effort to ensure that they match. This often results in chromosomal mutations
    - ***Homologous Recombination*** – The broken chromosome is cross-referenced with its homologous copy. The undamaged homologous chromosome is then used as a template to replace damaged DNA. This results in much fewer mutations then non-homologous end joining

CHAPTER 6 | **CLASSICAL GENETICS**

KEY TERMS

- ***Allele*** – A variation or version of a particular gene
- ***Genotype*** – The genetic makeup of an individual. A person's genotype determines their ***phenotype***
  - ***Homozygosity*** – A diploid individual with the same alleles for a particular gene
  - ***Heterozygosity*** – A diploid individual with different alleles for a particular gene
- ***Phenotype*** – An individual's observable characteristics and traits
- ***Epigenetics*** – The study of heritable changes in phenotype that do not have a corresponding change in genotype. Because of epigenetics, individuals with identical genotype (such as twins) may not necessarily have the same phenotype
- ***Pleiotropy*** – When one gene influences multiple phenotypic traits that are seemingly unrelated (ex: the same gene deletion can manifest as schizophrenia or autism)
- ***Polygenic Inheritance*** – When one trait is controlled by multiple genes, often resulting in a continuous spectrum of possible phenotypes (ex: hight is polygenetically inherited)
- ***Epistasis*** – When one gene affects the expression of a different gene (ex: the gene for baldness is epistatic to the gene for hair colour because the bald phenotype is expressed "on top" of and obscures the hair colour phenotype)
- ***Expressivity*** – When individuals with the same genotype show a varying spectrum of phenotypes
- ***Penetrance*** – The probability that individuals with a particular genotype will show the associated phenotype
- ***Nondisjunction*** – The failure of chromosomes to separate during mitosis or meiosis (anaphase I or II), resulting in aneuploid daughter cells. Nondisjunction during development often results in mortality or morbidity (such as Down's syndrome)
- ***Linked Genes*** – Genes in close proximity on the same chromosome and usually inherited together
- ***X Inactivation*** – The silencing of the X chromosome in females to produce the correct gene dosage. Inactivation occurs via packaging of the DNA into transcriptionally inactive heterochromatin

INHERITANCE ☆ HIGH-YIELD

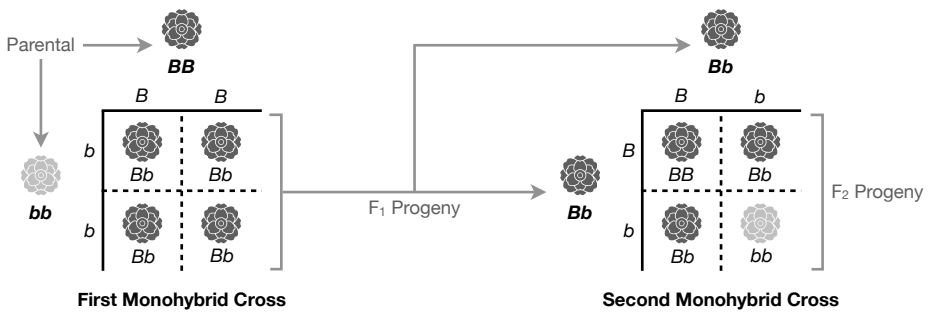
- ***Gregor Mendel*** discovered the basic principles of genetic inheritance by performing ***crosses*** (a controlled mating) between garden peas that were ***purebred*** (selectively bread until many generations of consistent, predictable progeny are produced)
- These experiments allowed Mendel to develop three ***laws of inheritance***:
  - ***Law of Segregation***
    - A ***gene*** controls a specific trait in an organism and exists in various forms called ***alleles***
    - An organism has two alleles for each inherited trait, one from each parent
    - The two alleles segregate during meiosis, so each gamete carries one allele
  - ***Law of Independent Assortment***
    - The inheritance of different traits is independent; their genes segregate independently
    - Modern genetics has proven this false, as two genes on the same chromosome that are closer to each other are more likely to be inherited together
  - ***Law of Dominance***
    - If two different alleles are present in an organism, one will be fully expressed (***dominant***) and the other will be silent (***recessive***)
    - Modern genetics has proven this false, as non-Mendelian inheritance patterns exist (ex: incomplete dominance, codominance)

- Although Mendel's laws were fairly simple, they helped other scientists discover ***inheritance patterns*** that explain the link between an organism's genotype and phenotype:
  - ***Complete Dominance*** – In a hetrozygote, the dominant allele's phenotype completely masks that of the recessive allele. For example, if B = black hair and b = brown hair, than a Bb individual will have black hair
  - ***Incomplete Dominance*** – In a heterozygote, the dominant allele's phenotype is blended with that of the recessive allele. For example, if R = red flowers and r = white flowers, then a Rr plant will have pink flowers. Both dominant and recessive phenotypes are partially expressed
  - ***Codominance*** – In a heterozygote, the dominant and recessive allele's phenotypes are both expressed. For example, if B = brown fur and b = white fur, the a Bb cow will have patches of red and white fur. In contrast to incomplete dominance, both phenotypes are completely expressed in codominance
  - ***Autosomal*** – When the gene that encodes a phenotypic trait is located on an autosomal (non-sex) chromosome. All progeny have the same probability of receiving a particular allele from the parents
  - ***Sex-Linked*** – When the gene for a phenotypic trait is located on the X or Y chromosome. The probability of inheriting a particular allele depends on the sex of the progeny. Recessive X-linked diseases disproportionally affect men, who only have one X chromosome and therefore cannot mask recessive alleles. Women who are heterozygous for the disease-causing allele are called ***carriers*** because they are not affected yet can pass the allele onto progeny
    - For recessive X-linked diseases:
      - XX = Unaffected female
      - XX_a = Carrier female
      - X_aX_a = Affected female
      - XY = Unaffected male
      - X_aY = Affected male
    - For recessive Y-linked diseases:
      - XX = Unaffected female
      - X_aY = Affected male

DAT TIP Punnet squares and the associated monohybrid and dihybrid crosses are very high-yield topics for the Canadian DAT. Be sure to know this section well, as there are always a few questions on classical genetics

MONOHYBRID CROSS ☆ HIGH-YIELD

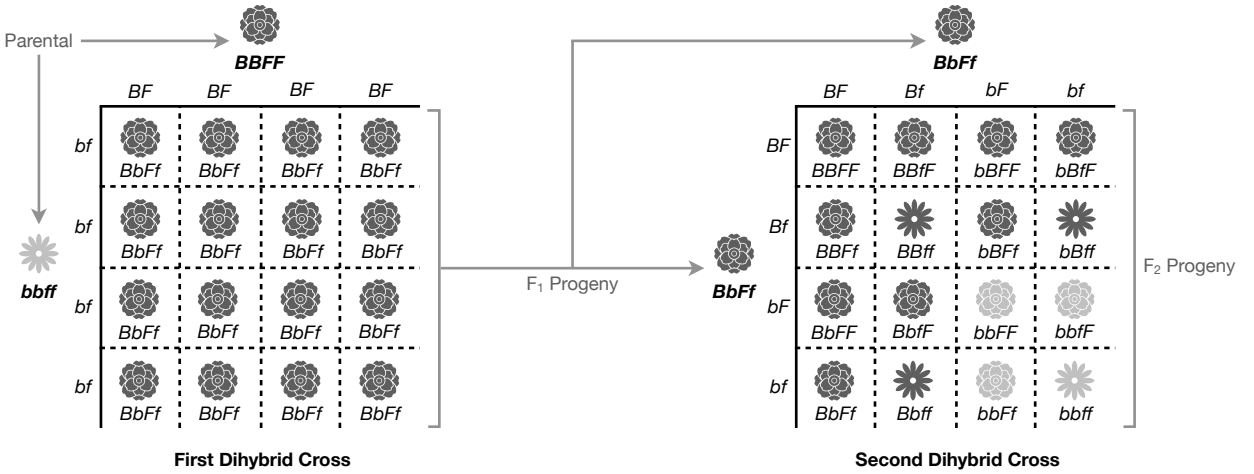
- A ***monohybrid cross*** is a controlled mating between two organisms that are purebred for different alleles at one gene of interest. This cross can be represented by a ***Punnet square*** diagram:



- The individuals being crossed are part of the ***parental (P) generation***
- The resulting progeny are part of the ***filial (F_1) generation***
- The progeny of the F_1 generation form the ***F_2 generation***
- Monohybrid crosses always have a characteristic ***1:2:1 ratio*** of F_2 genotypes

DIHYBRID CROSS ☆ HIGH-YIELD

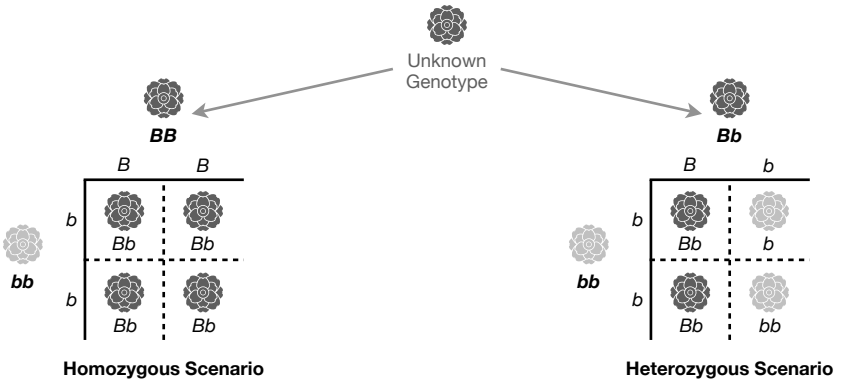
- A ***dihybrid cross*** is a controlled mating between two organisms that are purebred for different alleles at two genes of interest. This cross is represented by the following Punnet square diagram:



- When performing a dihybrid cross, assume independent assortment
- Dihybrid crosses always have a characteristic ***9:3:3:1 ratio*** of F_2 genotypes

TEST CROSS ☆ HIGH-YIELD

- A ***test cross*** is used to determine the genotype of an unknown individual. This is accomplished by crossing the unknown individual with a homozygous recessive individual and examining the ratio of progeny genotypes



PROBABILITIES ☆ HIGH-YIELD

- The DAT may ask you to calculate the probability of inheriting multiple traits in combination. The following two rules are essential for these types of questions:
  - ***Multiplication Rule of Probability*** – When each event is independent, the probability that *A* AND *B* will occur is equal to the probabilities of *A* and *B* multiplied together
  - ***Addition Rule of Probability*** – When each event is independent, the probability that *A* OR *B* will occur is equal to the probabilities of *A* and *B* added together

Example

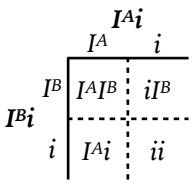
Blood type follows an inheritance pattern in which the alleles I^A and I^B are codominant with each other and dominant over i:

Genotype	→	Phenotype
I^AI^B		Type AB
I^AI^A or I^Ai		Type A
I^BI^B or I^Bi		Type B
ii		Type O

A man with genotype I^Ai and a woman with genotype I^Bi have three children. What is the probability that all three children have an AB or O blood type?

A) $\frac{1}{16}$ B) $\frac{1}{4}$ C) $\frac{1}{64}$ D) $\frac{1}{32}$

Worked Solution



Using the parent's genotypes, draw out the Punnet square. From here, we see that 25% of their offspring will have an AB blood type (I^AI^B), 25% will have an A blood type (I^Ai), 25% all have a B blood type (I^Bi), and 25% will have an O blood type (ii)

Probability AB $= \left(\frac{1}{4}\right)\left(\frac{1}{4}\right)\left(\frac{1}{4}\right) = \frac{1}{64}$

Use the multiplication rule to calculate the probability of child 1, 2, AND 3 having an AB blood type

Probability O $= \left(\frac{1}{4}\right)\left(\frac{1}{4}\right)\left(\frac{1}{4}\right) = \frac{1}{64}$

Use the multiplication rule to calculate the probability of child 1, 2, AND 3 having an O blood type

Probability AB or O $= \frac{1}{64} + \frac{1}{64} = \frac{1}{32}$

Use the addition rule to calculate the probability of the first situation OR the second situation occurring. Therefore the correct answer is D

PEDIGREE DIAGRAMS

- Used to visualize and analyze inheritance patterns of a phenotypic trait within a family tree
- Pedigree diagrams are drawn according to the following rules:
  - Squares represent males, while circles represent females
  - Black shapes represent individuals who have the trait, while white shapes represent individuals who do not
  - Individuals on the same row of the tree are in the same generation
  - Horizontal lines between a male and female represent mating
  - Offspring are drawn underneath the parent's row and connected with a branching line
- There are four important inheritance patterns:
  - ***Autosomal Dominant***
    - If both parents are affected, the offspring are either all affected (one or both parents homozygous dominant) or some/none are affected (both parents heterozygous)
    - If both parents are unaffected, the offspring must all be unaffected
    - If only one parent is affected, the offspring are either all affected (homozygous dominant parent) or some/none are affected (heterozygous parent)
  - ***Autosomal Recessive*** – Trait can appear to "jump" generations
    - If both parents are affected, the offspring must all be affected
    - If both parents are unaffected, the offspring are either all unaffected (one or both parents homozygous recessive) or some/none are affected (both parents heterozygous)
    - If only one parent is affected, the offspring must all be unaffected
  - ***X-Linked Dominant***
    - If a male is affected, his mother and all his daughters must be affected
    - If a female is affected, either one or both her parents are affected

    XX = ○ (Unaffected Female)
    XX_A = ● (Affected Female)
    X_AX_A = ● (Affected Female)

    XY = □ (Unaffected Male)
    X_AY = ■ (Affected Male)
  - ***X-Linked Recessive*** – Disproportionally affects males
    - If a male is affected, his mother is either affected or a carrier
    - If a female is affected, her father and all her sons must be affected

    XX = ○ (Unaffected Female)
    XX_a = ◐ (Carrier Female)
    X_aX_a = ● (Affected Female)

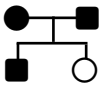
    XY = □ (Unaffected Male)
    X_aY = ■ (Affected Male)

    DAT TIP On the DAT, a carrier female may be illustrated as ○ rather than ◐, requiring you to use additional provided information to infer the actual genotype
  - ***Y-Linked***
    - If a male is affected, all his sons must also be affected
    - Females cannot be affected

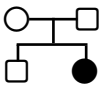
    XX = ○ (Unaffected Female)

    XY = □ (Unaffected Male)
    XY_a = ■ (Affected Male)

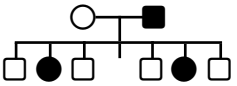
Examples



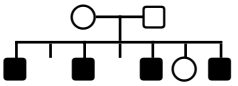
Because both parents are affected and one offspring is unaffected, this cannot be autosomal recessive. In an autosomal recessive pattern, all offspring of affected parents must also be affected. Instead, this is an autosomal dominant pattern, with both parents being heterozygous



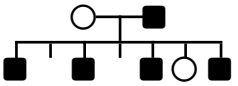
Because both parents are unaffected and one offspring is affected, this cannot be autosomal dominant. In an autosomal dominant pattern, all offspring of unaffected parents must also be unaffected. Instead, this is an autosomal recessive pattern, with both parents being heterozygous



Since all three daughters of the affected male are also affected, we can reasonably conclude that the inheritance pattern is X-linked dominant



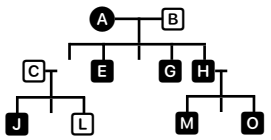
Since all four sons of the unaffected parents are affected, we can reasonably conclude that the inheritance pattern is X-linked recessive. Males are disproportionally affected, and the female parent must be a carrier



Since all four sons of the affected male are also affected, we can reasonably conclude that the inheritance pattern is Y-linked. This cannot be X-linked dominant because no daughters are affected. It also cannot be X-linked recessive because in that case, the allele would be only inherited by daughters

Example

Given that colour-blindness is an X-linked recessive trait, what is the probability that individuals C and D would have a son that is colour-blind?



A) 0% B) 25% C) 50% D) 75% E) 100%

Worked Solution

Since the inheritance pattern is X-linked recessive and individual A is an affected female, she must have the genotype X_aX_a. Since individual B is male and unaffected, he must have the genotype XY. Drawing a Punnet square for the cross between A and B shows that all sons (E, G, H) are affected, whereas all daughters (D, F) are carriers:

		$\boldsymbol{X_aX_a}$	
		X_a	X_a
$\boldsymbol{XY}$	X	X_aX	X_aX
	Y	X_aY	X_aY

Therefore individual D is a carrier and must have the genotype X_aX. Since individual C is male and unaffected, he must have the genotype XY. Finally, we draw a Punnet square for the cross between C and D:

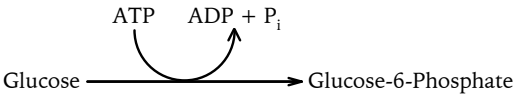
		$\boldsymbol{X_aX}$	
		X_a	X
$\boldsymbol{XY}$	X	X_aX	XX
	Y	X_aY	XY

Therefore the probability of having a son that is colour-blind is 50%. Answer C is correct

CHAPTER 7 | ENZYMES AND REACTIONS

REACTION THERMODYNAMICS ☆ HIGH-YIELD

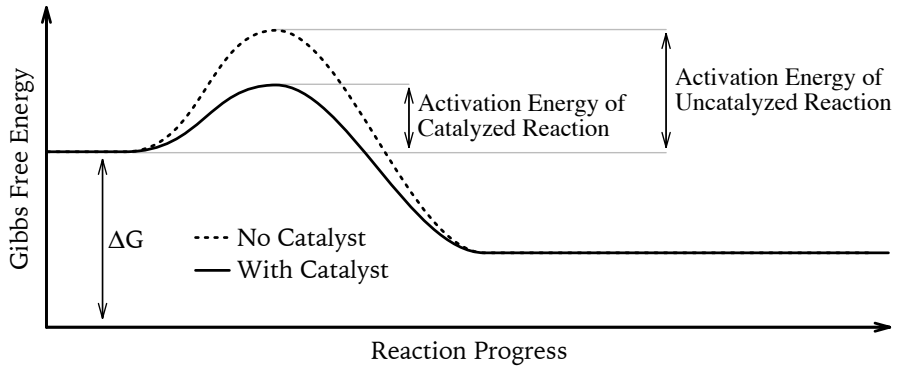
- In the context of biology, ***thermodynamics*** studies the spontaneity (favourability) of biochemical reactions. In contrast, ***kinetics*** studies the rate (speed) of reactions
- Biochemical reactions or pathways that release energy (such as glycolysis) are called ***exothermic***. In contrast, reactions that consume energy (such as photosynthesis) are called ***endothermic***
- ***Gibbs free energy (ΔG)*** is a thermodynamic property that describes the spontaneity of a reaction. If $\Delta G > 0$, then the reaction is spontaneous, and vice versa
- Biochemical reactions that release free energy are called ***exergonic***, and reactions that consume free energy are called ***endergonic***
- Cells are able to make endergonic reactions favourable by supplying free energy created in exergonic reactions. If the free energy provided by the exergonic reaction is greater than the free energy consumed by the endergonic reaction, then the overall reaction will be spontaneous. This energy dependence is called ***reaction coupling***. A common example is coupling the spontaneous dephosphorylation of ATP with the non-spontaneous conversion of glucose into glucose-6-phosphate:



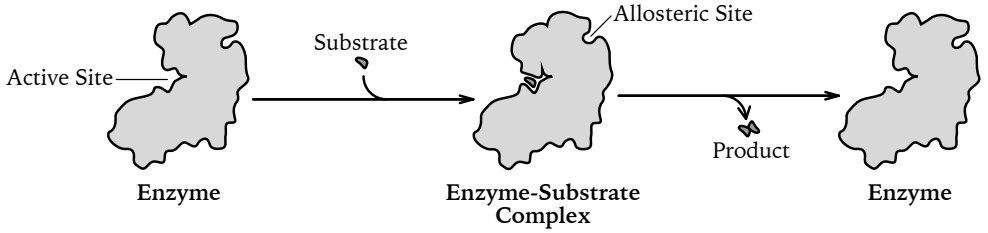
ATP → ADP + P_i	$\Delta G = -30$kJ/mol
Glucose → Glucose-6-Phosphate	$\Delta G = +12$kJ/mol
ATP + Glucose → ADP + P_i + Glucose-6-Phosphate	$\Delta G = -18$kJ/mol

ENZYME STRUCTURE AND FUNCTION ☆ HIGH-YIELD

- ***Catalysts*** are substances that increases the rate of a chemical reaction by lowering the ***activation energy***:



- ***Enzymes*** are proteins that act as biological catalysts. If enzymes did not exist, the biochemical reactions that sustain life (such as DNA replication) would take hundreds of years
- Note that enzymes only influences reaction kinetics, not thermodynamics. In other words, the presence of an enzyme does not change the spontaneity of the reaction
- The reactant that the enzyme binds to is called the ***substrate***. This binding occurs in a special region of the enzyme called the ***active site***. Other sites exist on the enzyme, called ***allosteric sites***

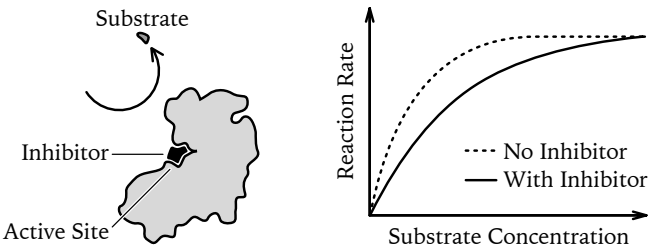


- When the substrate binds to the active site, the enzyme undergoes a conformational change such that the active site becomes an even more precise fit for the substrate. This is called the ***induced-fit model***
- ***Cooperative binding*** is when the binding of a substrate to one active site increases or decreases the substrate affinity of other actives sites. For example in hemoglobin, the binding of oxygen to any one of its four active sites will help other oxygen molecules bind to the remaining three active sites
- Some enzymes may require the addition of other structures that help them catalyze reactions:
  - ***Cofactors*** are non-protein molecules that help catalyze the reaction by spatially manipulating the substrate or accepting/donating electrons
  - ***Coenzymes*** are organic cofactors, such as vitamins
  - ***Prosthetic groups*** are non-organic cofactors that are covalently bound to the enzyme (i.e. iron is a prosthetic group of hemoglobin)
- When an enzyme is bound to its cofactor, it is called a ***holoenzyme***. When unbound, it is an ***apoenzyme***
- The performance of an enzyme (and thus the rate of reaction) can be influenced by the following factors:
  - ***Substrate Concentration*** – The more substrate that is available in the surrounding environment, the faster the enzyme can work. For most reactions, substrate concentration is the limiting factor. However, if there are more substrate molecules than available active sites, adding more substrate will not increase reaction rate. This results in ***saturation kinetics***
  - ***Temperature*** – All enzymes have an optimal temperature. Moderate deviations from this temperature will result in decreased performance. Extreme high temperatures will result in enzyme denaturation, while extreme low temperatures will result in a lack of the necessary kinetic energy to catalyze reactions
  - ***pH*** – Like temperature, all enzymes have an optimal pH. Deviations from this pH will result in detrimental changes to protein folding, or complete denaturation

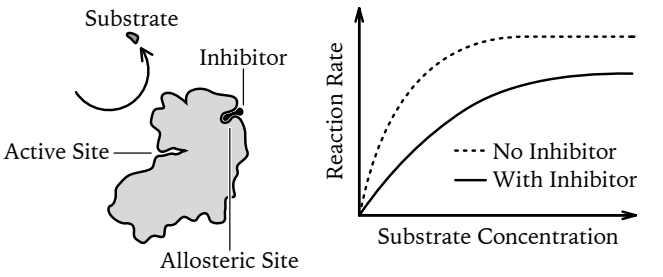
ENZYME INHIBITION

- Inhibitors decrease the performance of enzymes. There are two main categories of enzyme inhibition:
  - ***Competitive Inhibition*** – The inhibitor binds to the enzyme at its ***active site***, blocking the substrate
    - Increasing concentrations of the substrate will reverse the effects of competitive inhibition. In other words, adding more substrate will "out-compete" the competitive inhibitor
  - ***Noncompetitive Inhibition*** – The inhibitor binds to the enzyme at its ***allosteric site***, changing the enzyme's conformation and preventing it from binding to the substrate
    - Increasing concentrations of the substrate will *not* reverse the effects of competitive inhibition

Competitive Inhibition

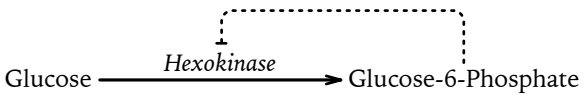


Noncompetitive Inhibition



ENZYME REGULATION

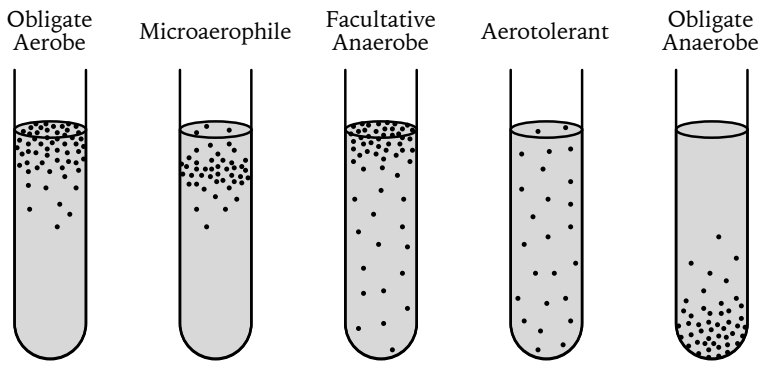
- ***Allosteric regulators*** are molecules that bind to an enzyme's allosteric site to inhibit or stimulate activity. The binding of these molecules is usually reversible
- An ***allosteric activator*** will stabilize the enzyme in a conformation that causes the active site to have a higher affinity for the substrate. In contrast, an ***allosteric inhibitor*** will stabilize a less active form of the enzyme
- When an allosteric inhibitor is also a product of the reaction catalyzed by the enzyme, ***feedback inhibition*** occurs. As the product accumulates, it inhibits the enzyme and the rate of reaction slows down. Once the excess of product is cleared, the enzyme loses inhibition and the reaction proceeds again. This cycle is called a ***negative feedback loop***
- Feedback inhibition is often used to regulate anabolic biochemical pathways and prevent the waste of cellular resources from the synthesis of unneeded products. For instance, glucose-6-phosphate is the product of a reaction catalyzed by the hexokinase enzyme. It is also an allosteric inhibitor that acts on hexokinase to slow down the reaction when glucose-6-phosphate is plentiful:



CHAPTER 8 | **METABOLISM**

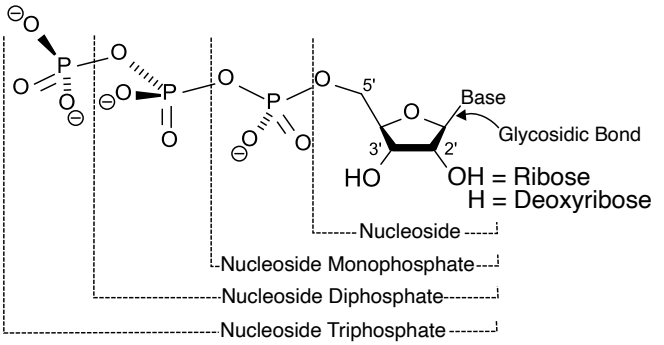
INTRODUCTION ☆ HIGH-YIELD

- ***Metabolism*** describes the biochemical reactions performed by an organism to stay alive. ***Anabolic metabolism*** involves building up larger compounds from smaller ones (ex: photosynthesis) while ***catabolic metabolism*** involves breaking down larger compounds into its constituents (ex: glycolysis)
- Organisms can be classified metabolically based on:
  - Energy Source for ATP Production
    - ***Phototroph*** – Energy is obtained through sunlight
    - ***Chemotroph*** – Energy is obtained through breaking chemical bonds
  - Electron Source for Biosynthesis or ATP production
    - ***Organotroph*** – Electrons are obtained from organic compounds (ie: glucose, proteins, lipids, etc)
    - ***Lithotroph*** – Electrons are obtained from inorganic compounds, usually mineral sources (ie: iron, nitrogen, sulphur, etc)
  - Carbon Source for Biosynthesis
    - ***Heterotroph*** – Carbon is obtained from the catabolism of food
    - ***Mixotroph*** – Carbon is obtained from both food catabolism and fixation of atmospheric carbon dioxide
    - ***Autotroph*** – Carbon is obtained from fixing atmospheric carbon dioxide
  - Relationship with Oxygen
    - ***Obligate Aerobe*** – Uses aerobic respiration; requires oxygen to survive
    - ***Microaerophile*** – Uses aerobic respiration; requires oxygen but cannot tolerate high concentrations
    - ***Facultative Anaerobe*** – Uses both aerobic respiration and fermentation but grows more efficiently using aerobic respiration; can tolerate oxygen
    - ***Aerotolerant Organisms*** – Uses fermentation; can tolerate oxygen
    - ***Obligate Anaerobe*** – Uses fermentation; poisoned by oxygen
    - Organisms of these categories have distinct distributions when cultured in a test tube:

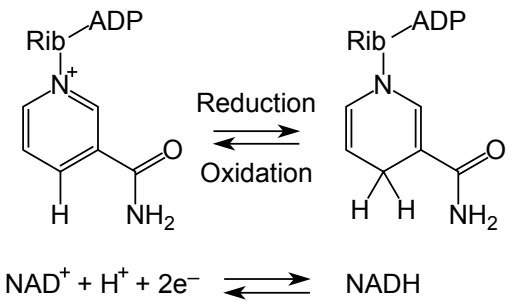


ATP AND NADH ☆ HIGH-YIELD

- ***Adenosine triphosphate (ATP)*** is an unstable ribose nucleoside triphosphate that is used to store energy. When the phosphate bonds are broken, free energy is released that can be coupled with endergonic reactions. ATP is most commonly broken down into ADP and inorganic phosphate (P_i), but double dephosphorylation can occur in some reactions, producing AMP and pyrophosphate (PP_i)



- ***Nicotinamide Adenine Dinucleotide (NADH)*** is a coenzyme used to store and transport electrons. For this reason, NADH is a source of reducing power for anabolic reactions. After acting as a reducing agent, NADH becomes its oxidized form NAD^+



CELLULAR RESPIRATION ☆ HIGH-YIELD

- Cellular respiration is a form of catabolic metabolism that uses the energy stored in biomolecules (carbohydrates, lipids, proteins) to phosphorylate ADP, creating high-energy ATP
- There are two types of ADP phosphorylation:
  - ***Substrate-Level Phosphorylation*** – When the synthesis of ATP is directly coupled to reactions that catabolize high-energy biomolecules, such as glucose
  - ***Oxidative Phosphorylation*** – When the synthesis of ATP is powered by ***chemiosmosis***, the flow of protons down a concentration gradient. This is more efficient and can produce more ATP than substrate-level phosphorylation
- Cellular respiration can involve aerobic pathways (such as the citric acid cycle, electron transport chain) or aerobic pathways (such as glycolysis, fermentation). We will review the mechanisms behind these four cellular respiration pathways in the following paragraphs

DAT TIP It is not necessary to memorize every molecule and enzyme involved in the mechanisms. However, it is important to know the reactants, products, and location in which the reactions occur

GLYCOLYSIS ☆ HIGH-YIELD

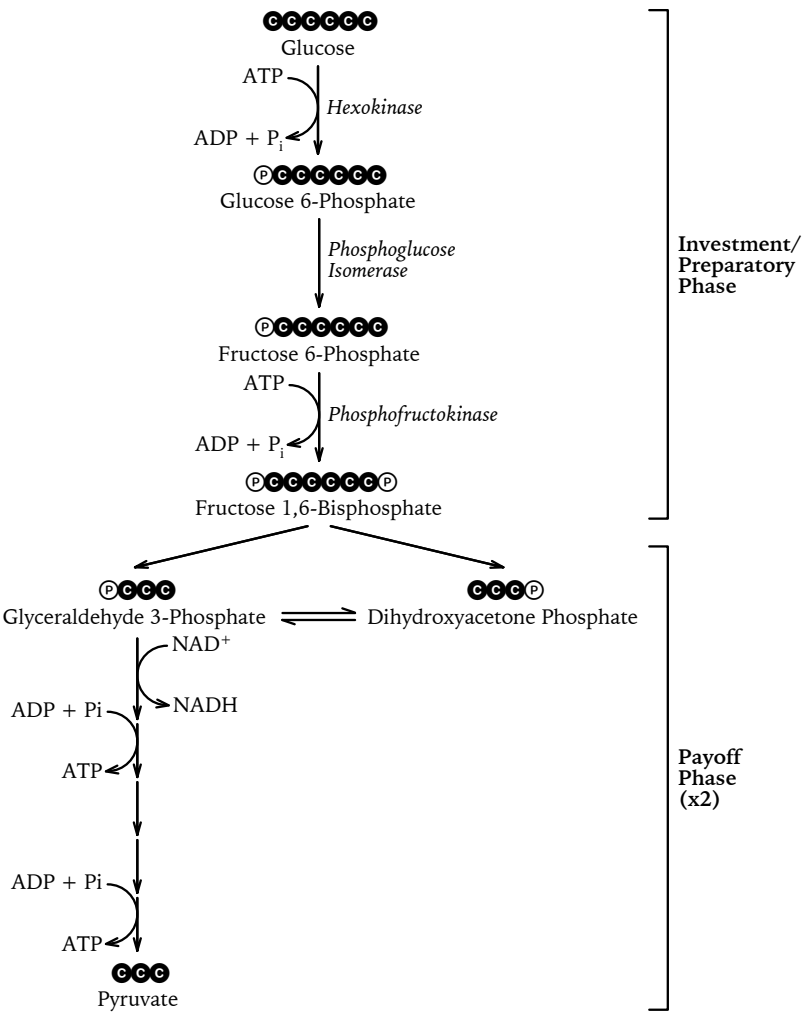
- Glycolysis is ***anaerobic*** and generates ATP through ***substrate-level phosphorylation***. It occurs in the ***cytosol*** of the cell. The net equation for this metabolic pathway is:

$$\text{Glucose} + 2\text{ADP} + 2\text{P}_i + 2\text{NAD}^+ \rightarrow 2\text{Pyruvate} + 2\text{ATP} + 2\text{NADH}$$

- The metabolic pathway of glycolysis can be broken down into two phases:

  - **Investment/Preparatory Phase** – Reactions during which ATP is consumed
    1. The enzyme ***hexokinase*** irreversibly converts glucose to ***glucose 6-phosphate (G6P)***, using 1 ATP
    2. An isomerase enzyme converts ***G6P*** to ***fructose 6-phosphate (F6P)***
    3. The enzyme ***phosphofructokinase*** irreversibly converts ***F6P*** to ***fructose 1,6-bisphosphate***, using 1 ATP. This is the rate-limiting step for glycolysis. At this point, fructose 1,6-bisphosphate exists in equilibrium with ***glyceraldehyde 3-phosphate (G3P)*** and ***dihydroxyacetone phosphate (DHAP)***. G3P and DHAP are both three-carbon molecules, so everything after this step is doubled (x2)

  - **Payoff Phase** – Reactions during which ATP is produced
    - The 2 G3P produced from the investment phase undergo a sequence of reactions, the details of which are beyond the scope of the Canadian DAT. These reactions each produce 2 ATP and 1 NADH
    - In the last reaction, the enzyme ***pyruvate kinase*** irreversibly converts ***2-phosphoglycerate*** into ***pyruvate***



• Here is a summary of the ATP and NADH produced during the glycolysis of one glucose molecule:

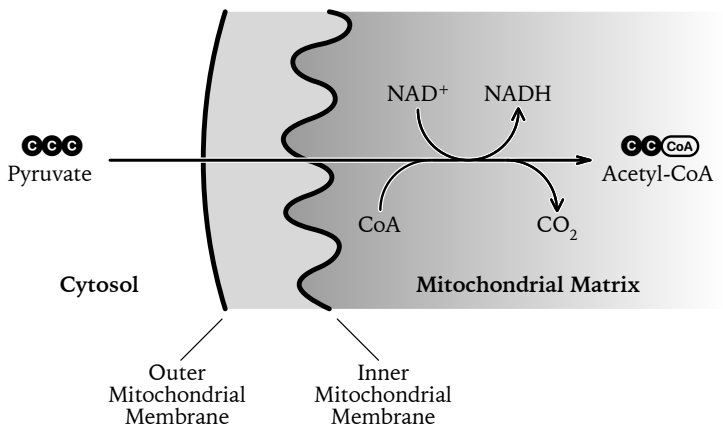
Investment/Preparatory Phase:	$-2ATP$
Payoff Phase:	$2 \times (2ATP + 1NADH)$
Net Production:	$2ATP + 2NADH$

PYRUVATE OXIDATION ☆ HIGH-YIELD

• This process is also called pyruvate decarboxylation, since a carbon is being removed from pyruvate
• Pyruvate oxidation is ***anaerobic*** and occurs in the ***mitochondrial matrix***. It does not produce ATP
• The net equation for this process is:

$$\text{Pyruvate} + NAD^+ + \text{CoA} \rightarrow \text{Acetyl-CoA} + \text{NADH} + CO_2$$

1. Pyruvate from glycolysis diffuses through the ***outer mitochondrial membrane*** and is assisted through the ***inner mitochondrial membrane*** by carrier proteins
2. Pyruvate undergoes a decarboxylation reaction, loosing its carboxyl group and producing CO_2 in the process
3. The remaining two carbons are oxidized, and the electrons are combined with NAD^+ to form NADH
4. The two-carbon molecule is transferred onto coenzyme A, forming acetyl-CoA

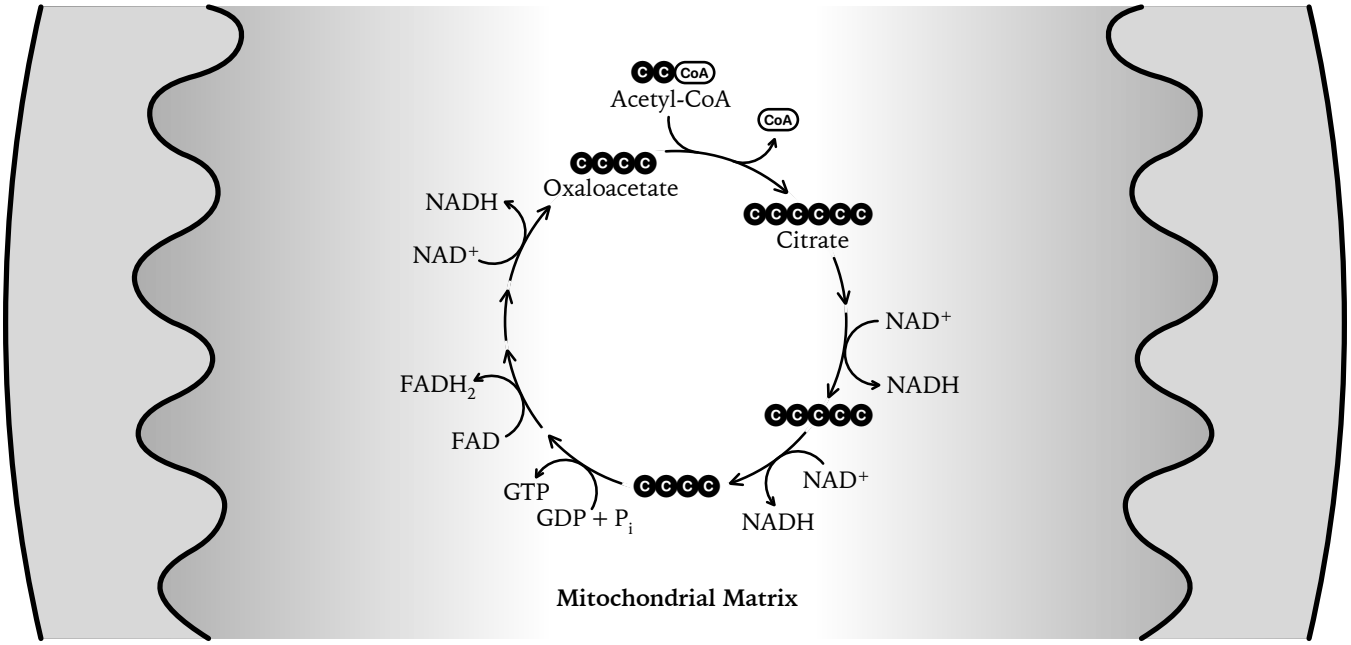


CITRIC ACID CYCLE ☆ HIGH-YIELD

- This pathway is also called the Krebs cycle and tricarboxylic acid cycle, since it was discovered by Krebs and citrate is a tricarboxylic acid
- The citric acid cycle is ***anaerobic*** and generates ATP through ***substrate-level phosphorylation***. It occurs in the ***mitochondrial matrix***. The net equation for this metabolic pathway is:

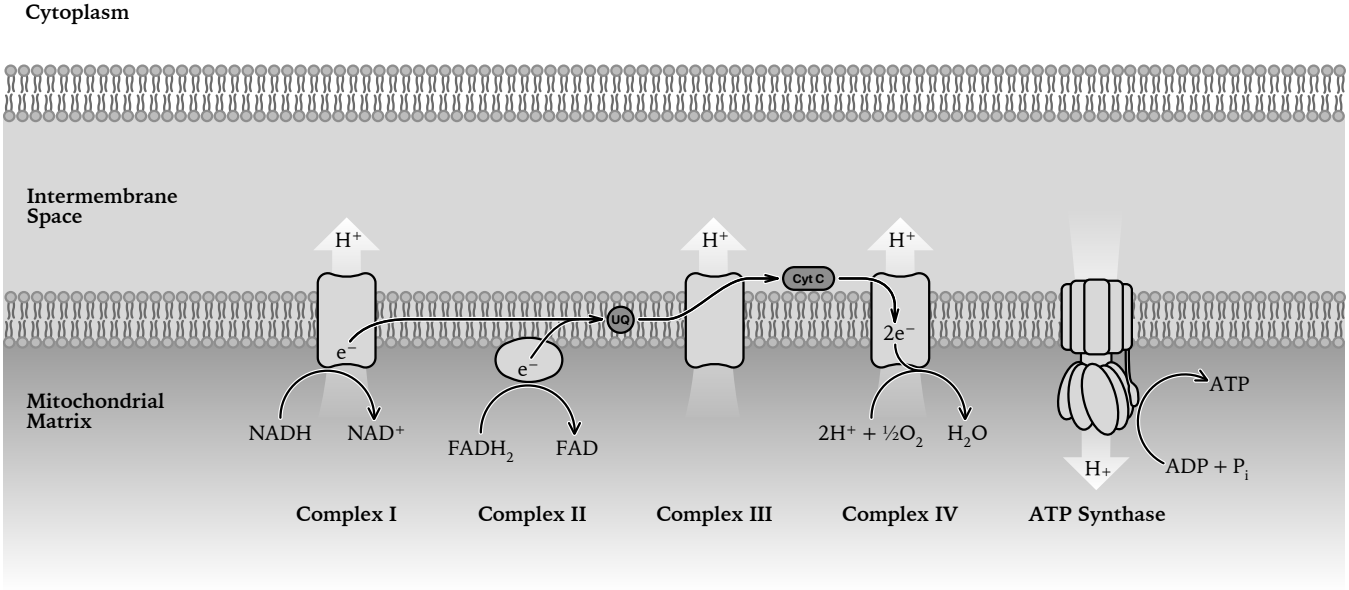
$$\text{Acetyl-CoA} + 3\text{NAD}^+ + \text{FAD} + \text{GDP} + \text{P}_i \rightarrow \text{CoA} + 2\text{CO}_2 + 3\ \text{NADH} + \text{FADH}_2 + \text{GTP}$$

- During the citric acid cycle, acetyl-CoA is further catabolized to release the remaining energy stored within its carbon-carbon bonds. The majority of the oxidative reactions in the citric acid cycle are highly detailed and rarely tested on the DAT. However, it is important to know that at the beginning of the cycle, acetyl-CoA is irreversibly combined with ***oxaloacetate*** to make ***citrate***, a six-carbon molecule. With each "turn" of the cycle, 3 NADH, 1 $FADH_2$, and 1 GTP are produced. Oxaloacetate is also regenerated, to be used in the next cycle



ELECTRON TRANSPORT CHAIN ☆ HIGH-YIELD

- The electron transport chain (ETC) is the only ***aerobic*** pathway of cellular respiration. It occurs at the ***inner mitochondrial membrane*** and generates ATP through ***oxidative phosphorylation***. The inner mitochondrial membrane contains folds called ***cristae*** to increase surface area for the ETC
- During the ETC, high-energy electrons from NADH and $FADH_2$ are involved in a series of oxidation reactions, mediated by ***cytochrome*** proteins. As the electrons flow through the ETC, the free energy released is used to pump protons from the mitochondrial matrix into the intermembrane space. This creates a chemiosmotic gradient that powers an enzyme called ***ATP synthase***, which creates ATP from ADP and P_i



- Note that NADH and $FADH_2$ are the ***initial electron donors***, while oxygen is the ***final electron acceptor***. Water is formed as a byproduct from the reduction of oxygen
- Each NADH that enters the pathway generates 3 ATP, while each $FADH_2$ generates only 2 ATP. This is because $FADH_2$ bypasses the first cytochrome complex, thus pumping less protons
- It is important to realize that NADH produced by glycolysis cannot cross the inner mitochondrial membrane and must be indirectly transported from the cytosol to the mitochondrial matrix by one of two shuttle systems:
  - ***Malate-Aspartate Shuttle*** – A series of redox reactions that consumes a cytosolic NADH and produces a matrix NADH. This process is highly efficient because a cytosolic and matrix NADH would both yield 3 ATP. This system is found in mammalian kidney, liver, and heart
  - ***Glycerol-Phosphate Shuttle*** – A series of redox reactions that consumes a cytosolic NADH and produces a matrix $FADH_2$. This process is less efficient because cytosolic NADH would yield 2 ATP instead of the usual 3 ATP produced by matrix NADH
- Prokaryotes avoid this problem entirely, since they have no mitochondria membranes for NADH to cross. Instead, the electron transport chain occurs at the cell's plasma membrane

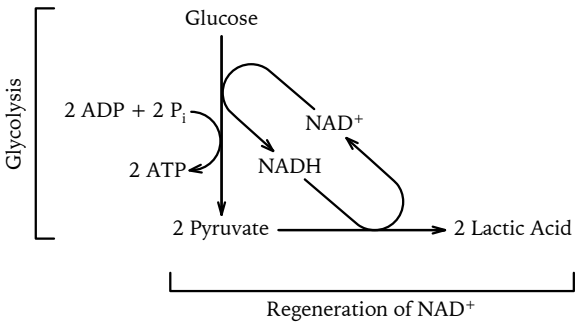
FERMENTATION ☆ HIGH-YIELD

- Fermentation is ***anaerobic*** and generates ATP through ***substrate-level phosphorylation.*** It occurs in the ***cytosol*** of the cell. The net equation for this metabolic pathway is:

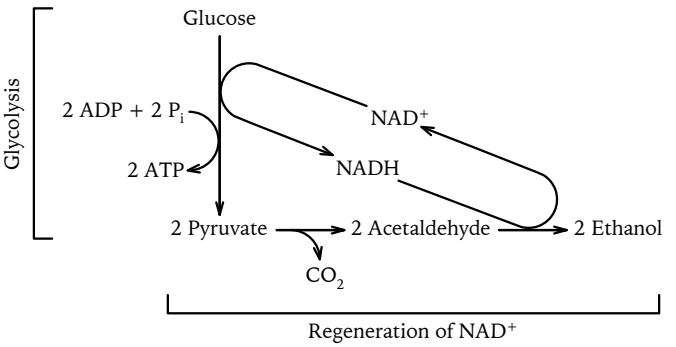
$$\text{Glucose} + 2\text{ADP} + 2\text{P}_i \rightarrow 2\text{Pyruvate} + 2\text{ATP} + \text{Ethanol or Lactic Acid}$$

- Fermentation occurs when there is an accumulation of NADH. This is most commonly a result of the cell being starved of oxygen, in which case there is no longer a final electron acceptor and the electron transport chain shuts down. This accumulation of NADH and lack of NAD^+ will also shut down glycolysis, effectively terminating all ATP production. Fermentation solves this problem by regenerating NAD^+, allowing glycolysis to continue. During fermentation, electrons are donated to pyruvate instead of the ETC. There are two types of fermentation:
  - ***Lactic Acid Fermentation*** – Electrons from NADH are used to reduce pyruvate into lactic acid. This pathway occurs in bacteria and humans. The buildup of lactic acid during exercise is partially responsible for acute muscle soreness
  - ***Ethanol Fermentation*** – Electrons from NADH are used to reduce pyruvate into ethanol. This pathway occurs in yeast, and is widely used in commercial alcohol and bread production. Unlike lactic acid fermentation, carbon dioxide is also produced as a side product

Lactic Acid Fermentation



Ethanol Fermentation



CELLULAR RESPIRATION SUMMARY

- For one molecule of glucose, the following products are obtained:

Pathway	Net ATP/GTP	Net NADH	Net FADH
Glycolysis	2 ATP	2 NADH → 4 ATP	–
Pyruvate Oxidation	–	2 NADH → 6 ATP	–
Citric Acid Cycle	2 GTP	6 NADH → 18 ATP	2 → 4 ATP
Totals	**4 ATP**	**10 NADH → 28 ATP**	**2 → 4 ATP**

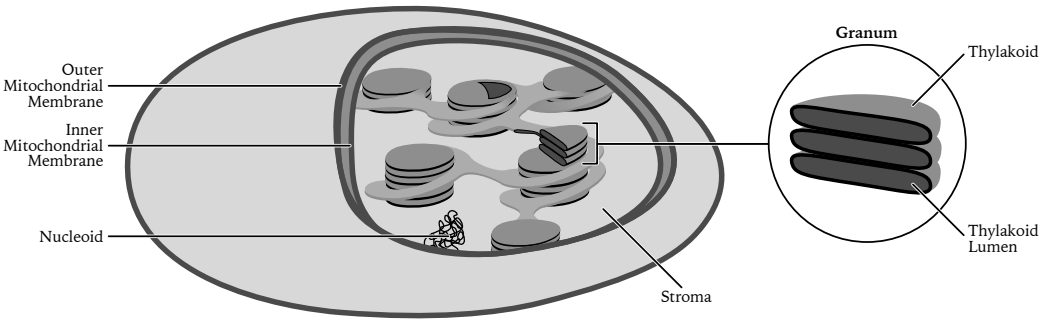
- Therefore a eukaryotic cell using the glycerol-phosphate shuttle would yield a grand total of 36 ATP
- Out of the 36 ATP, 4 are from substrate-level phosphorylation (glycolysis), while the other 32 are from oxidative phosphorylation (electron transport chain)

PHOTOSYNTHESIS ☆ HIGH-YIELD

- Photosynthesis is a form of anabolic metabolism that uses the energy in sunlight to fix gaseous carbon dioxide into glucose and other carbohydrates. In other words, it is a pathway that converts light energy into chemical energy, which can be stored for powering other metabolic reactions. The net equation for this metabolic pathway is:

$$6CO_2 + 6H_2O + \text{Light} \rightarrow \text{Glucose} + 6O_2$$

- Photosynthesis occurs in a specialized organelle called the ***chloroplast***. Like the mitochondria, the chloroplast has a double lipid bilayer and an intermembrane space. However, the innermost compartment of the organelle is filled with an aqueous fluid called the ***stroma***, and flat disks called ***thylakoids***. The thylakoids are arranged in stacks called ***grana***:



- The photosynthetic pathway consists of two major phases: the ***light-dependent reactions*** and the ***light-independent reactions***. We will discuss the mechanisms behinds these phases in the next few paragraphs

LIGHT-DEPENDENT REACTIONS ☆ HIGH-YIELD

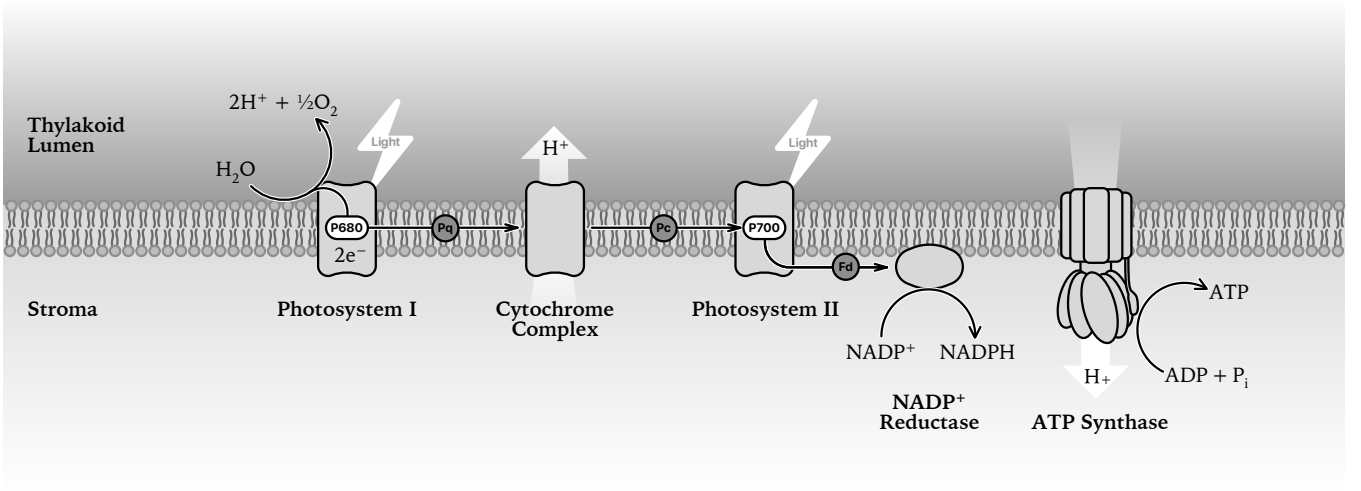
- The light-dependent reactions occur at the ***thylakoid membranes*** and generate ATP through ***oxidative phosphorylation***. This ATP is later used to fix carbon dioxide into glucose. The net equation for the light-dependent reactions is:

$$2H_2O + 2NADP^+ + 3ADP + P_i + \text{Light} \rightarrow 2NADPH + 3ATP + O_2$$

- During the light-dependent reactions, large protein complexes called ***photosystems*** absorb the energy contained in photons and use it to power a series of redox reactions. These reactions pump protons from the stroma into the thylakoid lumen. Like the electron transport chain, this creates a chemiosmotic gradient that powers ATP synthase, which generates ATP from ADP and P_i
- Photosystems absorb light through ***pigment molecules***, which are specific for certain wavelengths. This means that different pigments optimally absorb different colours. ***Chlorophyll A*** and ***B*** absorb red-orange light and reflect green-blue light, while ***carotenoids*** have the opposite absorption spectrum
- The following steps occur during the light-dependent reactions:

1. Photons hit ***photosystem II (PSII)***, causing an electron excitation that gets passed from pigment to pigment via a process called ***resonance energy transfer***. Eventually the energy is passed to the photosystem's ***reaction centre***, which contains a special chlorophyll pigment called ***P680***
2. 2 electrons in P680 are excited to a higher energy level and used to reduce PSII's ***primary electron acceptor***, which is ***pheophytin***
3. The electrons participate in a series of redox reactions called an ***electron transport chain***. The free energy is harnessed to pump protons from the stroma into the thylakoid lumen

4. Once the electrons reach ***photosystem I (PSI)***, they are excited again by a second round of photon absorption. This time, the energy is transferred to a special chlorophyll pigment called ***P700***. The energy is then passed to PSI's primary electron acceptor, which is ***chlorophyll A***
5. The electrons are eventually passed to the ***final electron acceptor***, which is ***NADP***$^+$. The reduction of $NADP^+$ forms ***NADPH***, which is a reducing agent used to fix carbon dioxide during the light-independent reactions



- Note that oxidized P680 is the strongest biological oxidizing agent known. This allows P680 to oxidize water in order to replace the two electrons lost to pheophytin. The splitting of water is called ***photolysis***, and it produces ***oxygen gas*** and ***hydrogen ions*** as byproducts. These hydrogen ions are released into the thylakoid lumen and contribute to the chemiosmotic gradient used by ATP synthase
- It is important to realize that photosystem II (PSII) and photosystem I (PSI) were named in the order that they were discovered, not in the order in which they function. This naming convention persists despite being a source of confusion, since PSII comes before PSI in the light-dependent reactions
- Here is a summary of the key differences between PSII and PSI:

	Photosystem II	**Photosystem I**
Reaction Order	First	Second
Reaction Centre Pigments	P680	P700
Primary Electron Acceptor	Pheophytin	Chlorophyll A
Electron Source	Photolysis	Electron Transport Chain

- The method of ATP generation described earlier is called ***linear photophosphorylation***. Another mechanism exists called ***cyclic photophosphorylation***, which generates ATP without consuming water or producing NADPH. Instead of giving the electrons to $NADP^+$ at the end of the electron transport chain, the electrons are recycled back to the beginning. This occurs in some bacteria that lack PSII, in addition to plants with high ATP demand. Cyclic photophosphorylation may also have a photoprotective effect against high-energy light

LIGHT-INDEPENDENT REACTIONS ☆ HIGH-YIELD

- The light-independent reactions is also called the ***Calvin cycle***. It occurs in the ***stroma*** of the chloroplast. This phase of photosynthesis is called "light-independent" because it does not directly require photons. However, it cannot occur in the complete absence of light because it requires ATP and NADPH, the products of the light-dependent reactions. The net equation for the light-dependent reactions is:

$$3CO_2 + 9ATP + 6NADPH \rightarrow 1G3P + 9ADP + P_i + 6NADP^+$$

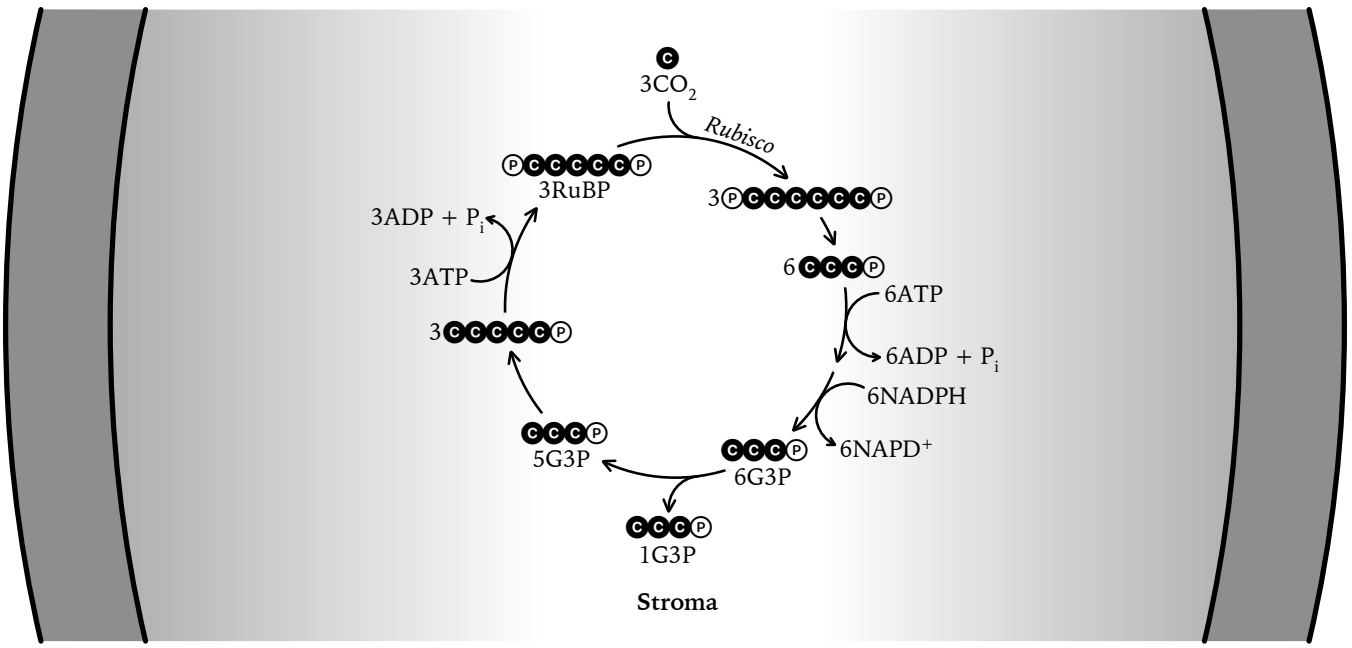
$$2G3P \rightarrow C_6H_{12}O_6$$

- Note that each "turn" of the Calvin cycle produces one glyceraldehyde 3-phosphate (G3P) molecule. Two G3Ps are combined to form one glucose molecule
- The Calvin cycle consists of three stages:

  - **Carbon Fixation**
    - In this stage, gaseous carbon dioxide is fixed into an organic compound
    - CO_2 and a 5-carbon molecule called ***ribulose bisphosphate (RuBP)*** are combined into a 6-carbon molecule by the enzyme ***ribulose bisphosphate carboxylase/oxygenase (RuBisCO)***
    - The 6-carbon molecule is a short-lived and is quickly converted to two 3-carbon molecules

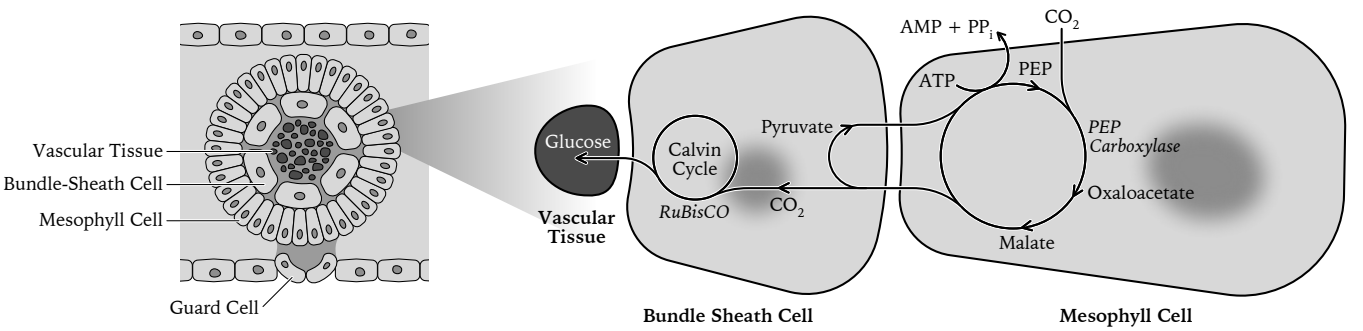
  - **Reduction to G3P**
    - Each 3-carbon molecule is reduced to ***glyceraldehyde 3-phosphate (G3P)*** by one NADPH and one ATP
    - One G3P leaves the Calvin cycle, to be combined with another G3P to form ***glucose***
    - G3P is the same compound formed at the end of the investment phase of glycolysis

  - **Regeneration of RuBP**
    - Five G3P molecules are reacted with three ATP to regenerate three RuBP molecules
    - Note that the number of carbons involved in this step remains the same, because 5 molecules × 3 carbons each = 3 molecules × 5 carbons each



C4 AND CAM PHOTOSYNTHESIS

- Under drought conditions, plants must keep their stomata closed to prevent ***transpiration***, the evaporation of water from leaves. The closure of stomata leads to decreased diffusion of CO_2 into the leaf, which causes O_2 to enter the Calvin cycle and bind to RuBisCO instead of CO_2. This leads to a problem known as ***photorespiration***
- In photorespiration, the substitution of O_2 for CO_2 leads to the formation of a waste product instead of G3P. The removal of this waste product is energetically costly and decreases the efficiency of photosynthesis
- Normal plants are called ***C3 plants*** because the first product of carbon fixation is a 3-carbon compound. C3 plants are susceptible to photorespiration. ***C4 plants*** use an adapted photosynthetic mechanism and are able to prevent photorespiration. They are named "C4" because they first fix carbon into a 4-carbon compound (***oxaloacetate***) before entering the Calvin cycle
- ***C4 photosynthesis*** prevents photorespiration by spatially separating CO_2 fixation and the Calvin cycle into different cells of the leaf:
  - ***Mesophyll Cells*** – The site of CO_2 fixation. Mesophyll cells absorb CO_2 and convert it to a four-carbon molecule called ***oxaloacetate***, via an enzyme called ***PEP carboxylase***. Unlike RuBisCO, PEP carboxylase is specific for CO_2 as its substrate, and does not bind O_2. The oxaloacetate is then converted into ***malate***, which is "shuttled" to bundle sheath cells. Since the bundle sheath cells are located deeper within the leaf, they are better shielded from environmental oxygen
  - ***Bundle Sheath Cells*** – The site of the Calvin cycle. Bundle sheath cells convert malate back into CO_2, which enters the Calvin cycle. Since the CO_2 concentration is much higher in the bundle sheath cells, RuBisCO is able to avoid binding to O_2 and photorespiration is less likely



- Plants that use C4 photosynthesis tend to live in hot and dry climates, where the chances of photorespiration are increased because plants are forced to keep their stomata closed. Examples of C4 plants include corn, sugarcane, Cleomaceae, papyrus, and Rhodes grass
- ***Crassulacean acid metabolism (CAM)*** is another photosynthetic mechanism that prevents photorespiration. CAM plants use the same CO_2/malate shuttle strategy as C4 plants, but CO_2 fixation and the Calvin cycle are temporally separated instead of spatially separated:
  - ***Night Time*** – Temperatures are cooler and the rate of transpiration is low. Thus the stomata are allowed to open and the fixation of CO_2 to malate occurs
  - ***Day Time*** – Temperatures are hotter and the rate of transpiration is high. Thus the stomata are closed and the Calvin cycle occurs using the CO_2 stored as malate
- Like C4 plants, CAM plants tend to live in hot and dry climates. Examples of CAM plants include pineapple, cacti, and most succulents

CHAPTER 9 | **EVOLUTION**

INTRODUCTION

- Evolution is defined as the change in allele frequencies in a population over time
- There are two major types of evolution:
  - ***Microevolution*** – Small scale changes in the allele frequencies of a population
  - ***Macroevolution*** – Large scale changes that transcend the boundaries of a single species

EVIDENCE FOR EVOLUTION

- ***Paleontology*** – The fossil record shows ancestors of modern species were different. For example, early horses were dog-sized and had separate toes instead of a hoof
- ***Biogeography*** – The observed geographic patterns of both living and fossilized species shows that island organisms are similar to organisms on the mainland. This suggests that the island organisms may have evolved from an ancestor from the mainland
- ***Embryology*** – Two species may have similar developmental pathways. Also, the stages of an embryo's development may resemble other simpler species (i.e. The two-layer human gastrula resembles the two-tissue-layer structure of cnidarians)
- ***Comparative Anatomy*** – Homologous and analogous structures suggest natural selection can cause both differences and similarities between species
  - ***Homologous Structures*** – Dissimilar features that are evolutionarily closely related. Ex: wings of bats and arms of humans
  - ***Analogous Structures*** – Similar features that are evolutionarily distantly related. Ex: eyes of a human and eyes of an octopus
  - ***Vestigial Structures*** – Features that have no current function but were useful in ancestors. Ex: snakes still have vestigial limb bones from their land-walking ancestors
- ***Molecular Biology*** – All living things use the same genetic code, and DNA sequence similarity is proportional to the evolutionary relatedness of two species. Also, related species have similar metabolic processes and biochemical pathways

LAMARCKIAN EVOLUTION

- In Jean-Baptiste Lamarck's now-discredited theory, he states that new organs and other biological changes arise because of the needs of an individual
- The theory has three main parts:
  1. ***Theory of Need*** – Organs and traits appear as the need arises
  2. ***Theory of Use/Disuse*** – The strength/development of an organ is proportional to the usage of the organ
  3. ***Inheritance of Acquired Characteristics*** – Any acquired characteristic is inherited by the next generation
- An example of the application of this theory is: "Giraffes developed long necks due to the need to reach high branches. As giraffes stretched their necks to reach food, they grew longer. The increase in length was then inherited by the giraffe's offspring"

DARWINIAN EVOLUTION ☆ HIGH-YIELD

- In Charles Darwin's widely-accepted ***theory of natural selection***, environmental pressure selects for the individual that is the most fit to survive and reproduce
- ***Fitness*** is defined as the ability to produce successive generations of viable, fertile progeny
- Darwin identified that the following factors are needed for evolution to occur:
  - ***Overpopulation*** – More offspring are produced than can survive
  - ***Variation*** – Offspring show differences in their traits (at the time, Darwin and other scientists did not understand the mechanism behind variation)
  - ***Competition*** – Offspring must compete against each other for the necessities of life. Many young must die such that the number of adults remains constant
  - ***Natural Selection*** – Some individuals have variations that give them an advantage over others, thus increasing their fitness
  - ***Inheritance of Variations*** – Individuals with favourable variations transmit them to their offspring (Darwin did not know the mechanism behind inheritance)

PATTERNS OF SELECTION

- There are nine patterns of selection; five are caused by nature, three are caused by random forces, and one is caused by humans
- Selection patterns due to nature:
  - ***Directional Selection*** – Favours individuals with one extreme phenotype and reduces the frequency of all other variations. This shifts the average phenotype over time. Ex: during the industrial revolution, thick smog in air caused directional selection for dark moths (that could camouflage better against predators) and reduced the amount of light or medium coloured moths
  - ***Stabilizing Selection*** – Favours the average phenotype and reduces extremes. This reduces genetic diversity. Ex: physiological complications that result from being extremely short or extremely tall cause stabilizing selection for humans with an intermediate hight
  - ***Disruptive Selection*** – Favours extreme phenotypes and reduces the average. This increases genetic diversity and may lead to ***adaptive radiation***. Ex: in the finch populations observed by Darwin in the Galapagos, the presence of either small or large seeds caused disruptive selection for either small or large beaks. Finches with medium beaks could not retrieve small seeds and were not strong enough for large seeds
  - ***Sexual Selection*** – Preference of one sex for certain traits in the other sex, resulting in sexual dimorphism. There are two drivers of sexual selection:
    - ***Female Choice*** – Also called ***intersexual selection*** because one sex is selecting for a trait in the other. Females often select for elaborate ornamentation or specific behaviours beneficial for child-rearing
    - ***Male Competition*** – Also called ***intrasexual selection*** because one sex is selecting within themselves. Phenotypes or behaviours that allow males to mate more frequently or produce more offspring are favoured
  - ***Frequency-Dependent Selection*** – When the fitness of a particular phenotype is dependent on the frequency of the phenotype within the population
    - ***Positive Frequency-Dependent Selection*** – Fitness increases as the phenotype becomes more common. Ex: cautionary coloration in aposematic species increases in effectiveness as more individuals adopt the coloration
    - ***Negative Frequency-Dependent Selection*** – Fitness decreases as the phenotype becomes more common. Ex: birds tend to search for snails based on a "mental image" of a generic-looking snail. Thus the less common a snail's phenotype, the less likely it is to be caught

- Selection patterns due to random forces:
  - ***Genetic Drift*** – Change in a population's allele frequency due to pure chance, often leading to loss of biodiversity. Smaller populations are more influenced by genetic drift because their allele frequencies are more volatile to fluctuations. Ex: a population of five tigers in a zoo loses their allele for long fur because the enclosure collapsed and killed the only two tigers that happened to have the allele
    - ***Bottleneck Effect*** – A huge reduction in population size due to a chance event, leading to loss of biodiversity. Rare alleles are eliminated or greatly reduced, and the amount of in-breeding increases. Ex: overhunting by humans caused a bottleneck in the northern elephant seal population
    - ***Founder Effect*** – A small group migrates away from their main population and contain different allele frequencies by chance. This initially reduces biodiversity in the resulting migrant population, but may eventually lead to speciation. Ex: French Canadians in Quebec arose from just 8,500 pioneers
- Selection patterns due to humans:
  - ***Artificial Selection*** – Humans select for certain phenotypes that benefit themselves. This decreases biodiversity, making the population more vulnerable to natural selective pressures like disease. Low biodiversity also increases risk of genetic disorders. Artificial selection also increases a species' dependence on humans for survival/reproduction

SOURCES OF GENETIC VARIATION

- ***Mutations*** – Spontaneous changes in DNA cause variation
- ***Sexual Reproduction*** – Independent assortment of genes, crossing over of homologous chromosomes, and fertilization of an egg by a random sperm all increase variation
- ***Diploidy*** – Recessive alleles are protected from natural selection because they are not expressed in the phenotype
- ***Random Outbreeding*** – Random mating increases variation, as well as mating with unrelated individuals
- ***Balanced Polymorphism*** – Two alleles are maintained in a population because individuals with both are better able to survive than those with only one of the alleles
  - ***Heterozygote Advantage*** – When heterozygotes have a survival advantage. Ex: humans heterozygous for sickle cells are resistant to malaria
  - ***Hybrid Vigour (Heterosis)*** – Improved function of any biological quality in a hybrid offspring compared to non-hybrid offspring
  - ***Negative Frequency-Dependent Selection*** – When the fitness of a phenotype decreases as it becomes more common. This allows variation to be maintained in a population, because rare phenotypes will become common and vice versa
- ***Gene Flow*** – Transfer of alleles from one population to another through migration. This increases biodiversity and prevents two separate populations from diverging through genetic drift

HARDY-WEINBERG EQUILIBRIUM ☆ HIGH-YIELD

- A Hardy-Weinberg equilibrium exists when there is no net change in allele frequencies in a population (the population is not evolving)
- For this to be true, the following assumptions are made:
  - The population is infinitely large and has no genetic drift
  - No mutations occur in the population
  - No gene flow (isolated population)
  - No natural or artificial selection (all alleles are equally fit)
  - Mating is random

- Under these conditions, we can use the ***Hardy-Weinberg formula*** to predict allele frequencies:

$$p^2 + 2pq + q^2 = 1 \text{ and } p + q = 1$$

p represents frequency of dominant allele
q represents frequency of recessive allele
p^2 represents frequency of dominant homozygotes
q^2 represents frequency of recessive homozygotes
$2pq$ represents frequency of heterozygotes

Example

A population of tigers are in Hardy-Weinberg equilibrium. The allele for black stripes (B) has a frequency stripes (b) has a frequency of 0.81. What is the percentage of heterozygotes in the population?

A) 66% B) 31% C) 4% D) 15%

Worked Solution

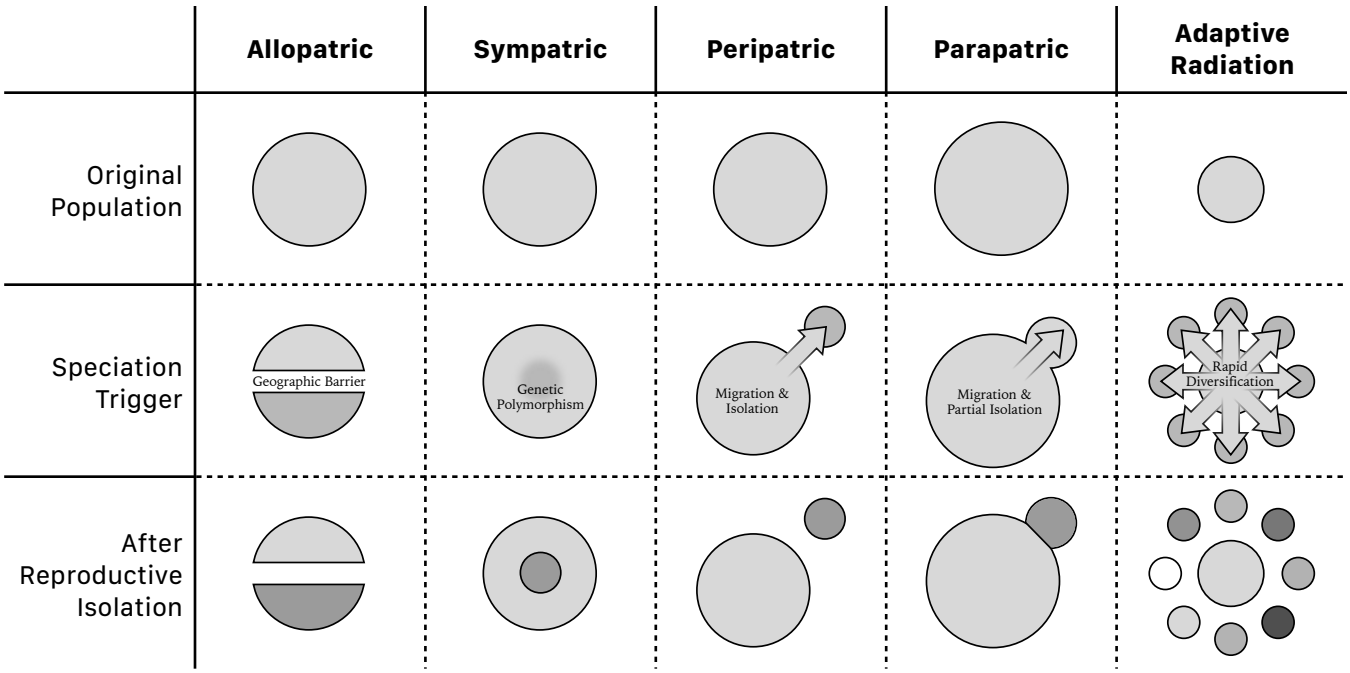
$p^2 + 2pq + q^2 = 1$	Write out the equation
$2pq = 1 - p^2 - q^2$	We want the frequency of heterozygotes, so rearrange for $2pq$
$2pq = 1 - 0.19^2 - 0.81^2$	Substitute known values into the equation
$2pq \approx 1 - 0.2^2 - 0.8^2$ $2pq \approx 1 - 0.04 - 0.64$ $2pq \approx 1 - 0.68$	Approximate the squared values to solve without a calculator
$2pq \approx 0.32$	Answer is closest to B)

MACROEVOLUTIONARY PATTERNS

- ***Divergent Evolution*** – Two species share the same common ancestor but evolved to have different traits (i.e. homologous structures)
- ***Convergent Evolution*** – Two species without a common ancestor but evolved to share similar traits (i.e. analogous structures)
- ***Parallel Evolution*** – Two species share the same common ancestor and evolve to share similar traits
- ***Coevolution*** – When one species evolves in response to the evolutionary changes of another
- ***Gradualism*** – A macroevolutionary theory that states evolution is a slow and steady process
- ***Punctuated Equilibrium*** – A macroevolutionary theory that states evolution occurs as long periods of stasis (equilibrium) interrupted by sudden blooms in biodiversity or mass extinctions. Palaeontology may support this theory because fossils showing intermediate stages of evolution (the "missing link") are hard to find, suggesting that evolution occurs in short, rapid bursts

SPECIATION ☆ HIGH-YIELD

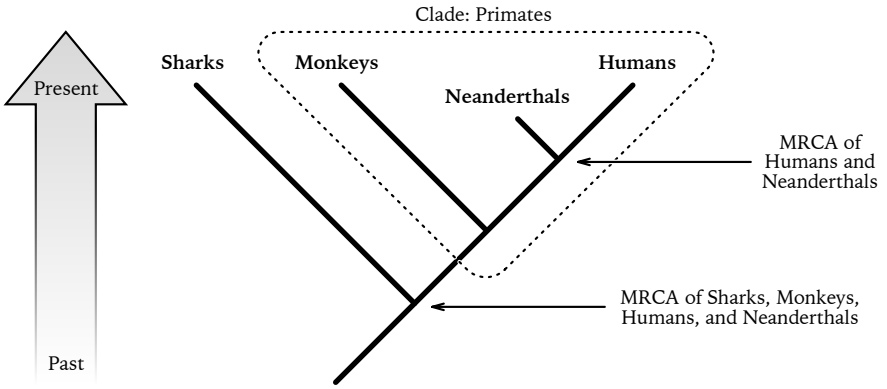
- ***Speciation*** is the evolution of a new ***species***, which is defined as a group of individuals who can interbreed to produce viable and fertile progeny
- ***Hybrids*** are the offspring of two individuals from different species. Hybrids may survive into adulthood, but cannot reproduce
- In order for two new species to arise from a single ancestral species, the individuals must be reproductively isolated from each other. There are two major categories of reproductive isolation:
  - ***Prezygotic*** – Occurs before the zygote stage of development
    - ***Ecological Isolation*** – Species live in different habitats and don't meet
    - ***Temporal Isolation*** – Species have different breeding seasons
    - ***Behavioural Isolation*** – Species have different signals/rituals for mating
    - ***Mechanical Isolation*** – Species have physically incompatible genitals
    - ***Gamete Isolation*** – Species produce gametes that don't recognize each other
  - ***Postzygotic*** – Occurs after the zygote stage of development
    - ***Zygote Mortality*** – Hybrid zygotes die before birth
    - ***Hybrid Inviability*** – Hybrids are born but die prematurely
    - ***Hybrid Sterility*** – Hybrids are born and survive, but cannot reproduce due to different numbers of chromosomes
- There are five different scenarios in which reproductive isolation may occur, referred to as the five ***modes of speciation***:
  - ***Allopatric Speciation*** – Formation of new species after the original population is separated by a geographic barrier (i.e. a river) and split into two or more isolated populations
  - ***Sympatric Speciation*** – Formation of new species without a barrier. This can result from disruptive selection, spontaneous mutations, genetic polymorphism, or non-disjunction in plants (leading to a new species of aneuploid plants)
  - ***Peripatric Speciation*** – Formation of new species in isolated peripheral populations (niche). This is similar to what happens in the founder effect
  - ***Parapatric Speciation*** – Formation of new species in semi-isolated peripheral populations (niche), with interbreeding prevented by heterozygote disadvantage
  - ***Adaptive Radiation*** – Population is exposed to many new environments, resulting in the rapid formation of many species from one ancestral species



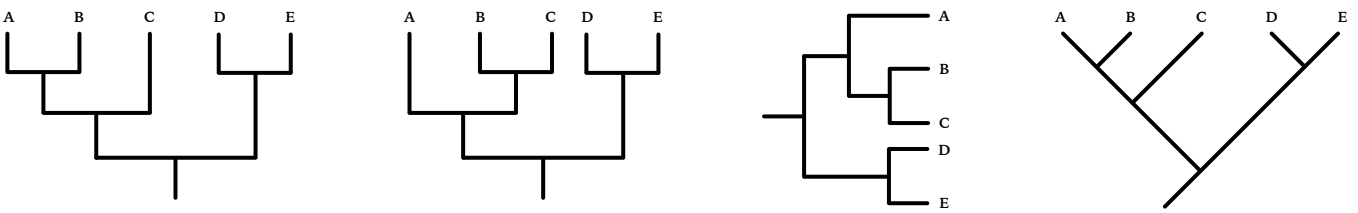
CHAPTER 10 | **CLADISTICS**

CLADOGRAMS/PHYLOGENETIC TREES

- ***Phylogeny*** is the study of evolutionary relationships between species based on evidence gathered from morphology, biochemistry, and DNA sequencing. ***Cladistics*** is the classification of species based on phylogeny
- A ***clade*** is a group of organisms that includes the ***most recent common ancestor (MRCA)*** and all of its descendants. A ***cladogram/phylogenetic tree*** is a visual representation of how organisms are related.
- In a cladogram, each branch tip represents a species, and each fork represents a common ancestor. Extinct lineages are represented by the premature termination of a branch as time moves from the past (branch roots) towards the present (branch tips)

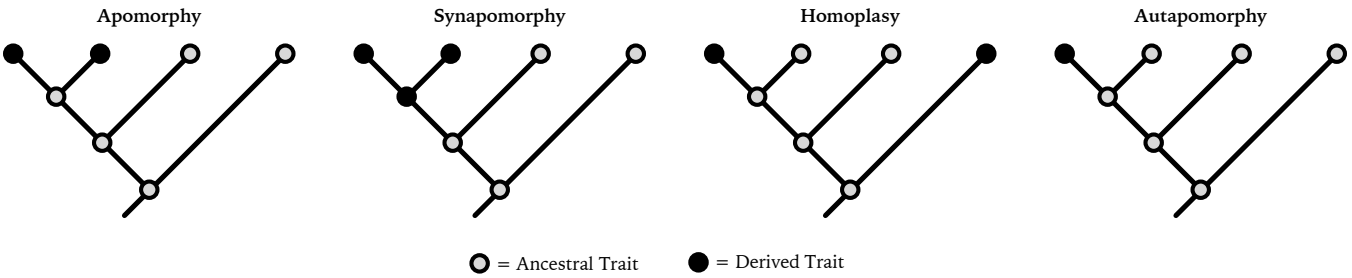


- The relatedness of two species is inversely proportional to the age of their most recent common ancestor
- A branch with more than two species coming from it means that we do not have enough information to determine evolutionary relatedness, and thus branching order. This is called a ***polytomy***
- It is important to recognize that the order in which species are listed does not matter. In other words, reflecting a branch across its axis results in the same information being conveyed. Cladograms can also be constructed in various different styles and orientations. For instance, the following three cladograms all contain the same information:

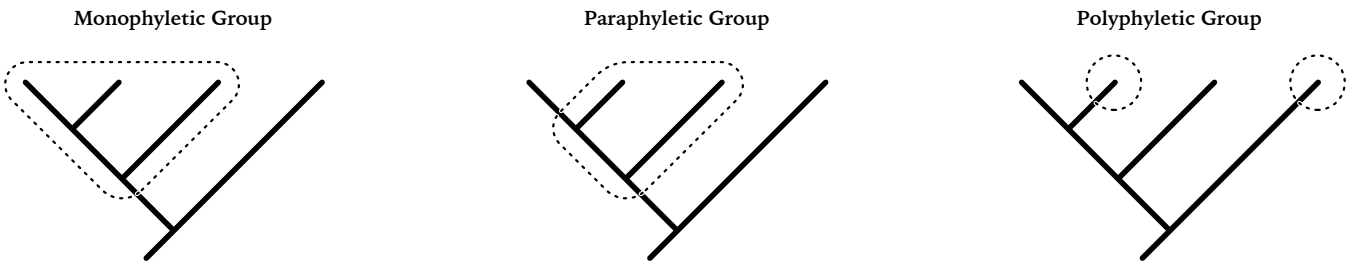


PATTERNS OF DERIVED TRAITS

- ***Apomorphy*** – A trait that distinguishes a clade from other clades, but is not found in the most recent common ancestor
- ***Synapomorphy*** – A trait that distinguishes a clade from other clades, and is found in the most recent common ancestor. In other words, it is a trait present within all species of a clade
- ***Homoplasy*** – A trait that has been gained independently in separate taxa through convergent evolution
- ***Autapomorphy*** – A trait that is unique to a single taxon



- ***Monophyletic Group*** – A group that contains a common ancestor and all its descendants (also called a ***clade***)
- ***Paraphyletic Group*** – A group that contains a common ancestor and all its descendants minus one or more monophyletic groups
- ***Polyphyletic Group*** – A group that does not share a common ancestor. May contain species with homoplasies (convergent traits)



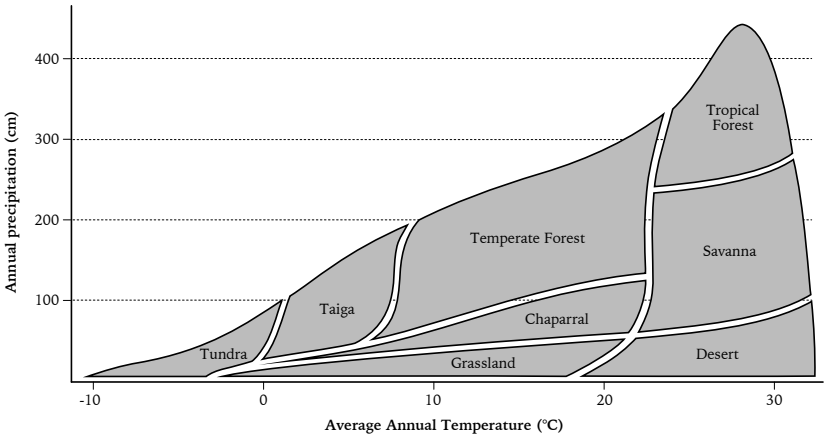
CHAPTER 11 | **ECOSYSTEM ECOLOGY**

INTRODUCTION

- An ***ecosystem*** consists of all the ***biotic*** (living) components of a region and their interactions with the ***abiotic*** (non-living) environment
- Ecosystems can be small (i.e. plants growing in a garden) or large (i.e. Amazon rainforest)
- The broadest classification of different ecosystems has three categories:
  - ***Marine/Saltwater*** – Most common, covers around 75% of the Earth
  - ***Lake/Freshwater*** – Rarest, covers around 1.8% of the Earth
  - ***Terrestrial*** – Covers 23.2% of the Earth
- Ecosystems are further classified into ***biomes*** based on their climate
- A ***climate*** is a long-term average of a region's weather

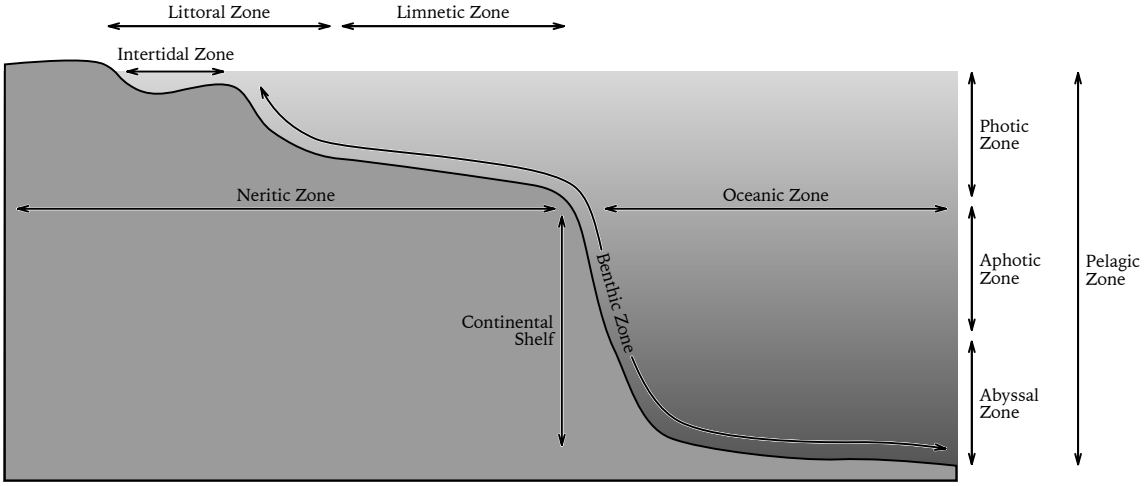
TERRESTRIAL BIOMES

- There are ten major terrestrial biomes:
  - ***Tropical Forest*** – Located along the equator and characterized by high rainfall, high year-round temperatures, and the highest level of biodiversity of any biome. Examples include the Amazon rainforest, Borneo, and South Africa
  - ***Savanna*** – Located along and below the equator. Characterized by seasonal rainfall, warm year-round temperatures, and common forest fires. Unlike a temperate grassland, the soil is nutrient-poor. Trees and large shrubs are scattered, and large herbivorous mammals (wildebeests, zebras) exist, along with carnivorous predators. Examples include Kenya and North Australia
  - ***Desert*** – Located 30 degrees north and south of the equator. Characterized by low rainfall, variable extreme temperatures, and low vegetation. Most plants are C_4/CAM and most animals are nocturnal. Examples include the southwestern United States and North Africa
  - ***Chaparral*** – Located in midlatitude (around 45 degrees from equator) costal regions. Characterized by rainy, cool winters and dry, warm summers. Plant diversity is high, and shrubs/small trees dominate. Examples include the Mediterranean and California
  - ***Temperate Forest*** – Located midlatitude. Characterized by moderate winters and summers. Deciduous trees dominate, forming distinct layers (canopy, tree strata, shrubbery, herbs). In the winter, most mammals hibernate, and birds migrate to warmer biomes. Examples include Ontario, France, and Shanghai
  - ***Temperate Grassland*** – Located in the prairies of central America, the veldts of South Africa, and the steppes of Russia. Characterized by dry, cold winters and wet, hot summers. Grazing animals such as horses and bison feed on plentiful grass. Trees and shrubs are almost non-existent, in contrast to a savanna
  - ***Boreal Forest/Taiga*** – The largest biome on Earth. Located just south of the arctic circle. Characterized by warm summers and snowfall during cold winters. Conifer trees dominate, with scattered shrubs. Mammals include brown bears and caribou. Examples include North America and Russia
  - ***Polar Tundra*** – Located in the Arctic. Characterized by high winds and low temperatures. Mosses, grasses, and short shrubs dominate. Mammals include herbivorous oxen, bears, and arctic foxes. Examples include Alaska, Yukon, and Siberia
  - ***Alpine Tundra*** – Located wherever elevation is high. As latitude approaches the poles, the elevation threshold decreases until alpine tundra merges with polar tundra
  - ***Polar Ice*** – Located at both extremes of latitude. Characterized by permafrost, which is soil that remains frozen for at least two consecutive years



AQUATIC BIOMES

- Unlike land biomes, aquatic biomes show far less latitudinal variation
- There are only two aquatic biomes, which are classified based on their chemical composition: ***marine/saltwater*** and ***lake/freshwater***
- The transition between saltwater and freshwater biomes is called an ***estuary***. The water in estuaries are a mix of salt and fresh water, called ***brackish water***
- Marine/saltwater and lake/freshwater biomes are further classified into ***zonations*** based on:
  - Depth of water/light penetration
    - ***Photic Zone*** – Shallow waters with enough sunlight for photosynthesis
    - ***Aphotic Zone*** – Deeper waters with little light penetration
    - ***Abyssal Zone*** – Even deeper waters typically only seen in oceans. The deepest layer of this zone is devoid of oxygen and may trap and kill organisms unable to quickly surface
    - ***Pelagic Zone*** – Consists of photic, aphotic, and abyssal zones, collectively known as "open water" because it represents the majority of the lake or ocean
    - ***Benthic Zone*** – The lowest level of a lake or ocean, which includes the "floor" or sediment. Organic matter called detritus rains down from shallower zones
  - Distance to shore
    - ***Littoral Zone*** – Part of a lake that is close to shore
    - ***Limnetic Zone*** – Part of a lake that is far from shore
    - ***Intertidal Zone*** – Part of an ocean that is above water at low tide and underwater at high tide
    - ***Neritic Zone*** – Part of an ocean that is above the drop-off of the continental shelf
    - ***Oceanic Zone*** – Part of an ocean that is under the drop-off of the continental shelf



HIGH-IMPACT SPECIES

- A ***dominant species*** is the most abundant or has the highest collective biomass out of all other species in its ecosystem
- A ***keystone species*** has an important ecological role and often disproportionally large effect on its ecosystem
  - Unlike a dominant species, keystone species need not be the most abundant
  - The decline or removal of a keystone species will dramatically effect the populations of its predators, prey, and other species in the same food chain
  - For example, the sea otter is a keystone species that preys on sea urchins, which in turn eats kelp. If the sea otter was removed, sea urchin populations would skyrocket and kelp forests would nearly disappear
  - Likewise, humans can be considered a keystone species because we have a disproportional effect on our environment
- ***Ecosystem engineers*** are species that dramatically alter their environment
  - For example, beavers can transform a forest into a flooded wetlands through building dams. The consequences can be positive or negative for other species
- An ***umbrella species*** is not necessarily an ecologically important species, but rather one that is selected for conservation due to how they indirectly protect other species in the ecosystem
- A ***flagship species*** is one that is chosen to represent and raise public support for a conservation effort

RESISTANCE V.S. RESILIENCE

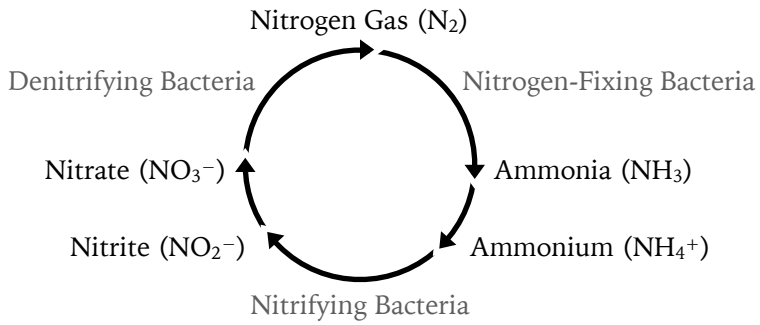
- Both terms describe how an ecosystem responds to disruption
- A ecosystem's natural state is one of equilibrium (no net change in biotic and abiotic composition)
- Disruption from equilibrium may occur through natural (i.e. tornado) or artificial (i.e. deforestation) causes
- ***Resistance*** is the ability of an ecosystem to remain at equilibrium despite disruption
- ***Resilience*** is how fast an ecosystem returns to equilibrium after disruption
- In general, both resistance and resilience are higher in ecosystems with high biodiversity

ECOLOGICAL SUCCESSION

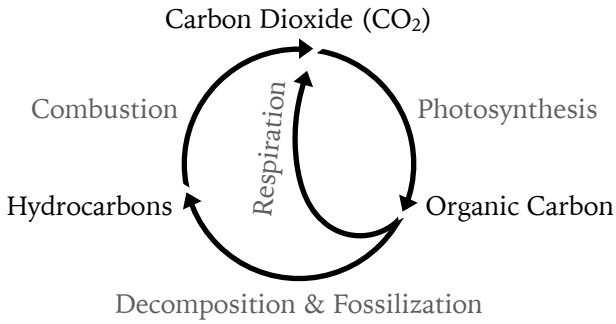
- Ecological succession describes the process in which an ecosystem develops from barren land, usually after a disruption such as a forest fire, tornado, or mass extinction
- ***Primary Succession*** – The colonization of land with previously no life (ex: a solidified lava flow)
  - The ***pioneer species*** is the first species to colonize the land, making it more hospitable for subsequent species to colonize
  - A ***climax community*** forms when each species has reached equilibrium and there is no net change
- ***Secondary Succession*** – The colonization of land that previously had life (ex: forest after a fire)
  - Unlike primary succession, soil is usually already present

BIOGEOCHEMICAL CYCLES

- **The Nitrogen Cycle**
  - Nitrogen is an element found in organic macromolecules such as DNA and proteins. It is also an important component in fertilizer for plants
  - The nitrogen cycle describes how the element is constantly recycled back into the environment after being used in biochemical pathways by living organisms. Gaseous nitrogen is converted to ammonia by ***nitrogen-fixing bacteria*** in the soil. The ammonia is then converted to nitrates by ***nitrifying bacteria***. Finally, ***denitrifying bacteria*** convert nitrates back into atmospheric nitrogen gas. Plants are able to use ammonia and nitrates as nutrients to build organic molecules



- **The Carbon Cycle**
  - Carbon is a major component in many macromolecules such as polysaccharides and proteins. Hydrocarbons isolated from fossil sources can also be a source of chemical energy
  - The carbon cycle describes how the element is constantly recycled back into the environment through biotic and abiotic processes. ***Photosynthesis*** is a biotic processes that fixes atmospheric carbon dioxide into organic carbon. The ***decomposition*** of dead organisms and ***fossilization*** of organic matter produces hydrocarbons/fossil fuels. The burning of fossil fuels via industrial ***combustion*** is an abiotic process that releases carbon back into the atmosphere. ***Cellular respiration*** is a biotic processes that also releases carbon into the atmosphere

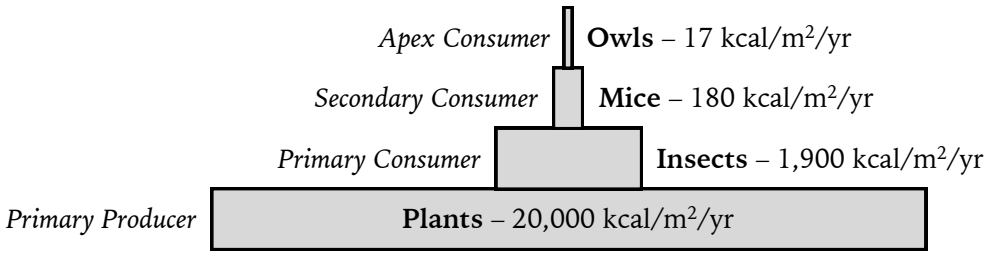


CHAPTER 12 | **COMMUNITY ECOLOGY**

- Community ecology is the study of how multiple species interact with each other in the same geographical area
- Unlike ecosystems, communities are solely composed of the biotic components of a region

TROPHIC STRUCTURE

- The sun is the ultimate energy producer for ecosystems on earth – almost all organisms consume this energy in one form or another
- ***Trophic structure*** describes the feeding relationships between organisms, and consists of the following trophic levels:
  - ***Primary Producers*** – Autotrophic species that generate their own food from the sun's energy (ex: grass)
  - ***Primary Consumers*** – Heterotrophic species that eat primary producers (ex: rabbit)
  - ***Secondary Consumers*** – Heterotrophic species that eat primary consumers (ex: fox)
  - ***Tertiary Consumers*** – Heterotrophic species that eat secondary consumers (ex: humans)
  - This pattern continues until we reach a species that is not consumed by any other species. This is called the ***apex consumer***
  - ***Decomposers*** – Saprobes that obtain energy from the breakdown of organic matter from other trophic levels. May also produce nutrients for primary producers
- The transfer of food energy up the trophic levels is called a ***food chain***
- Multiple food chains interconnect to form ***food webs***
- There are two models that describe how a change in biomass of one trophic level causes a change in others:
  - ***Bottom-Up Model*** – Change in lower trophic level biomass impacts higher levels, but not vice versa (ex: number of rabbits is limited by amount of grass, but not vice versa)
  - ***Top-Down Model*** – Change in higher trophic level biomass impacts lower levels, but not vice versa (ex: number of rabbits is limited by number of wolves, but not vice versa)
  - In reality, food webs operate with a mix of both models
- Energy transfer between trophic levels is only around 10% efficient. 90% of the energy consumed is unabsorbed
- This inefficient energy transfer limits the length of food chains and is mostly due to heat loss. Heat is a natural "waste" product of metabolism and many biochemical pathways. Solar energy that is not absorbed by primary producers also becomes heat
- ***Gross Productivity*** describes a trophic level's overall rate of energy capture
- ***Net Productivity*** is gross productivity minus the energy used for metabolism. This represents the energy stored as biomass
  - Due to the first law of thermodynamics, the sum of an ecosystem's total net productivity plus energy used for metabolism and converted to heat must equal the total energy produced from the sun
- ***Energy pyramids*** visually represent the rate of energy flow through trophic levels, in terms of energy units (i.e. kcal) or biomass units (i.e. kilograms)



- ***Bioaccumulation*** is the gradual acquisition of certain substances (usually toxic) within an organism. Occurs when the rate of absorption is higher than the rate of excretion or metabolism. For example, bioaccumulation in tuna leads to high levels of heavy metals such as mercury
- ***Biological magnification*** describes how certain substances can increase in concentration as they work their way up the food chain, due to bioaccumulation. For example, heavy metals accumulate in smaller aquatic organisms, which are eaten by larger fish (i.e. salmon). Since predators consume many smaller prey, they accumulate even more heavy metals. Eventually the highest concentrations are found in the apex consumer

SYMBIOSIS ☆ HIGH-YIELD

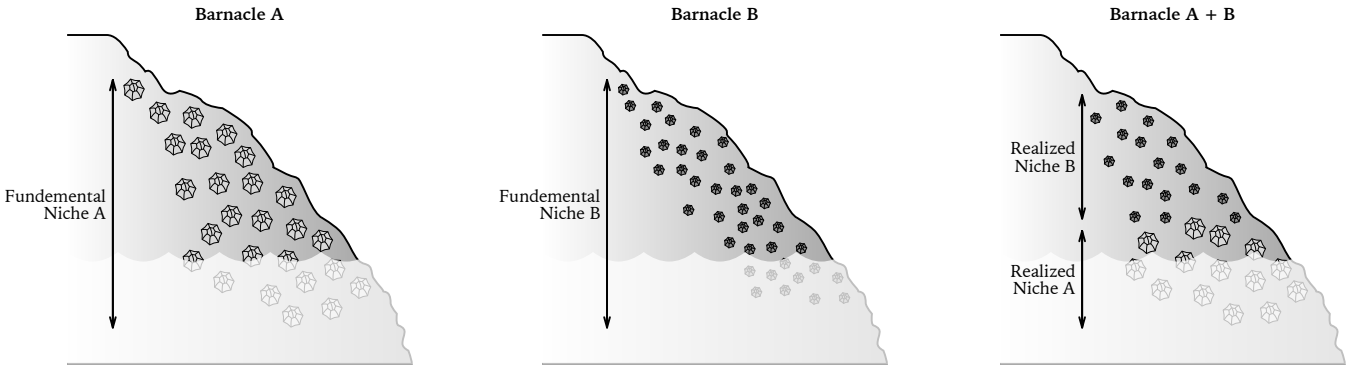
- When two species undergo long-term interaction, they are ***symbiotic***
- Symbiosis can exist in six forms:
  - ***Competition*** – Both populations are harmed. Ex: a lion and rhinoceros fight for over a carcass. There are two main forms of interspecific competition:
    - ***Interference Competition*** – Fitness of one species is directly reduced by another. Ex: animals fighting, fungi releasing antibiotics into surroundings, and allelopathy in plants
    - ***Exploitative Competition*** – Fitness of one species is indirectly reduced by another. Ex: tall trees outcompete shorter bushes for sunlight
    - ***Apparent Competition*** – The predation of one species is directly correlated to the success of another species, who shares the same predator. For example, nettle aphids and grass aphids are both prey of ladybugs. If grass aphids are successful and increase in population, there will be more food for ladybugs, which will in turn increase in population and eat more nettle aphids
  - ***Predation*** – Predator benefits and prey are harmed. Ex: a lion kills a gazelle
  - ***Herbivory*** – Herbivore benefits and plants are harmed. Ex: a tortoise eats a tomato plant
  - ***Parasitism*** – Parasite benefits and host is harmed. Ex: malaria infects a human
  - ***Amensalism*** – One species is harmed and the other is unaffected. Ex: a goat tramples some grass
  - ***Commensalism*** – One species benefits and the other is unaffected. Ex: moss grows on a tree, getting light and nutrients while the tree is unaffected
  - ***Mutualism*** – Both species benefit. Ex: honey bee helps plants reproduce via pollination and receives nectar in return

DEFENCE MECHANISMS

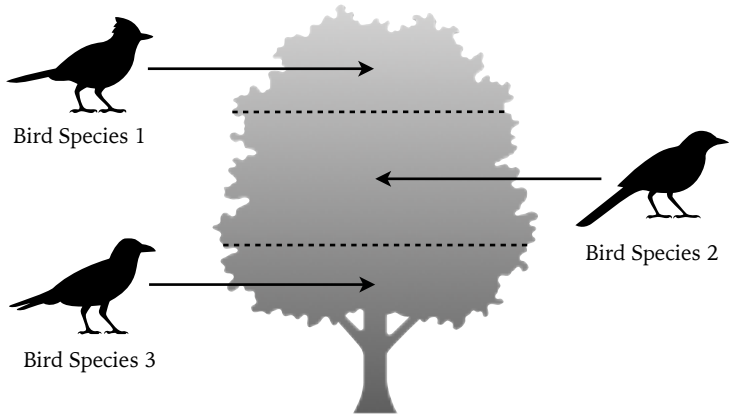
- Species can evolve a variety of mechanisms to prevent predation or herbivory, including:
  - ***Camouflage*** – Organisms mimics the appearance of its environment
  - ***Chemical Defence*** – Organism releases caustic chemicals or contains poison
  - ***Behavioural Defence*** – Organism hides, plays dead, flees, herds, or uses distraction displays. For example, an octopus can release ink to distract predators and escape
  - ***Mimicry*** – One species evolves to resemble another. There are two types:
    - ***Batesian Mimicry*** – A harmless species resembles another poisonous/repulsive species. For example, a species of harmless flies mimics the yellow and black coloration of wasps
    - ***Mullerian Mimicry*** – Two or more poisonous/repulsive species that have common predators resemble each other. For example, the viceroy butterfly and the monarch butterfly are both repulsive-tasting to predators and similar in appearance
  - ***Spines and Armour*** – Organism has hard or thorny outer layers. Examples include cacti and porcupines

NICHES AND RESOURCE PARTITIONING

- An ***ecological niche*** describes the relationship between a species and the specific biotic and abiotic resources it requires (food, shelter, nutrients, light intensity, temperature, etc.). There are two types of niches:
  - ***Fundamental Niche*** – The range of environmental conditions tolerated by the species
  - ***Realized Niche*** – The range of environmental conditions actually inhabited by the species in nature. This is often smaller than the fundamental niche because not all tolerable conditions are always present in nature, and some resources are used by competitors
- The ***competitive exclusion principle*** (also known as ***Gause's law***), states that two species cannot be made to coexist in the same niche while maintaining their original population levels. In other words, combining two species that share the same niche will always result in one species out-competing the other. The species that is less adapted to that niche will likely decline to extinction over the long term



- ***Resource partitioning*** is when several species occupy the same habitat but use resources in slightly different ways, thus creating their own niches and avoiding competition. For example, several species of monkeys might live in a different layer of the tree canopy, or they might feed/hunt at different times of the day



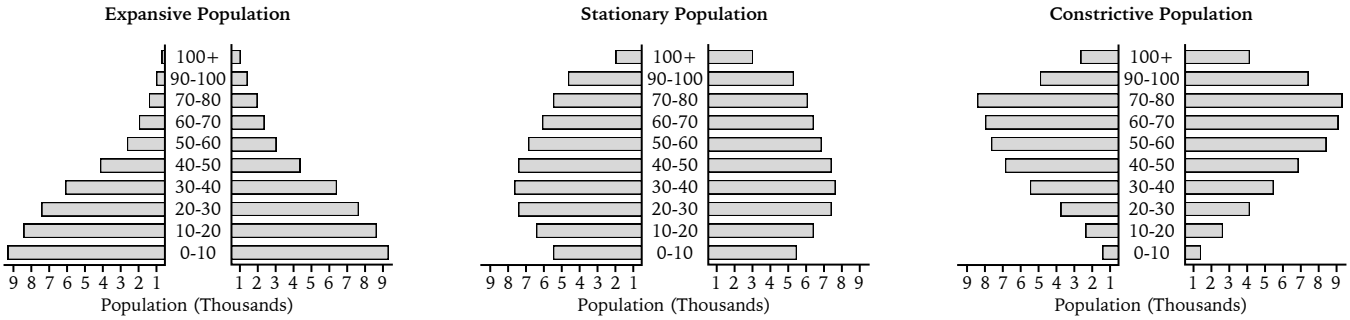
CHAPTER 13 | **POPULATION ECOLOGY**

INTRODUCTION

- A ***population*** is defined as individuals of the same species living in the same area
- Unlike communities, populations are solely composed of the individuals of *one* species
- ***Population ecology*** is the study of how biotic (living) and abiotic (non-living) factors influence the size, density, and dispersion of a population
  - ***Size*** – Population size is represented by "*N*" (ex: a population of 500 fish is *N*=500)
  - ***Density*** – The number of individuals per unit area or volume
  - ***Dispersion*** – The pattern in which individuals are distributed within a population
    - ***Uniform*** – Occurs when the distance between individuals are maximized. Often associated with competitive interactions between individuals, such as the secretion of plant toxins/inhibitory hormones, or animal territoriality (ex: redwood trees in a forest, gerbil burrows in the desert)
    - ***Clumped*** – Occurs when the distance between individuals is minimized. It is the most common type of dispersion and is often associated with scarce resources and social structure. (ex: humans in cities, birds in a nest, bees in a hive)
    - ***Random*** – Occurs when individuals neither attract or repel each other. It is the most rare type of dispersion and is usually associated with consistent environmental conditions/resources (ex: shafts of grass in a field, dispersion of seeds by the wind)

POPULATION PYRAMIDS

- ***Population pyramids*** (also called ***age-sex pyramids***) graphically represent the distribution of individuals with a particular age and sex in a population. The y axis represents different age groups, while the x axis represents the number of individuals in a particular age group. By convention, the male population distribution is shown on the left, while the female distribution is on the right
- The shape of a population pyramid describes the stage of growth the population is in:
  - ***Expansive Population*** – Pyramid shaped graph due to high frequency of young individuals. Associated with high birth rate and low life expectancy in fast-growing populations such as developing countries
  - ***Stationary Population*** – Box shaped graph due to relatively equal frequency of all age groups. Associated with zero net population growth
  - ***Constrictive Population*** – Inverse pyramid shaped graph due to low frequency of young individuals. Associated with low birth rate and long life expectancy in slow growing populations such as developed countries



GROWTH CURVES

- Describes the size of a population as a function of time
- The per capita growth rate of the population for a particular interval of time (t) is represented by:

$$r = \frac{(\text{Births} + \text{Immigration}) - (\text{Deaths} + \text{Emigration})}{A}$$

r represents per capita growth rate over time interval t
A represents initial population size

- When r is at it's maximum, it is called the ***intrinsic rate of growth***
- There are two main types of growth curves:
  - ***Exponential Growth*** – r is constant and greater than zero
    - Occurs in situations lacking environmental constraint (unlimited resources)
    - Population size as a function of time is modelled by the formula:

$$N = A \cdot r^t$$

N represents population size after the time interval t
A represents initial population size
r represents per capita growth rate over time interval t

    - Instantaneous growth rate is modelled by the formula:

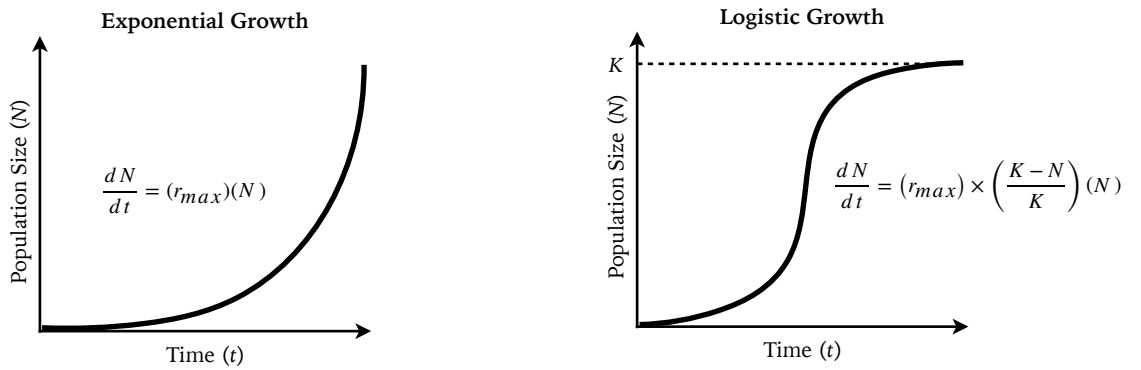
$$\frac{dN}{dt} = (r_{max})(N)$$

dN/dt represents growth rate of population at a given instant
r_{max} represents maximum per capita growth rate
N represents population size

  - ***Logistic Growth*** – R decreases over time and is dependent on the environment's carrying capacity (K)
    - Occurs when environmental constraints exist, limiting the population to K
    - When $N = K$, the population has reached the environment's carrying capacity and the instantaneous growth rate becomes zero
    - Instantaneous growth rate is modelled by the formula:

$$\frac{dN}{dt} = \left(r_{max}\right) \times \left(\frac{K - N}{K}\right)(N)$$

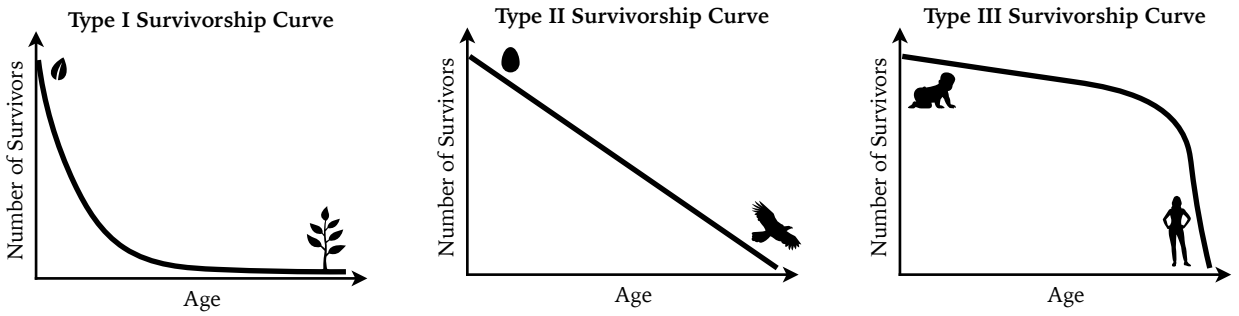
dN/dt represents growth rate of population at a given instant
r_{max} represents maximum per capita growth rate
N represents population size
K represents carrying capacity size



- ***r/K Selection Theory*** describes the strategic trade-off between a species' quantity and quality of offspring
  - ***r-selected species*** maximize growth via high fecundity (producing many offspring), but only few survive to adulthood. This is common in species that have small body sizes, short maturation times, and unstable living conditions
  - ***K-selected species*** maximize survival via low fecundity (producing few offspring). This is common in species that have large body sizes, long maturation times, and stable living conditions

SURVIVORSHIP CURVES

- Describes the survival rate of individuals in a species throughout their lifetime
- There are three major types of survivorship curves:
  - ***Type I*** – Most individuals survive to middle life, followed by a rapid decline in late life. Common in *K*-selected species. Examples include humans and large mammals such as elephants and whales
  - ***Type II*** – Survival is constant throughout the individual's lifetime. Examples include birds and lizards
  - ***Type III*** – Most individuals die young and very few survive to late life. Common in *r*-selected species. Examples include species that produce many eggs/spores, such as frogs, oysters, and trees

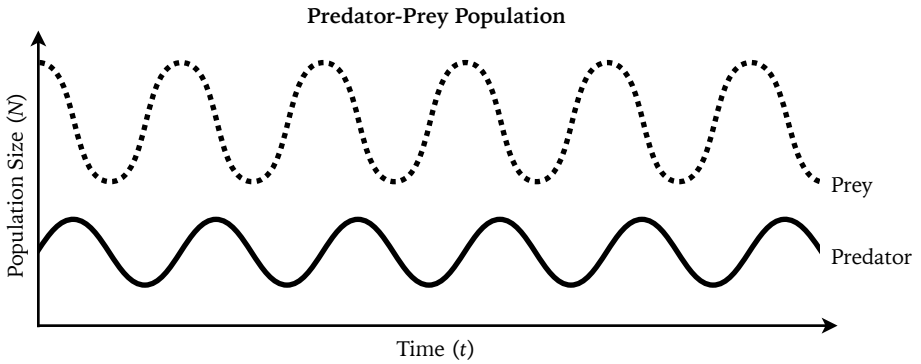


DETERMINANTS OF GROWTH RATE

- The following factors determine the maximum per capita growth rate (r_{max}) of a population:
  - ***Carrying Capacity*** – Maximum population size an environment can sustain
  - ***Biotic Potential*** – The maximum growth rate of a species under ideal conditions. Depends on quantity of offspring per reproductive event, offspring survivorship, reproduction frequency, and age of reproductive maturity
  - ***Limiting Factors*** – Describes anything that prevents a species from reaching its biotic potential. There are two types:
    - ***Density-Dependent Factors*** – The larger the population, the greater the effect of limiting growth. Examples include:
      - ***Competition*** – The more individuals, the fiercer the competition
      - ***Predation*** – The more individuals, the easier it is to get caught by predators
      - ***Disease*** – The more individuals, the faster disease spreads
    - ***Density-Independent Factors*** – Limiting effect is independent of population size. Examples include: natural disasters and a harsh environment (ex: if a population is not adapted to low temperatures, a harsh winter will kill 80% of them regardless of density)

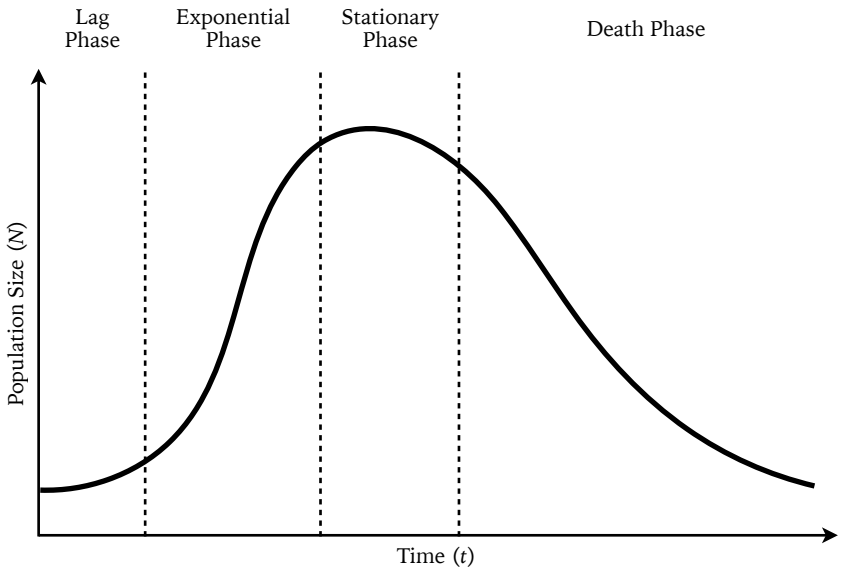
PREDATOR-PREY POPULATION DYNAMICS

- Predator and prey populations tend to be modelled as two sinusoidal functions that are offset by a quarter cycle. The prey population function is always higher than that of the predator
- This is because whenever the prey population reaches its maximum, there is the most food available for the predator, meaning the predator population is growing at its fastest
- On the other hand, whenever the prey population reaches its minimum, there is the least food available for the predator, meaning the predator population is declining at its fastest



BACTERIAL GROWTH DYNAMICS

- Bacterial populations tend to follow a growth curve with the following specific phases:
  - ***Lag Phase*** – Slow growth as bacteria adapt to the new environment or growth medium
  - ***Exponential/Log Phase*** – Fast growth as bacteria grow exponentially via binary fission
  - ***Stationary Phase*** – Plateau as rate of bacterial death equals the rate of growth
  - ***Death Phase*** – Decline in population after the environment or growth medium is depleted, and as metabolic waste products accumulate



CHAPTER 14 | **ANIMAL BEHAVIOUR**

- Behaviour is a result of natural selection and can be ***innate*** (hard-wired in genetics) or ***learned*** (developed through experiences)

INSTINCTIVE BEHAVIOUR

- ***Instincts*** are innate tendencies of an animal to make a complex decision in response to environmental stimuli without reasoning
  - Instincts result from natural selection and thus tend to increase an organism's fitness
- ***Fixed action patterns*** are instinctive behavioural sequences that are consistent between members of a species and inevitably run to completion once started
  - Occur reliably when the individual is exposed to a ***sign stimulus***, the trigger for the fixed action pattern. For example, the beak movements of chicks trigger the mother bird to regurgitate food. Other examples include the egg-retrieval behaviour of greylag geese, or the tendency of male stickleback fish to attack any red object
- ***Reflexes*** are simple nerve circuits that trigger an instinctive, involuntary response without the involvement of the brain. For example, the patellar tendon reflex requires only afferent and efferent nerves synapsing with the spinal chord to produce a knee jerk
- ***Kinesis*** is when an animal instinctively changes its rate of movement in response to environmental cues (non-directional)
- ***Taxis*** is when an animal instinctively moves towards or away from a stimulus (directional)

LEARNED BEHAVIOUR

- ***Associative Learning*** – Involves reinforcement or punishment
  - ***Classical Conditioning*** – A form of associative learning in which a response that is associated with an unconditioned stimulus is associated with a second, conditioned stimulus to which it had no previous connection. For example, Ivan Pavlov trained his dogs to salivate (response) after hearing a bell (conditioned stimulus) by repeatedly ringing the bell when presenting food (unconditioned stimulus)
  - ***Operant Conditioning*** – A form of associative learning in which an animal receives positive or negative reinforcement for completing a task. For example, a dog sits when told (behaviour) and the owner gives it a treat (positive reinforcement). The learning process is often initiated through trial and error, since the animal must complete the task by chance in order to receive the reinforcement. When reinforcement is removed, the behaviour slowly diminishes in a process called extinction
- ***Non-Associative Learning*** – Does not involve reinforcement or punishment
  - ***Imprinting*** – A special type of automatic learning in which young animals identify an object or location as meaningful. This must occur within the ***critical period***, or the behaviour will not be learned. Once imprinting has occurred, it is irreversible. For example, goslings will identify the first moving object they see as their mother
  - ***Observational Learning*** – When an animal observes the behaviour/actions of another and copies it without needing reinforcement. For example, Albert Bandura showed that kids learned to punch an inflatable doll after watching violent TV
  - ***Habituation*** – When an animal becomes decreasingly sensitive to repeated, unimportant stimuli. Habituation responses involve the entire animal (i.e. you gradually learn to disregard background noise in a busy cafe) or only components of an animal (i.e. your brain becomes less sensitive after repeated drug usage)
  - ***Sensitization*** – The opposite of habituation. When an animal becomes increasingly sensitive to repeated stimuli (i.e. you gradually learn to better recognize the sound of your ringtone among background noise)

- ***Spatial Learning*** – An advanced form of learning in which animals are able to construct a mental map of their surroundings with or without reinforcement. For example, rats that were left to wander a maze for three days are able to obtain a food reward faster than rats who were not previously exposed to the maze
- ***Insight*** – An advanced form of learning in which animals are able to arrive at a solution to a problem suddenly after a period of cognition. This "ah-ha" moment is often associated with the ability to "see the bigger picture" and use objects in a way you are not accustomed to

ANIMAL COMMUNICATION

- Animals communicate for various reasons, such as to find mates, defend territory, establish dominance/submission, warn against predators, teach others the location of food, etc.
- Communication can be intraspecific (within a species) or interspecific (between species)
- Animals communicate through four main types of signalling:
  - ***Chemical Signalling*** – Pheromones are secreted chemical messengers used to trigger a response in an individual of the same species. They are common in social species. For example, the queen bee of a hive emits pheromones to inhibit ovary development in worker bees
    - There are two main types of pheromones:
      - ***Releaser Pheromones*** – Cause rapid change in behaviour but degrades quickly
      - ***Primer Pheromones*** – Cause a change in developmental events (physiological change, as opposed to behavioural)
  - ***Auditory Signalling*** – Includes language, song, crying, calls, and other vocalizations in air and water
  - ***Visual Signalling*** – Includes facial expressions, gestures, posture, and coloration
  - ***Tactile Signalling*** – Includes dance, grooming, licking, etc.

FORAGING BEHAVIOUR

- Foraging means "looking for food", which includes grazing, scavenging, fishing, and hunting
- Foraging can be done in a ***solitary*** or ***group*** setting, each with benefits and drawbacks
- Animals use ***search images*** (a generic mental representation of prey) to increase efficiency

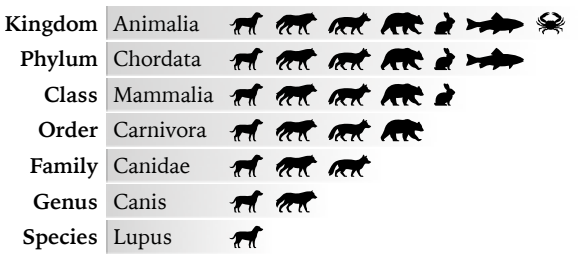
SOCIAL BEHAVIOUR

- ***Aggression/Agnostic Behaviour***
  - Social behaviour intended to harm others or obtain dominance
  - Caused by biological (i.e. testosterone) and social factors (i.e. competition, mating, observational learning)
- ***Altruistic Behaviour***
  - Social behaviour intended to help others
  - Animals have a tendency to be altruistic to those who are related to them (***kin selection***). For example, ground squirrels make alarm calls to alert relatives of predators, often exposing themselves in the process
  - Altruistic behaviour may reduce an individual's ***personal fitness***, but it often increases their ***inclusive fitness***, which includes the survival of relatives
  - ***Reciprocal altruism*** is when the receiver of altruistic acts is expected to return the favour in the future
  - ***Cost signalling*** is when apparently wasteful acts of altruism are justified by the benefit of "showing off" an individual's social status or quality for mating
- ***Territoriality***
  - When animals communicate their ownership or occupancy of space
  - Important for breeding animals, who must defend their offspring
- ***Dominance Hierarchies***
  - A social hierarchy used to avoid fighting each time individuals must compete for limited resources. This saves the animals from the mutual costs of agnostic behaviour

CHAPTER 15 | **TAXONOMY**

INTRODUCTION ☆ HIGH-YIELD

- Taxonomy is the classification of organisms based on shared characteristics
- There are seven ranks in the taxonomic hierarchy, each referring to a group of similar organisms called a taxon:
  - Domain
  - Kingdom
  - Phylum
  - Class
  - Order
  - Family
  - Genus
  - Species



MNEMONIC "Dear King Phillip Came Over For Good Soup"

- Organisms are named after the genus and species that they belong in (i.e. *Homo sapiens*). The genus is always capitalized and the species is always lowercase. The full organism name is always italicized

DAT TIP The DAT requires you to understand and memorize domains, kingdoms, and animal phyla. This section is critical, since there are almost always 2-3 questions in the biology section every year of the Canadian DAT. This chapter will review the three domains, four eukaryotic kingdoms, and ten animal phyla that are the most likely to appear on the Canadian DAT

DOMAIN: ARCHEA/ARCHEABACTERIA

- Archaea are prokaryotes that have a polysaccharide cell wall
- Archaea have similarities and differences with bacteria and eukaryotes that are critical to understand:

	Archea	**Bacteria**	**Eukaryotes**
Cell Wall Composition	Polysaccharide	Peptidoglycan	-
Phospholipids in Plasma Membrane	Branched Hydrocarbon Chains	Unbranched Hydrocarbon Chains	Unbranched Hydrocarbon Chains
Presence of Histones	Yes	No	Yes
Ribosome Activity Inhibited by Antibotics	No	Yes	No

- There are two important groups of archaea:
  - ***Methanogens*** – Obligate anaerobes (cannot live with oxygen) that reduce CO_2 to CH_4 (methane gas), using H_2 as a reducing agent. They are found in soil, wetlands, and the guts of ruminants and humans
  - ***Extremophiles*** – Organisms that live in a variety of extreme environmental conditions:
    - ***Halophiles*** live in high concentrations of salt (i.e. the Dead Sea, preserved foods). They can be aerobic heterotrophs or anaerobic autotrophs (photosynthetic halophiles that use the pigment bacteriorhodopsin as a proton pump). ***Thermophiles*** live in high temperatures (i.e. hydrothermal vents on the seafloor, hot springs). Most thermophiles are sulphur-dependent chemoautotrophs. ***Psychrophiles/Cryophiles*** live in low temperatures. ***Acidophiles*** live in low pH conditions (i.e. in stomach). ***Piezophiles/Barophiles*** live under high pressures. ***Xerophiles*** live under dry conditions

DOMAIN: BACTERIA/EUBACTERIA

- Archea and bacteria were historically classified under the same kingdom, called ***monera***
- Bacteria are prokaryotes (no membrane-bound organelles) that have a peptidoglycan cell wall
- Instead of a nucleus, bacterial cells have a ***nucleoid*** region that contains the bacterial chromosome
- Bacteria also have ***pili***, which functions for exchange of genetic information (conjugation) and cell adhesion
- ***Peptidoglycan*** is a polymer consisting of sugar and amino acids
- Bacteria are classified by the following features:
  - The biochemical reactions they use for nutrition (i.e. photosynthetic bacteria, chemosynthetic bacteria, nitrogen-fixing bacteria)
  - Their ability to produce ***endospores***, a non-reproductive structure containing the bacteria's DNA designed to allow survival through unfavourable conditions
  - How they move (i.e. Propelled by flagella, corkscrew motion, gliding on slime)
  - Their shape, which can be ***cocci*** (spherical), ***bacilli*** (rod shaped), or ***spirochete*** (spiral shaped)
  - Cell wall thickness visualized using Gram stain (***Gram positive*** = thick peptidoglycan layer, ***Gram negative*** = thin peptidoglycan layer)
- Gram positive and negative bacteria have similarities and differences that are important to understand:

	Gram Positive	**Gram Negative**
Cell Wall Appearance Under Gram Stain	Purple	Pink
Peptidoglycan Layer	Thick	Thin
Periplasmic Space (Between Peptidogylcan and Membrane)	Thin	Thick
Lipopolysaccharide (LPS) Membrane Outside Cell Wall	No	Yes
Secrete Endotoxin (LPS)	No	Yes
Secrete Exotoxin	Yes	Yes
Teichoic Acid	Yes	No
Capsule	Yes	Yes

  - Note that only gram positive bacteria have ***teichoic acid***, an acid polysaccharide that connects the peptidoglycan cell wall to the cell membrane and provides rigidity
  - Both gram positive and negative bacteria have a protective outer ***capsule*** and ***virulence factors***, which help the bacteria penetrate and colonize host cells
- Common groups of bacteria include:
  - ***Cyanobacteria*** – Photosynthetic autotrophs that use chlorophyll A and phycobilin. Some have cells called heterocysts that fix nitrogen to synthesize amino acids or nucleotides
  - ***Nitrifying Bacteria*** – Chemosynthetic autotrophs that oxidize ammonia to nitrites (NO_2^-)and then to nitrates (NO_3^-)
  - ***Nitrogen-Fixing Bacteria*** – Heterotrophs that convert nitrogen gas into ammonia. Often have a mutualistic relationship with plants and live within root nodules
  - ***Spirochetes*** – Spiral bacteria that move in a corkscrew motion via an internal flagella

DOMAIN: EUKARYA

- Eukaryotic organisms have nucleated cells with membrane-bound organelles. There are four kingdoms in the eukaryote domain: protista, fungi, plantae, animalia. These kingdoms will be discussed individually in their own sections below

KINGDOM: PROTISTA

- This kingdom is unique because it can be thought of as a "catch-all" for organisms that were unable to be classified under the three other kingdoms (fungi, plantae, animalia)
- Therefore, the evolutionary relatedness between organisms in this kingdom may be lower than organisms in the other kingdoms. Many similarities may be the result of convergent evolution
- Protists can be plant-like, fungus-like, or animal-like. They can also be unicellular or multicellular
- ***Plant-Like Protists***
  - ***Euglenoids*** – Unicellular photoautotroph with usually a few flagella for moving. Instead of a cell wall they have a pellicle, a thin protein layer that wraps around the membrane. They have an eyespot that allows phototaxis but can become heterotrophic in the absence of light
  - ***Dinoflagellates*** – Unicellular photoautotroph with two flagella (one posterior, one transverse). They are bioluminescent and can produce neurotoxins
  - ***Diatoms*** – Unicellular photoautotroph that are covered by silica shells and move by gliding (no flagella)
  - ***Brown Algae*** – Multicellular photoautotroph that reproduces with flagellated sperm cells. Includes many species of giant seaweeds and kelp
  - ***Red Algae (Rhodophyta)*** – Multicellular photoautotroph that reproduces with non-flagellated gametes. They contain red pigments called phycobilins (same pigment in cyanobacteria)
  - ***Green Algae (Chlorophyta)*** – Multicellular photoautotroph that contains chlorophyl A and B. They may be isogamous (sperm and egg same size), anisogamous (sperm and egg different sizes), or oogamous (sperm is small and motile, egg is large and immotile). Charophytes are a type of green algae believed to be the ancestor of modern plants
- ***Animal-Like Protists (Protozoa)***
  - ***Rhizopoda/Amoeba*** – Unicellular heterotroph that moves via pseudopodia, extensions of the cytoplasm
  - ***Foraminifera*** – Unicellular heterotroph that has hard calcium carbonate shells called tests. Frequently found near oil deposits
  - ***Apicomplexa*** – Unicellular parasite of animals that have a unique apicoplast organelle. They move by gliding (no flagella) and form spores to complete their lifecycle, sometimes in multiple host species (i.e. *Plasmodium* causes malaria and lives in both mosquitos and humans)
  - ***Ciliates*** – Unicellular heterotroph that has many cilia and complex structures (mouths, anus, contractile vacuoles for water balance, two nuclei). *Paramecium* is a well-known example and model organism
- ***Fungus-Like Protists***
  - ***Cellular Slime Mold*** – Unicellular heterotroph that aggregates in multicellular masses to find food. They move using flagella or pseudopods. When food is limited, the cells secrete cAMP, which stimulates aggregation of the mass into a "slug." To reproduce, a spore-bearing body is sprouted, similar to fungi. Their lifecycles follow an alternation of generations system
  - ***Plasmodial Slime Mold*** – Very similar to cellular slime mold except it exists as one large multinuclear cell (coenocyte), instead of an aggregate of many mononuclear cells
  - ***Oomycota*** – Unicellular heterotroph that form hyphae to feed on surrounding food. The hyphae are aseptate, existing as a coenocyte. Their cell walls are made of cellulose, instead of chitin like true fungi

KINGDOM: FUNGI

- Fungi are characterized by filaments called hyphae, which coalesce to form a mass called mycelium
- ***Septate*** fungi have septa, an internal cell wall that divides hyphae into cells
- ***Aseptate*** fungi do not have septa, therefore their hyphae are coenocytic
  - A coenocyte is a multinucleate cell that arises from multiple nuclear divisions without cytokinesis
  - A syncytium is a multinucleate cell that arises from the aggregation of multiple cells and dissolution of internal cell membranes
- Fungi cell walls are made of ***chitin***, a nitrogen-containing polysaccharide that also forms the exoskeleton of arthropods (crustaceans, insects, arachnids)
- Fungi can be saprobes (feed off decomposing matter) or parasites (feed off another organism)
  - Parasitic fungi have penetrative hyphae called haustoria that absorb nutrients from their host
- The six major types of fungi are:
  - ***Zygomycota*** – Aseptate fungi that reproduce sexually via aerial hyphae called zygospores. Examples include common bread and fruit moulds. Many are insect parasites
  - ***Glomeromycota*** – Aseptate fungi that reproduce asexually via glomerospores that bud from the tips of hypha. All glomeromycetes form symbiotic relationships with plant roots
  - ***Ascomycota*** – Septate fungi that reproduce sexually via ascospores. Examples include yeast
  - ***Basidiomycota*** – Septate fungi that reproduce sexually via basidiospores. Most are saprobes. Examples include mushrooms
  - ***Deuteromycota*** – A "catch-all" group of asexual fungi. Also known as "imperfect fungi." Examples include penicillin
  - ***Lichens*** – A symbiotic mass of two different organisms living together – fungi and algae. The fungus provides water and protection, while the photosynthetic algae provides sugar and nitrogen

KINGDOM: PLANTAE ☆ HIGH-YIELD

- Plants are characterized by a cuticle, a waxy layer that protects the underlying cells from drying out
- Plants have two vascular tissues:
  - ***Xylem*** – For water transport
  - ***Phloem*** – For sugar transport
- There are five major types of plants:
  - ***Bryophyta (Mosses, Liverworts, Hornworts)*** – The simplest plants, with no leaves, stems, roots, or vasculature (xylem and phloem). Bryophytes are the only non-tracheophyte (non-vascular) plants. Thus, they can only survive in moist environments. They produce swimming sperm in structures called antheridia and eggs in structures called archegonia. They follow an alternation of generations lifecycle
  - ***Lycophyta (Club Mosses)*** – One of the oldest lineages of vascular plants. They produce spore-bearing strobili (a cone-like structure). Like bryophytes, they follow an alternation of generations lifecycle, except their sporophytes are photosynthetic and much larger than gametophytes
  - ***Pterophyta (Ferns)*** – Have rhizomes, underground stems that grow horizontally. They produce spore-bearing sori (clusters of sporangia). They have special leaves called fronds. Young fronds are curled and called "fiddleheads" due to their shape
  - ***Coniferophyta (Gymnosperms)*** – Produces seeds instead of spores. Seeds are protected in specialized wooden strobili called cones
  - ***Anthophyta (Angiosperms)*** – Produces seeds instead of spores. Seeds are produced in specialized reproductive structures called flowers. Flowers may develop into fruits after pollination and double fertilization. This is the most diverse group of plants and also the most important plant category for the Canadian DAT. Angiosperm physiology will be covered separately in Chapter 16

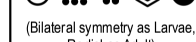
KINGDOM: ANIMALIA ☆ HIGH-YIELD

- All animals are heterotrophic, multicellular, diploid, usually motile, and undergo embryonic development
- Animals are classified based on the following features:
  - ***Tissue complexity*** **–** ***Eumetazoa*** have "true tissue" layers that develop into organs, while ***parazoa*** do not have tissue layers or organs
  - ***Body Plan Symmetry*** **–** ***Radially symmetric*** animals have no left/right sides, while ***bilaterally symmetric*** animals are divided in half
  - ***Gastric Cavity*** – Some animals have a ***gastrovascular cavity*** with only one opening (food travels in two directions), while others have a ***alimentary canal*** with two openings (food travels in one direction)
  - ***Innervation*** – Some animals have a ***spinal cord*** surrounded by cartilage or bone, while others do not
  - ***Cephalization*** – Some animals have a ***head***, defined by increased innervation. Most bilaterally symmetric animals have a head
  - ***Embryonic Development*** **–** Some animals have a ***coelom***, a cavity that develops from the mesoderm germ layer and protects the organs. Also, the embryonic blastopore (first opening) of some animals develop into their head (***protostomes***), while the blastopore of others develop into their anus (***deuterosomes***). All animal phyla are protostomes except echinodermata and chordata, which are deuterosomes
  - ***Segmentation*** – Some animals have segmented body parts, which repeat within their body plan

THE TEN ANIMAL PHYLA ☆ HIGH-YIELD

- The next page contains a concise summary of the ten animal phyla. It is important to memorize all ten animal phyla discussed in this section for the Canadian DAT

MNEMONIC The five animal phyla that have a coelom can be memorized with the following mnemonic:
"CAAME" → Chordata Arthropoda Annelida Mollusca Echinodermata

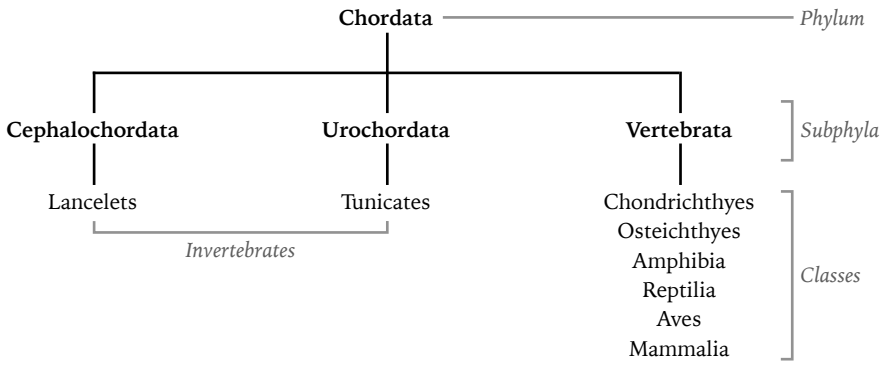
Phylum	Tissue Summary	Circulatory System	Respiratory System	Nervous System	Digestive System	Description
Porifera		None (Diffusion)	None (Diffusion)	None	Phagocytosis	Sessile, aquatic filter-feeders that absorb and expel water through pores. Examples include sea sponges
Cnidaria		None (Diffusion)	None (Diffusion)	Nerve Net	Gastrovascular Cavity (Two-Way)	Mobile aquatic animals that usually have a polyp and medusa lifecycle. Examples include jellyfish, hydra, sea anemone, and coral
Platyhelminths		None (Diffusion)	None (Diffusion)	Ganglia	Gastrovascular Cavity (Two-Way)	Usually parasitic and live in the digestive tracts of hosts. Examples include tapeworms and flukes. Tapeworms don't have a digestive system, absorb nutrients directly from their surroundings, and contain flame cells for excretion
Nematoda		None (Diffusion)	None (Diffusion)	Nerve Ring	Alimentary Canal (One-Way)	Usually parasitic and live in the digestive tracts of hosts. Unlike platyhelminths, nematodes secrete a cuticle for protection against the host's digestive system. They lack circumferential muscles. Examples include C. elegans
Rotifera		None (Diffusion)	None (Diffusion)	Ganglia	Alimentary Canal (One-Way)	Very small filter feeders that draw in water using cilia. They live in mostly freshwater environments and are a major component of zooplankton. Like platyhelminths, they contain flame cells for excretion
Annelida		Closed, Aortic Arches	None (Diffusion)	Ganglia	Alimentary Canal (One-Way)	Segmented worms with both longitudinal and circular muscles (unlike nematoda). Segments contain identical anatomy (including organs) and are separated by septa. Examples include earthworms, leaches, and tube worms
Mollusca		Open, Hemolymph	Gills	Brain	Alimentary Canal (One-Way)	Soft-bodied animals with a mantle that secretes a hard calcium carbonate shell. They have a tongue-like organ called a radula that scrapes food from surfaces. Examples include snails, slugs, clams, oysters, squid, and octopus
Arthropoda		Open, Hemolymph	Trachea & Gills	Ganglia	Alimentary Canal (One-Way)	The most species-diverse phylum. They have hard, chitinous exoskeletons and jointed appendages. Divided into three major subphyla: hexapods (insects), crustaceans (lobsters, crabs), and arachnids (spiders, scorpions)
Echinodermata	 (Bilateral symmetry as Larvae, Radial as Adult)	Open, No Heart	None (Diffusion)	Nerve Ring	Alimentary Canal (One-Way)	Spiny-skinned aquatic animals that are the closest related to chordata. Unlike most other phyla, echinoderms are deuterosomes. Examples include sea urchins, sea cucumber, starfish, and sand dollars
Chordata		Closed, Heart* *(Except Cephalochordata)	Lungs & Gills	Brain* *(Except Cephalochordata & Urochordata)	Alimentary Canal (One-Way)	Animals containing a notochord, dorsal hollow nerve chord, pharyngeal gill slits, and post-anal tail. Unlike most other phyla, chordata are deuterosomes. Examples include mammals, birds, reptiles, and amphibians

SYMBOL LEGEND

- = Acoelomate
- = Pseudocoelomate
- = Coelomate
- = Bilateral Symmetry
- = Radial Symmetry
- = Asymmetrical
- = Parazoa (No Tissues)
- = Diploblast (2 Layers)
- = Triploblast (3 Layers)
- P = Protostome
- D = Deuterostome
- N = Neither

THE SIX CHORDATA CLASSES ☆ HIGH-YIELD

- All chordates possess the following key characteristics:
  - ***Notochords*** – A mesoderm-derived cartilaginous rod that supports the body during development. Most chordates will lose their notochord during maturation, but in vertebrates it is replaced by a bony vertebral column/backbone. Note that the notochord and vertebral column are *not* the same embryonic structure
  - ***Dorsal Hollow Nerve Cord*** – An ectoderm-derived embryonic tissue that becomes the spinal cord, a long tube of nervous tissue that runs through the vertebral column. Do not confuse this with the ***spinal column***, which is just another word for vertebral column/backbone
  - ***Pharyngeal Gill Slits*** – Embryonic structures that allow the flow of fluids into/out of the pharynx, and eventually develop into the adult pharynx, gills, or other feeding structures. They can also disappear during development. In mammals, they form into the Eustachian tubes
  - ***Post-Anal Tail*** – A muscular structure unrelated to the notochord that extends behind the anus and is often lost during development
- For the Canadian DAT, it is important to know the order in which a few key chordate traits have evolved:
  - Notochord > Head > Vertebrae > Jaw and Mineralized Skeleton > Lungs and Lung Derivatives > Lobed Fins > Limbs with Digits > Amniotic Egg > Mammary Glads and Milk
- Chordates can be categorized based on the presence of the aforementioned traits:
  - ***Craniates*** are chordates that have a head. Hagfish (*Myxini*) are the only craniates without a spinal chord
  - ***Vertebrates*** are craniates that have a backbone
  - ***Gnathostomes*** are vertebrates that have jaws
  - ***Tetrapods*** are gnathostomes that have four limbs
  - ***Amniotes*** are tetrapods that have land-adapted eggs
  - ***Mammals*** are amniotes that have hair and produce milk
- Chordates can also be divided broadly into ***invertebrate chordates*** and ***vertebrate chordates***:



- The next page contains a concise summary of the six vertebrate chordata classes plus two invertebrate chordata subphyla. It is important to memorize this information for the Canadian DAT

Subphylum or Class	Tissue Summary	Circulatory System	Respiratory System	Nervous System	Digestive System	Description
Cephalochordata (Lancelets)	◎ ⁞⁞⁞ ◆ D	Closed, No Heart	Diffusion & Gills	No Brain	Alimentary Canal (One-Way)	One of the only two invertebrate subphyla, aside from urochordata. They are mobile filter-feeders that have elongated bodies. Since they lack a vertebral column, cephalochordates keep their notochord to adulthood.
Urochordata (Tunicates)	◎ ⁞⁞⁞ ◆ D	Closed, Simple Heart	Diffusion & Gills	No Brain	Alimentary Canal (One-Way)	One of the only two invertebrate subphyla, aside from cephalochordata. They are sessile filter-feeders that live on the ocean floor. They also have an exoskeleton composed of proteins and carbohydrates called a tunic
Chondrichthyes	◎ ⁞⁞⁞ ◆ D	Closed, Two-Chamber Heart	Gills	Brain	Alimentary Canal (One-Way)	Part of the vertebrata subphylum. They contain a notochord only in the embryonic stage. It is replaced by cartilaginous vertebrae in adulthood. Examples include sharks, rays, skates, and sawfish
Osteichthyes	◎ ⁞⁞⁞ ◆ D	Closed, Two-Chamber Heart	Gills	Brain	Alimentary Canal (One-Way)	Part of the vertebrata subphylum. Unlike chondrichthyes, osteichthyes have scales and boney vertebrae (instead of cartilage). Examples include salmon, tuna, swordfish
Amphibia	◎ ⁞⁞⁞ ◆ D	Closed, Three-Chamber Heart	Gills (Juvenile) & Lungs (Adult)	Brain	Alimentary Canal (One-Way)	Part of the vertebrata subphylum. Juveniles are aquatic while adults are terrestrial. They reproduce via external fertilization and therefore require water. Examples include frogs, toads, salamanders, and newts
Reptilia	◎ ⁞⁞⁞ ◆ D	Closed, Three-Chamber* Heart *(Except Crocodiles & Alligators)	Lungs	Brain	Alimentary Canal (One-Way)	Part of the vertebrata subphylum. They reproduce via internal fertilization and have a land-adapted leathery egg. They are cold blooded (ectothermic and poikilothermic). Examples include turtles, snakes, and crocodiles
Aves	◎ ⁞⁞⁞ ◆ D	Closed, Four-Chamber	Lungs (Extremely Efficient)	Brain	Alimentary Canal (One-Way)	Part of the vertebrata subphylum. Warm blooded (endothermic and homothermic) animals that lay eggs with calcium carbonate shells. They possess wings, feathers, and a specialized respiratory system
Mammalia	◎ ⁞⁞⁞ ◆ D	Closed, Four-Chamber	Lungs	Brain	Alimentary Canal (One-Way)	Part of the vertebrata subphylum. Warm blooded (endothermic and homothermic) animals containing mammary glands, hair, a neocortex, and three middle ear bones. Examples include bats, whales, and kangaroos

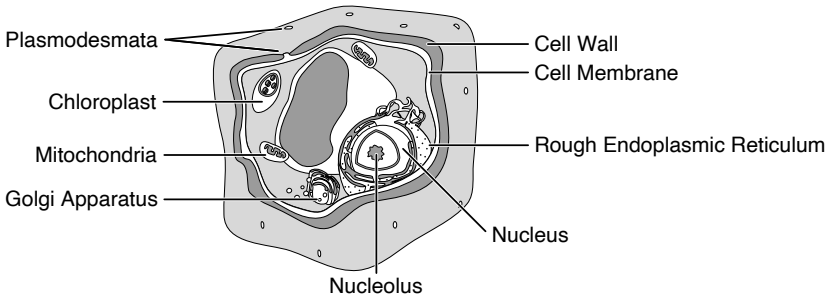
SYMBOL LEGEND

- ● = Acoelomate
- ◉ = Pseudocoelomate
- ◎ = Coelomate
- ⁞⁞⁞ = Bilateral Symmetry
- ✿ = Radial Symmetry
- ▬ = Asymmetrical
- ◆ = Parazoa (No Tissues)
- ◆ = Diploblast (2 Layers)
- ◆ = Triploblast (3 Layers)
- P = Protostome
- D = Deuterostome
- N = Neither

CHAPTER 16 | **PLANT PHYSIOLOGY**

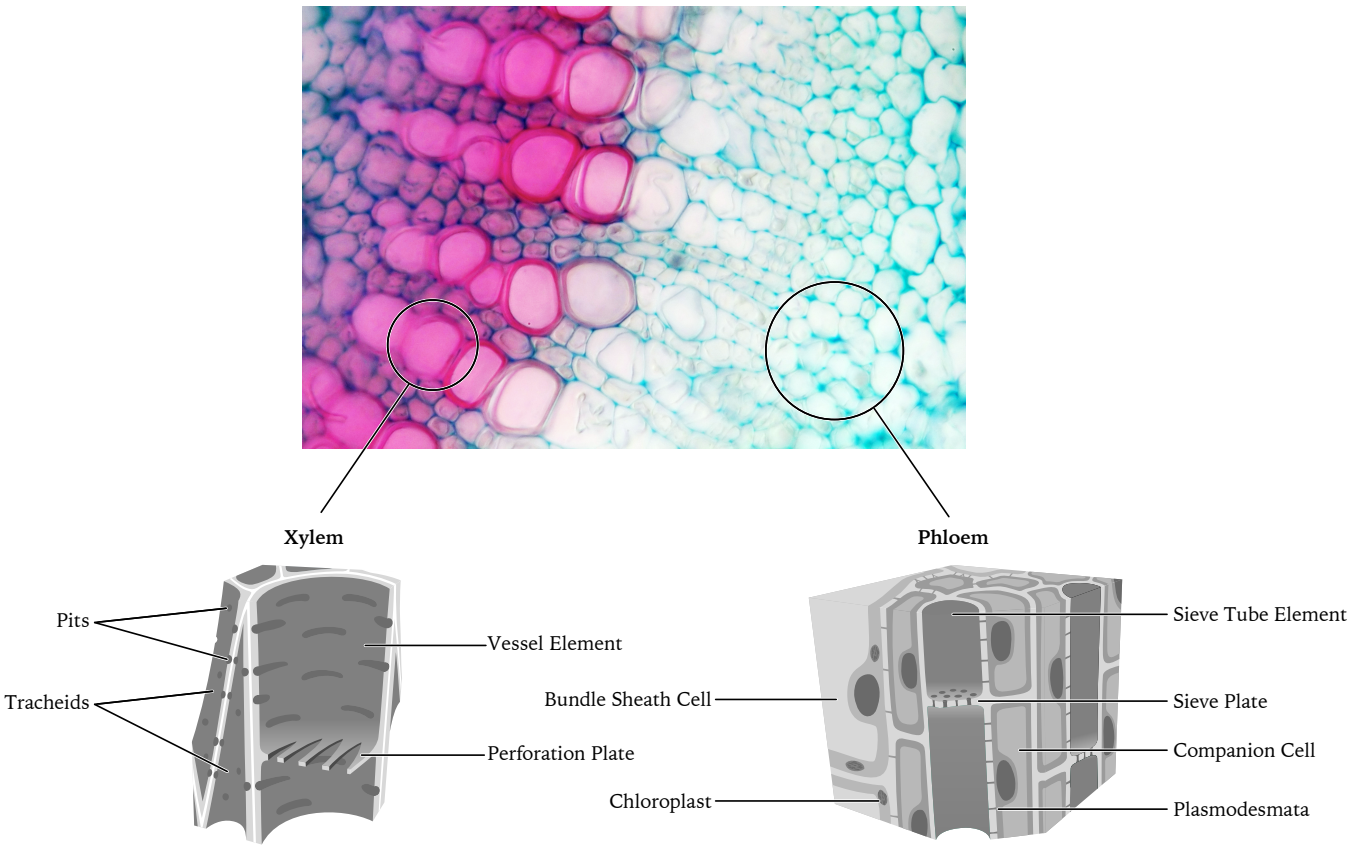
PLANT CELLS ☆ HIGH-YIELD

- Only the cellular components that differ from animal cells are discussed in this section. For a complete list of organelles, see Chapter 4
- ***Plastid*** – A double membrane-bound organelle that manufactures and stores food. It is an organelle unique to plants and may differentiate into several specialized forms:
  - ***Chloroplast*** – Plastids that photosynthesize
  - ***Chromoplast*** – Coloured plastids for pigment synthesis and storage
  - ***Amyloplast*** – Plastids that store starch
- ***Vacuole*** – A membrane-bound organelle that regulates turgor pressure. Plant vacuoles are much larger than animal vacuoles
- ***Cell Wall*** – A cellulose-containing border that gives a plant structure. There are two types:
  - ***Primary Cell Wall*** – A thin, flexible and extendable layer composed of cellulose, hemicellulose, and pectin
  - ***Secondary Cell Wall*** – A thicker cellulose layer formed between the primary cell wall and plasma membrane. Wood and cork are very rigid due to their secondary cell walls



PLANT TISSUES ☆ HIGH-YIELD

- ***Dermal Tissue*** – Forms the outer layer of plants
  - ***Epidermal Cells*** – Secrete wax, which forms the waterproof cuticle
  - ***Guard Cells*** – Found on the surface of the leaf. A pair of guard cells control the opening/closing of perforations called ***stomata***. The opening of stomata allows CO_2 to enter the leaf, at the cost of increased ***transpiration*** (evaporation of water from the leaves). The closing of stomata decreases transpiration but does not allow for gas exchange
  - ***Trichrome Cells*** – Specialized outgrowths that function for defence (i.e. stinging nettles) or predation (i.e. sticky trichomes of carnivorous plants)
- ***Vascular Tissue*** – Only found in vascular plants (lycophytes, pterophytes, angiosperms, and gymnosperms)
  - ***Xylem*** – Specialized for water and mineral transport. Consists of two types of cells that are dead at maturity:
    - ***Tracheids*** – Long, thin cells with tapered ends. Water flows through holes in the secondary cell wall called ***pits***
    - ***Vessel Elements*** – Wider and shorter cells with flat ends. Water flows through holes in both the primary and secondary cell wall called ***perforation plates***
  - ***Phloem*** – Specialized for sugar transport and consists of three types of cells that are alive at maturity:
    - ***Sieve Tube Elements*** – Anuclear cells that form hollow tubes. They contain no ribosome, vacuole, or cytoskeleton, and are metabolically dependent on ***companion cells***. The perforated end walls between sieve tube elements are called ***sieve plates***
    - ***Companion Cells*** – Connected to sieve tube elements via holes in the cell wall called ***plasmodesmata***
  - A ***vascular bundle*** consists of xylem and phloem. The xylem is always closer to the centre of the stem/root



- ***Meristematic Tissue*** – Undifferentiated cells found in areas where plant growth occur. They develop into specialized cells and tissues after receiving a growth stimulus, similar to stem cells in animals
- ***Ground Tissue*** – any tissue that is not dermal or vascular
  - ***Parenchyma*** – Cells with a thin primary cell wall that perform plant metabolism
  - ***Collenchyma*** – Cells with a thick primary cell wall that support developing shoots
  - ***Sclerenchyma*** – Extremely thick and rigid cells that contain ***lignin*** in their secondary cell walls. They are responsible for the strength of wood and are dead at maturity

MONOCOTS VS DICOTS ☆ HIGH-YIELD

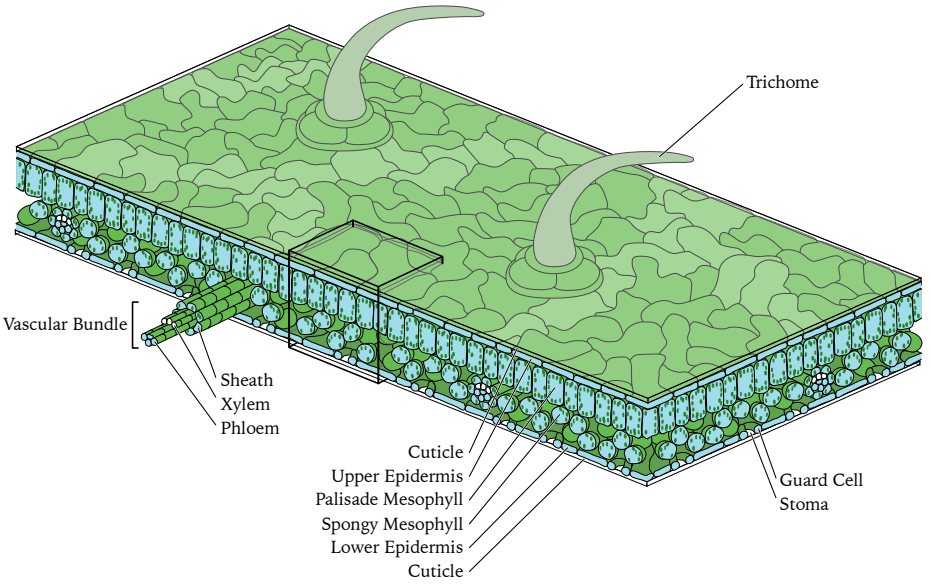
- Seed-producing plants (angiosperms) can be classified based on whether or not their seed contains one or two ***cotyledons***. A cotyledon is an embryonic leaf that is the first to sprout and may also serve as a nutrient storage organ prior to germination. Plants with one cotyledon are called ***monocots***, while those with two are called ***dicots***. Monocots and dicots have anatomical differences, which are summarized below:

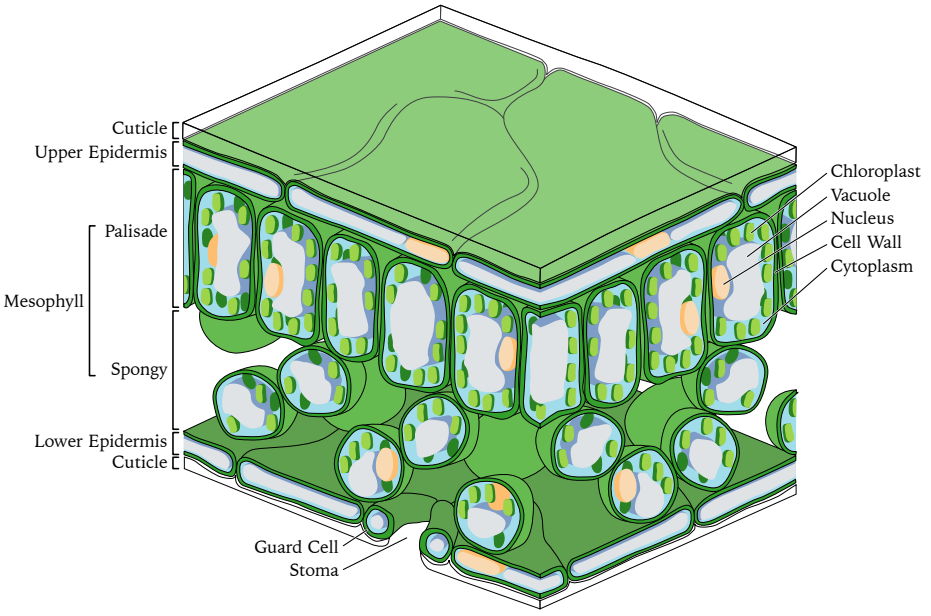
Anatomical Feature	Monocots	Dicots
Embryo	 One cotyledon	 Two cotyledons
Leaf Venation	 Parallel veins	 Branching veins
Stem Vasculature	 Arranged in a ring	 Scattered
Root System	 Fibrous	 Taproot
Flower Petals	 Multiples of three	 Multiples of four or five

MNEMONIC Remember the anatomical features of dicots with the "five Ds": Dual Cotyledons, Divergent Leaf Veins, Donut-shaped Vascular Bundles, Roots that go Straight Down, and Quadruple or Quintuple Petals

LEAF ANATOMY

- Leaves are the site of photosynthesis and consist of the following layers:
  - ***Waxy Cuticle*** – A hydrophobic layer that protects the upper and lower epidermal cells. It also reduces water loss from the leaf due to transpiration
  - ***Upper Epidermis*** – Consist of standard epidermal cells and specialized trichrome cells for protection
  - ***Palisade Mesophyll*** – Consist of tightly-packed, vertically elongated parenchymal cells. These cells contain the highest number of chloroplasts and are the main contributor to photosynthesis
  - ***Spongy Mesophyll*** – Contains loosely-packed, irregular parenchymal cells. This layer contains many air pockets, allowing a high surface area for gas exchange with the environment. This layer also contains vascular bundles, which consist of the xylem and phloem surrounded by bundle sheath cells for protection
  - ***Lower Epidermis*** – Consist of epidermal cells and guard cells surrounding stomata
- Deciduous trees shed their leaves during the winter in a process called ***abscission***, while coniferous trees keep their leaves year-round

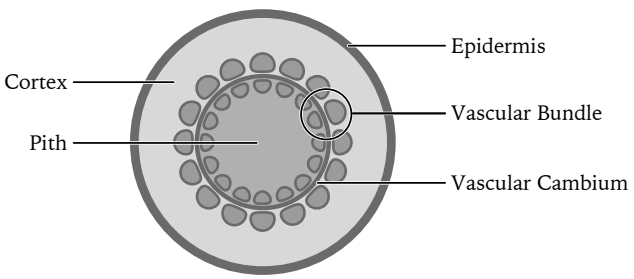




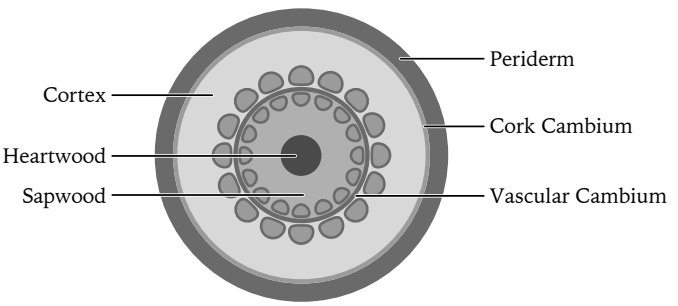
STEM ANATOMY

- Stems allow plants to have vertical structure and transport substances between the leaves and roots
- ***Herbaceous plants*** have stems that do not contain a bark, while ***woody plants*** do have stems with bark
- Herbaceous stems are composed of the following layers:
  - ***Epidermis*** – Almost identical to leaf epidermis, except the epidermis of woody plants do not contain chloroplasts can cannot perform photosynthesis
  - ***Cortex*** – Ground tissue that is superficial to the vascular tissue layer. Composed of parenchymal and/or collenchyma cells that function in carbohydrate storage
  - ***Vascular Tissue*** – This layer only exists in dicots, and is composed of vascular bundles arranged in a ring. In monocots, the vascular bundles are scattered and thus no layer is formed. The ***vascular cambium*** is a layer of meristematic cells between the xylem and phloem that adds new layers of vascular tissue to increase the stem's thickness
  - ***Pith*** – Ground tissue that is deep to the vascular tissue layer. Composed of spongy parenchymal cells that function in the storage and transport of substances
- Woody stems have the following additional layers:
  - ***Periderm*** – Replaces the epidermal layer found in herbaceous stems. Consists of dead, structural sclerenchyma cells. A layer of meristematic cells called the ***cork cambium*** coverts tissue from the vascular cambium into periderm
  - ***Sapwood*** – Consists of young xylem tissue produced by the vascular cambium. The xylem are still functional, transporting water and minerals throughout the stem
  - ***Heartwood*** – Consists of old xylem tissue that have filled up with oil and resin. The xylem are no longer functional and purely structural. This layer is found at the centre of the stem and is very rigid

Herbaceous Dicot Stem

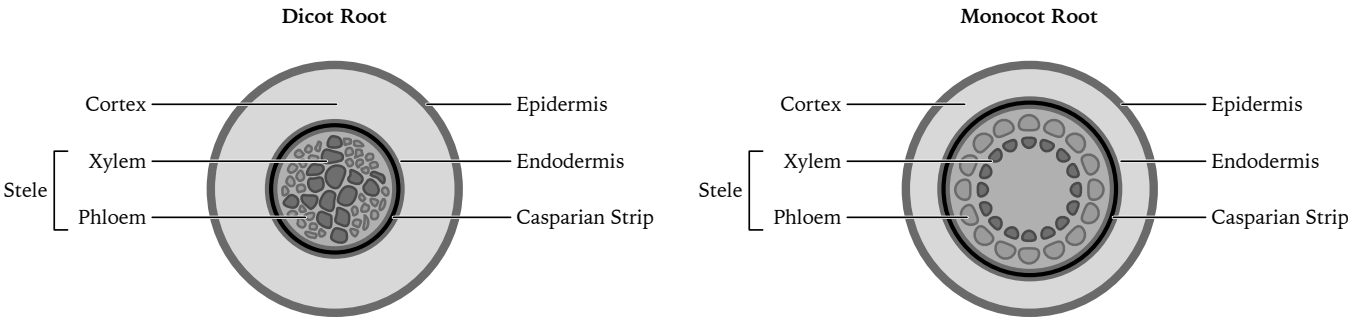


Woody Dicot Stem



ROOT ANATOMY

- Roots allow plants to absorb water/minerals and store carbohydrates. They are consist of the following layers:
  - ***Epidermis*** – Similar to stem epidermis, except the presence of ***root hairs*** dramatically increases the surface area available for water/mineral absorption. The ***apical meristem*** is located at the tip of each root, and produces new cells during elongation. The ***root cap*** is a covering that protects the apical meristem
  - ***Cortex*** – Consists of parenchymal cells that store carbohydrates and help transport water/minerals
  - ***Endodermis*** – Consists of cells wrapped with a hydrophobic substance, forming a continuous barrier called the ***Casparian strip***. This forces all substances to pass through the endodermal cells, instead of between them. As a result, the plant is able to selectively transport substances to the vascular tissue and prevent backflow
  - ***Vascular Cylinder/Stele*** – Consist of vascular tissue. In dicots, xylem tissue is at the centre, surrounded by phloem. In monocots, the xylem and phloem form a ring around parenchymal cells at the centre

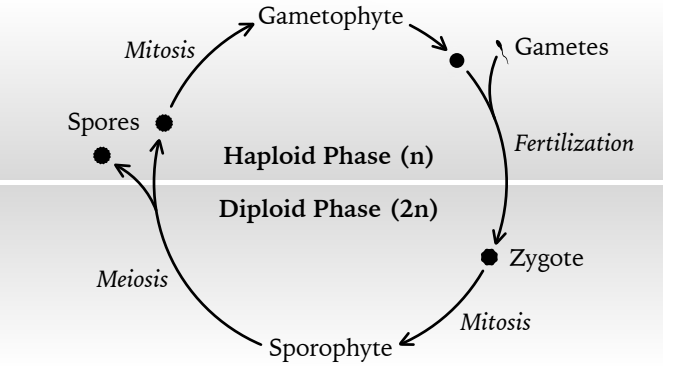


TRANSPORT IN VASCULAR PLANTS

- Water and minerals enter the roots via osmosis and are transported to the vascular tissue via two pathways:
  - ***Apoplastic Pathway*** – Flow through the cell walls. The Casparian strip interrupts this pathway
  - ***Symplastic Pathway*** – Flow through the cell cytoplasm and plasmodesmata
- Once water reaches the vascular tissue, it is "pulled" and "pushed" up to the leaves via these forces:
  - ***Root Pressure*** – Caused by water flowing from the root cortex and into the stele. This force "pushes" water upwards, and may lead to excess fluids being exuded from the leaves (***guttation***)
  - ***Capillary Action*** – Water's adhesive properties allows binding between water molecules and the xylem walls, causing water to climb upwards
  - ***Cohesion-Tension Theory*** – Transpiration creates negative pressure in leaf vasculature, causing water to move upwards due to its cohesive properties. This ***transpirational pull*** results in a "column" of water molecules drawing each other upwards, called ***bulk flow***
- Unlike water, carbohydrates can be transported both up and down the plant. There are two forces of carbohydrate flow:
  - ***Source and Sink Theory*** – Carbohydrates flow from regions of high concentration (source) to regions of lower concentration (sink). The location of sources and sinks changes according to the season. In winter, the leaves are no longer photosynthesizing, so they are the sink. The roots are full of stored carbohydrates, so they are the source. In the summer, the leaves start producing glucose, so they become the source. Likewise, the roots have relatively lower concentrations of carbohydrates, so the become the sink
  - ***Pressure Flow Hypothesis*** – Increased sugar concentrations in phloem cells attract water via osmosis, creating a pressure gradient that pushes the sugar towards a carbohydrate sink

ALTERNATION OF GENERATIONS

- Plants follow a reproductive cycle that alternates every generation between two phases: a haploid ***gametophyte*** and a diploid ***sporophyte***
- Bryophytes/nonvascular plants (liverworts, hornworts, mosses) are ***gametophyte-dominant***, meaning the haploid gametophytes are much larger than the diploid sporophytes
- Vascular plants (lycophytes, pterophytes, angiosperms, gymnosperms) are ***sporophyte-dominant***, meaning the diploid sporophytes are much larger than the microscopic haploid gametophytes (pollen and embryo sac)

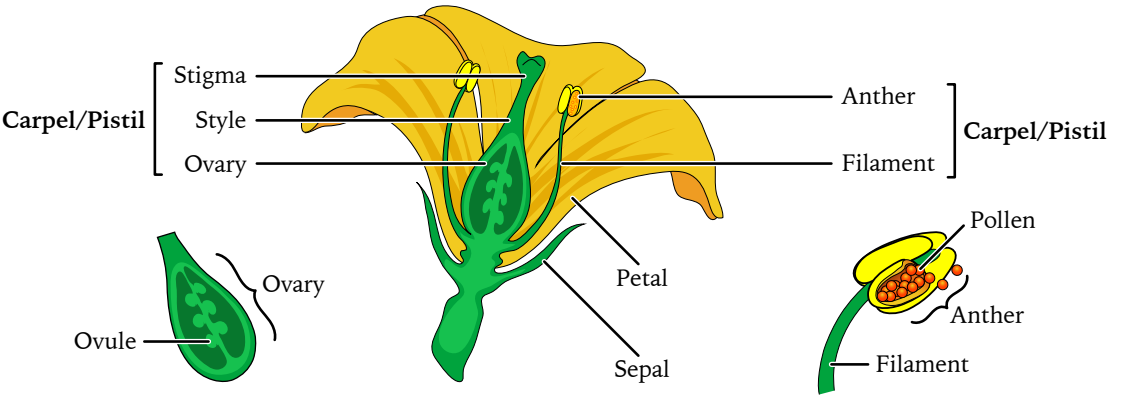


POLLINATION AND FERTILIZATION ☆ HIGH-YIELD

- Angiosperms have developed three unique traits:
  - ***Flowers*** – Special reproductive organs that attract insects and other pollinating animals
  - ***Fruits*** – Seed-bearing structures developed from the ovary after fertilization
  - ***Double Fertilization*** – Fusion of one sperm with two polar nuclei to form a triploid cell

  MNEMONIC Remember the "three Fs" of angiosperms: Flowers, Fruits, and Double Fertilization

- Before we discuss the mechanism of plant fertilization, lets review the anatomy of flowers:
  - The ***stamen*** is the male reproductive structure, which consists of the ***anther*** and the ***filament*** (a vertical shaft). The anther contains ***microsporangia***, which produce ***pollen***, the male gametophyte
  - The ***carpel/pistil*** is the female reproductive structure, which consists of the ***ovary***, the ***style*** (a vertical shaft), and the ***stigma*** (an opening). The ovary contains ***ovules***, which each produce a single ***embryo sac***, the female gametophyte



  - The male and female gametophytes can meet through self pollination or cross pollination:
    - ***Self Pollination*** – Pollen meets embryo sac via the anther rubbing against the carpel on the same plant
    - ***Cross Pollination*** – Insects visit flowers for nectar and carries pollen from one plant to another

- Fertilization begins when a male gametophyte (pollen grain) lands on the stigma:
  1. A ***pollen tube*** begins to grow from the stigma down into the style, towards the ovary. It contains two sperm cells. This process is called ***pollen germination***
  2. In the ovary, a diploid ***megasporangium*** cell divides by meiosis and produces four haploid cells. Only one survives to become a ***megaspore***
  3. The megaspore divides by mitosis three times to produce an ***embryo sac***, the multicellular female gametophyte
  4. The pollen tube enters the embryo sac via the ***micropyle***
  5. One sperm fertilizes the egg, forming a diploid ***zygote***. The second sperm fuses nuclei with two ***polar nuclei***, forming a triploid cell. This is called ***double fertilization***
  6. The triploid nucleus divides by mitosis to produce a seed's ***endosperm***, which provides nutrients for the embryo prior to germination

THE SEED

- Seed formation is unique to angiosperms and gymnosperms
- In angiosperms, the seeds are enclosed in ***fruit***, which can be consumed and dispersed by animals
- In gymnosperms, the seeds are unenclosed and carried openly on ***cones***. Their dispersal is dependent mostly on non-biotic factors (wind, rain, etc.)
- A generalized seed consists of the following components:
  - ***Seed Coat*** – Hard, hydrophobic layer that protects the embryo from water loss and mechanical stress
  - ***Endosperm*** – Stores carbohydrates, lipids, and proteins to feed the developing embryo
  - ***Embryo*** – Consists of the following structures:
    - ***Cotyledon(s)*** – Embryonic leaves. Monocots have one while dicots have two
    - ***Epicotyl*** – Parts of the embryonic shoot that are above the cotyledons. The plant's first true leaves are derived from a region of the epicotyl called the ***plumule***
    - ***Hypocotyl*** – Parts of the embryonic shoot that are below the cotyledons
    - ***Radicle*** – Embryonic precursor to the roots

GERMINATION AND GROWTH

- Seeds are usually dormant until environmental conditions (temperature, humidity, sunlight, etc) are optimal for germination. There are two types of germination patterns:
  - ***Epigeal Germination*** – Hypocotyl elongates into a bent-over hook, pulling the cotyledons upwards through the soil. Once the surface is reached, the shoot straightens and undergoes primary growth
  - ***Hypogeal Germination*** – Epicotyl elongates into a hook, pulling itself upwards through the soil. The cotyledons remain underground and eventually decompose
- After the initial germination of a seed, the plant undergoes two types of growth:
  - ***Primary Growth*** – Increase in length of a shoot or root via cell division at ***apical meristems***. The apical meristem is broken down into three zones:
    - ***Zone of Cell Division*** – Region of active meristematic cell division
    - ***Zone of Elongation*** – Most lengthening of the shoot or root occurs in this zone
    - ***Zone of Differentiation/Maturation*** – Cells specialize into epidermal, vascular, or parenchymal cells. Root hairs also begin to develop in this zone
  - ***Secondary Growth*** – Increase in the circumference of a root or shoot via cell division at ***lateral meristems***. There are two types of lateral meristem:
    - ***Vascular Cambium*** – Produces ***secondary xylem*** in some plants, forming wood
    - ***Cork Cambium*** – Produces ***periderm*** in some plants, forming bark
- ***Allelopathy*** is when a plant produces chemicals that influence the germination, growth, and survival of other plants nearby. Allopathy can be negative (hinders other plants) or positive (helps other plants)

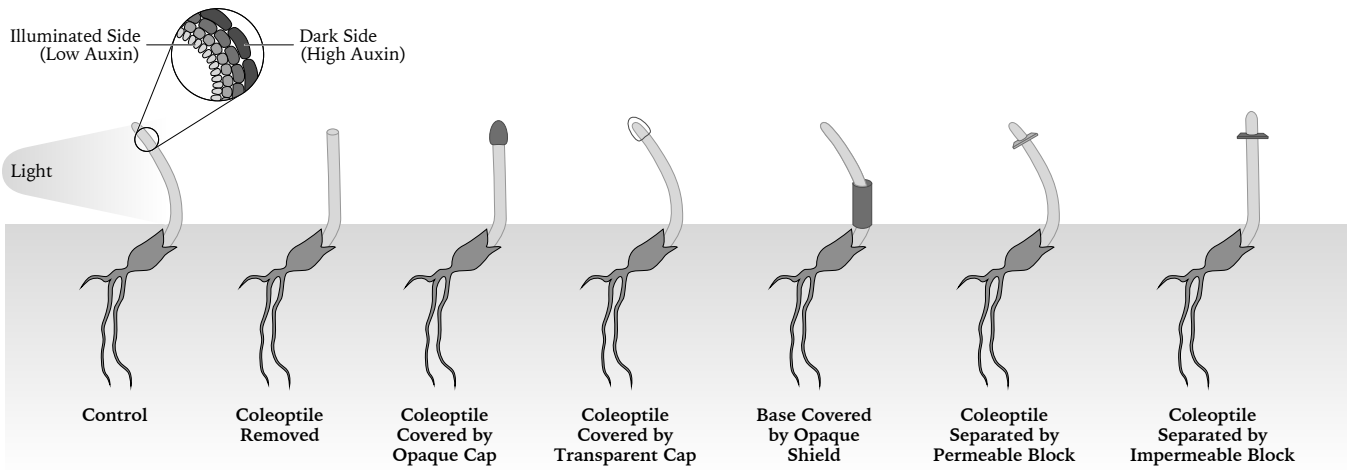
HORMONES

- ***Gibberellin*** – Promotes germination, shoot elongation, flowering, and fruit development
- ***Auxin*** – Promotes cell elongation and is responsible for ***phototropism***
- ***Cytokinin*** – Promote cell division in the roots and shoots. It also slows down leaf death and ***abscission***. Cytokinin is often used by farmers to increase crop yields
- ***Ethylene*** – A gas that promotes the ripening of fruit. Most consumer fruit is actually harvested prematurely and exposed to ethylene after being shipped
- ***Abscisic Acid*** – Inhibits growth and promotes stomatal closure in response to drought. It also promotes the dormancy of seeds and abscission of leaves

	Gibberellin	Auxin	Cytokinin	Ethylene	Abscisic Acid
Germination	✔	⊗	⊗	⊗	⊗
Cell Growth	✔	✔	✔	⊗	⊗
Flowering	✔	✔	✔	✔	⊗
Fruit Development	✔	✔	✔	✔	⊗
Abscission	⊗	⊗	⊗	✔	✔
Seed Dormancy	⊗	⊗	⊗	⊗	✔

PHOTOTROPISM

- ***Phototropism*** is the growth or bending of plants towards a source of light
- This response is mediated by auxin, which is produced at the ***coleoptile*** (shoot tip) in response to blue light. Auxin is transported from the coleoptile to only regions of the shoot that are exposed to darkness. Auxin then causes cell elongation, causing bending of the shoot
- Early experiments performed by Darwin showed that the coleoptile was the structure responsible for phototropism, not the stem. Experiments by other scientists have also demonstrated that the chemical responsible (auxin) was water-soluble and able to penetrate permeable substances such as agar:



CHAPTER 17 | **THE RESPIRATORY SYSTEM**

- There are two main forms of respiration:
  - ***External Respiration*** – Exchange of oxygen and CO_2 between alveoli and blood
  - ***Internal Respiration*** – Exchange of oxygen and CO_2 between blood and cells
- Animals require oxygen for ***cellular respiration***, the metabolic reactions that produce ATP

GAS EXCHANGE SYSTEMS

- There are four main gas exchange systems in animals:
  - ***Simple Diffusion***
    - This system is used in animals small enough that the simple diffusion of air in the environment is enough to satisfy their cell's oxygen demand
    - Most of the cells must be close enough to the outside world for diffusion to occur at a sufficient rate. This necessitates a high surface area to volume ratio and thus a smaller body size
    - Gasses must first dissolve in a liquid to diffuse across a membrane, so animals using this system must also live in a moist environment (ex: flatworms, small amphibians)
    - Some animals may also have a gas distribution system, such as a closed circulatory system (ex: segmented worms)
  - ***Gills***
    - Gills are evaginated (external) structures that increase surface area for sufficient gas exchange
    - Used in large aquatic animals that have a relatively low surface area to volume ratio and require more oxygen than simple diffusion provides
    - Water flows past the gills, which contain circulatory fluid that absorb oxygen and release CO_2. Gills use ***countercurrent flow***, in which the water and circulatory fluid flow in opposite directions to maximize gas exchange
    - Gills can be internal (protected) or external (unprotected). In fish, the gills are further protected by a bony cover called the ***operculum***
  - ***Tracheae***
    - Invaginated (internal) structures that consist of holes in the exoskeleton called ***spiracles***, which extend as chitinous tubes into the body, ending in air sacs
    - Used in large terrestrial animals (mostly insects) with a low surface area to volume ratio
    - Air is "inhaled" into the trachea via muscle movements and distributed, usually through an open circulatory system
  - ***Lungs***
    - Invaginated (internal) structures that consist of trachea, bronchioles, and multiple alveoli that interface with the circulatory system
    - Used in large terrestrial animals with a low surface area to volume ratio
    - Arachnids have special ***book lungs***, which consist of flat and stacked membranes
    - Birds have special ***air sacs***, which serve as reservoirs, allowing the air to be re-circulated through the lungs upon exhalation. This is called ***double breathing***. Their lungs also use ***cross-current flow*** gas exchange, in which blood is oxygenated perpendicular to the direction of airflow

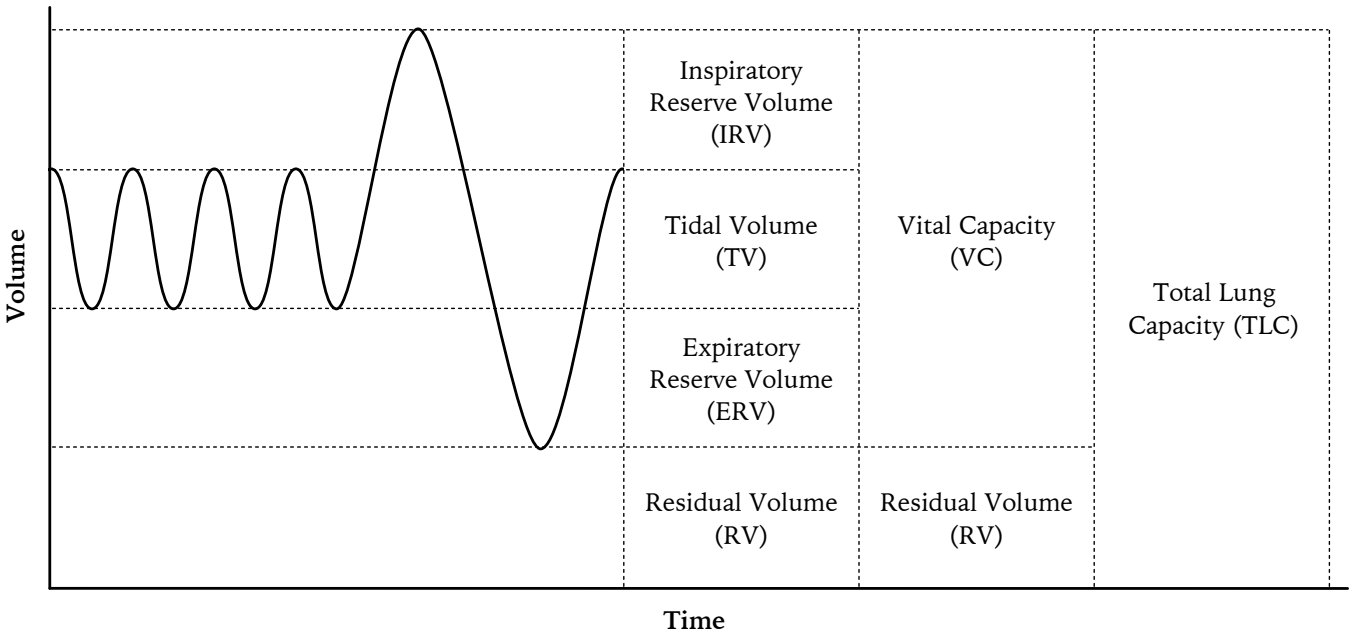
VENTILATION ☆ HIGH-YIELD

- Ventilation is the movement of air in and out of the lungs (breathing) to facilitate gas exchange:
  - ***Inhalation***
    - The ***diaphragm muscle*** (located underneath the lung) contracts downwards, creating negative pressure inside the thoracic cavity
    - Simultaneously, the ***external intercostal muscles*** (located between the ribs) contract upwards and outwards, opening up the thoracic cavity
    - The combined effect of these two muscles causes external air to travel down a negative pressure gradient and into the lungs
  - ***Exhalation***
    - The diaphragm muscle and external intercostal muscles relax, reducing the vacuum created during inhalation
    - During vigorous exercise or coughing, the ***internal intercostal muscles*** also contract, resulting in a more forceful exhalation

MNEMONIC "Ex for In and In for Ex" → External Intercostals for Inhalation and Internal Intercostals for Exhalation

LUNG VOLUMES

- Lung volumes describe the amount of air in the lungs at different points in the respiratory cycle:
  - ***Tidal Volume*** – The change in lung volume at rest (normal inhalation and exhalation)
  - ***Inspiratory Reserve Volume*** – The volume that can be inhaled on top of a normal inhalation
  - ***Expiratory Reserve Volume*** – The volume that can be exhaled on top of a normal exhalation
  - ***Residual Volume*** – The volume remaining in lungs after maximum exhalation. This prevents lung collapse and cannot be measured with a spirometer
  - ***Vital Lung Capacity*** – Everything added together, except residual volume
  - ***Total Lung Capacity*** – Everything added together



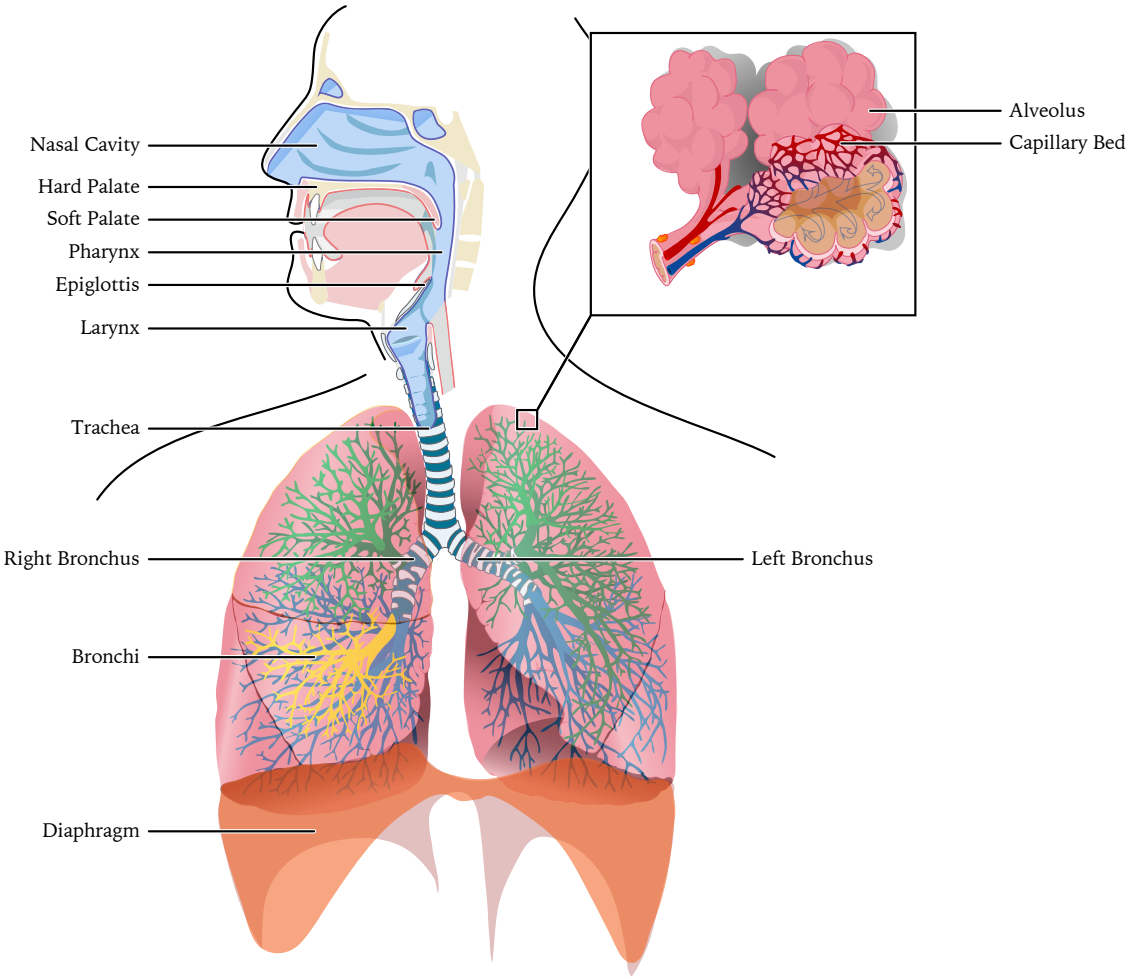
- ***Compliance*** is defined as the change in lung volume divided by the change in pressure. This can be described as the "stretchability" of lungs
- ***Surfactant*** is an amphipathic molecule that decreases surface tension, allowing the lung to inflate more easily and thus increasing compliance. ***Type II pneumocytes*** secrete surfactant

RESPIRATION ☆ HIGH-YIELD

- Respiration is the exchange of gasses between cells and the environment
- Air enters the body through the ***nasal cavity***, and then passes through the ***pharynx***, ***larynx*** (voice-box), and into the ***trachea***. The ***epiglottis*** is a flap that moves over the entrance to the trachea during inhalation to prevent aspiration of food. The trachea branches into two ***bronchi***, then multiple ***bronchioles***, before ending in an ***alveolus***. The walls of alveoli are made of ***type I pneumocytes***, which are extremely thin and allow respiration or gas exchange. Oxygen diffuses down its concentration gradient across the alveolar and capillary membrane into the blood, and CO_2 diffuses in the opposite direction.
- Four oxygen molecules are carried per red blood cell via a protein called ***hemoglobin***, which contains a porphyrin ring and Fe^{2+} as cofactors. At O_2-poor and CO_2-rich tissues, the affinity of hemoglobin for oxygen is lower, and therefore the oxygen is released into interstitial fluid. This shift in hemoglobin's affinity for oxygen is called the ***Bohr Effect***. The same decrease in affinity also occurs at high temperatures
- A very small percentage of CO_2 travels in the blood in its dissolved state or bound to hemoglobin. Instead, the majority of CO_2 travels as bicarbonate ions (HCO_3^-). This is called the ***bicarbonate buffering system***. An enzyme called ***carbonic anhydrase (CA)*** in red blood cells convert CO_2 into carbonic acid, which forms an equilibrium with bicarbonate molecules and protons:

$$CO_2 + H_2O \overset{CA}{\rightleftharpoons} H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

- Notice that an increase in CO_2 levels causes the equilibrium to shift to the right, resulting in increased H^+ levels. Thus hypoxia is associated with low blood pH



REGULATION

- The respiratory centre in the ***medulla oblongata*** regulates breathing depth and rate based on information from these sources:
  - ***Chemoreceptors***
    - ***Central Chemoreceptors*** – Cells of the medulla oblongata which monitor CO_2 levels and blood pH
    - ***Peripheral Chemoreceptors*** – Cells of the aorta and carotid arteries which monitor CO_2 levels, blood pH, and O_2 levels
  - ***Mechanoreceptors*** – Stretch and baroreceptors found in the respiratory tract
  - ***Hypothalamus*** – This allows our emotions to influence our breathing
  - ***Cerebrum*** – This allows us to voluntarily control our breathing

PATHOLOGIES

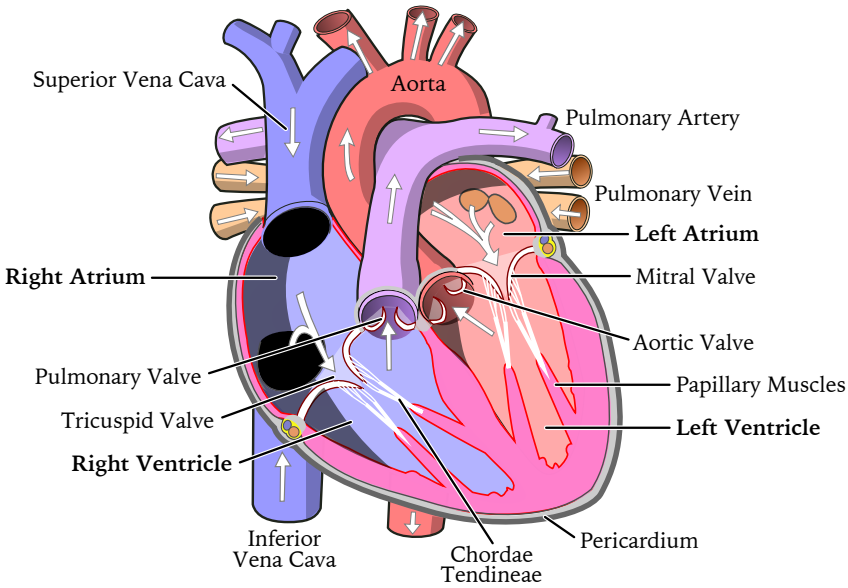
- Super short, concise one sentence explanations about major pathologies
- ***Obstructive Lung Disease*** – Decreased ability to exhale air and empty the lungs
  - ***Emphysema*** – Damage to the alveoli
  - ***Chronic bronchitis*** – Irritated and swollen bronchial tubes
  - ***Chronic obstructive pulmonary disease (COPD)*** – A combination of emphysema and chronic bronchitis
  - ***Asthma*** – Acute swelling of the airways
  - ***Cystic fibrosis*** – Defective chloride ion transporter, causing thickened respiratory mucus
- ***Restrictive Lung Disease*** – Decreased ability to inhale air and expand the lungs. Includes interstitial lung disease, sarcoidosis, obesity, and muscular dystrophy
- ***Respiratory Acidosis*** – Decreased blood pH (more acidic) due to a buildup of CO_2
- ***Respiratory Alkalosis*** – Increased blood pH (more basic) due to low concentrations of CO_2

CHAPTER 18 | **THE CIRCULATORY SYSTEM**

- The circulatory system is responsible for delivering oxygen, metabolic waste, hormones, immune cells, and thermal energy throughout the body
- All circulatory systems have three common features:
  - ***Fluid*** – Can be blood (as in mammals) or hemolymph (as in arthropods)
  - ***Vessels*** – Arteries, veins, capillaries
  - ***Pump*** – The heart, which can have one to four chambers
- There are two major classifications of circulatory systems:
  - ***Open Circulatory Systems***
    - This system is found in arthropods
    - Circulating hemolymph is pumped through vessels directly into an internal body cavity called a ***hemocoel***, where it bathes the organs and gas exchange takes place
    - The hemolymph returns to the heart though openings called ***ostia***
  - ***Closed Circulatory Systems***
    - This system is found in vertebrates and annelids (segmented worms)
    - Circulating blood is pumped through vessels into capillaries, where gas exchange takes place. Thus, the blood is isolated from interstitial fluid and lymph

HUMAN CARDIAC ANATOMY ☆ HIGH-YIELD

- Blood flows through the heart in the following order:
  - ***Right Atrium***
    - Deoxygenated blood enters the right atrium from the superior and inferior ***vena cava***
    - Blood flows into the right ventricle through the ***tricuspid valve***
  - ***Right Ventricle***
    - Contains thicker walls than right atrium, since it must pump blood to the lungs
    - Deoxygenated blood flows through the ***pulmonary valve***, then enters the lungs via two ***pulmonary arteries***
  - ***Left Atrium***
    - Oxygenated blood flows from the lungs through four pulmonary veins, then enters the left atrium
    - Blood flows into the left ventricle through the ***bicuspid/mitral valve***
  - ***Left Ventricle***
    - Contains the thickest walls, since it must pump blood to the entire body
    - Oxygenated blood leaves the heart through the ***aortic valve***, and travels into the ***aorta***
- The stretch of vessels from right ventricle to the left atrium is called the ***pulmonary circuit***, while the stretch from left ventricle to the right atrium is called the ***systemic circuit***
- The pulmonary and aortic valves are called ***semilunar valves***, since they each have three flaps that are shaped like half-moon crescents
- The tricuspid and bicuspid/mitral valves are called ***atrioventricular (AV) valves***, since they are located between the atria and ventricles. Note that the tricuspid valve has three flaps while the bicuspid/mitral valve has only two. The AV valves are supported by ***chordae tendineae*** and ***papillary muscles***, which pull the valves shut to prevent back flow



HUMAN CARDIAC CYCLE ☆ HIGH-YIELD

- The cardiac cycle describes the rhythmic contraction of the heart, which is self-sustaining and can function completely independently from the central nervous system if necessary
- Contractions are generated via the following mechanism:
  - The ***sinoatrial (SA) node*** is located in the right atrium and spontaneously generates an action potential at around 100 bpm
  - This action potential spreads and reaches the left atrium through a path of highly conductive cells called ***Bachmann's bundle***. This results in the simultaneous contraction of the right and left atria
  - Next, the action potential reaches the ***atrioventricular (AV) node***, which has a lower conduction velocity than Bachmann's bundle. Therefore, the action potential slows down such that the ventricles contract after the atria, and not at the same time
  - Finally, the action potential travels through the ***bundle of His*** (which bifurcates into right and left bundles) and then into the ***Purkinje fibres***, which spread the action potential into the right and left ventricles
- There are two main phases of the cardiac cycle:
  - ***Systole*** – Ventricular contraction during which blood is pumped into the aorta and pulmonary arteries, and blood pressure is at its maximum. The AV valves are closed and semilunar valves are open.
  - ***Diastole*** – Atrial contraction during which blood is pumped into the right atrium and pulmonary veins, and blood pressure is at its minimum. The AV vales are open and semilunar valves are closed
- The closing of the AV valves at the beginning of systole causes the "lub" sound of a heartbeat. The closing of the semilunar valves at the beginning of diastole cause the "dub" part
- The flow of blood through arteries and capillaries is due to the hydrostatic pressure generated by the heart, which gradually decreases as blood approaches the veins. The flow of blood through veins is due to skeletal muscle contractions, which push the blood through one-way valves back towards the heart
- ***Cardiac output*** is the total volume of blood pumped by the left ventricle per minute. It is dependent on heart rate (beats per minute) and stroke volume (amount of blood pumped per contraction):

$$\text{Cardiac Output} = \text{Stroke Volume} \times \text{Heart Rate}$$

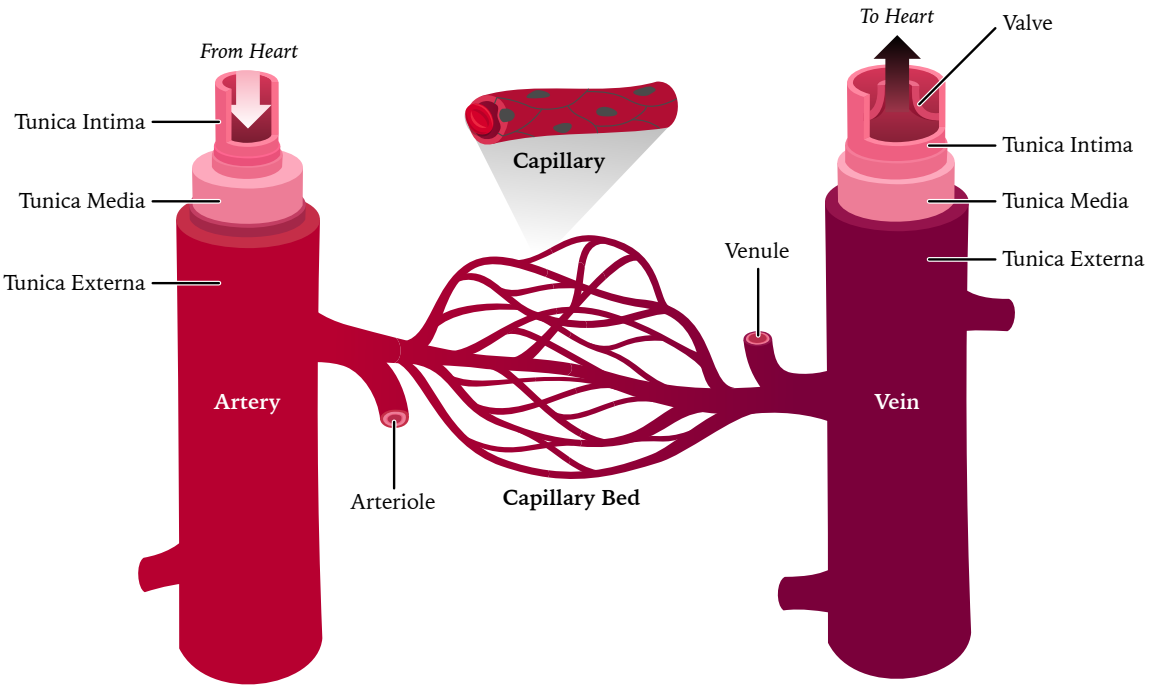
BLOOD

- Blood is considered to be a type of connective tissue, and is composed of:
  - ***Erythrocytes/Red Blood Cells***
    - Anuclear (no nucleus), biconcave cells that transport oxygen
    - Produced in the bone marrow in a process called ***erythropoiesis*** and released into the circulation where they mature (decrease size, lose nucleus, and produce more hemoglobin)
    - When centrifuged, red blood cells appear clumped together near the bottom of the tube as ***hematocrit***
    - ***Bilirubin*** is a waste product of hemoglobin, and is removed from the blood stream by the liver and excreted in faeces as bile
  - ***Leukocytes/White Blood Cells***
    - Immune cells that work to destroy pathogens and infected/cancerous cells
    - When centrifuged, white blood cells appear in a layer called the ***buffy coat***, located in the middle of the tube below the plasma and above the hematocrit
  - ***Platelets***
    - Anuclear cytoplasmic fragments of ***megakaryocytes*** which aggregate when activated by ***thrombin*** or when collagen in a damaged vessel is exposed
    - Release coagulation factors which converts inactive ***fibrinogen*** into ***fibrin***, forming a blood clot. This process is called ***hemostasis***
    - When centrifuged, platelets appear near the middle of the tube in the buffy coat
  - ***Plasma***
    - The liquid component of blood that contains proteins, nutrients, hormones, and waste products
    - ***Albumin*** is a plasma protein synthesized in the liver and functions to maintain ***oncotic pressure*** within capillaries (also called colloid osmotic pressure)
- Red blood cells may have four different configurations of ***A*** and ***B surface antigens***, which are the basis for the four blood types. The *A* and *B* antigens are inherited and autosomal dominant. Giving a person the wrong blood type transfusion will result in an immune response against the foreign antigen:
  - ***AB Blood Type*** – *A* and *B* antigens both present. People with this blood type are considered the ***universal acceptor*** because they can accept all blood type transfusions
  - ***A Blood Type*** – Only *A* antigens present
  - ***B Blood Type*** – Only *B* antigens present
  - ***O Blood Type*** – Neither *A* or *B* antigens present. People with this blood type are considered the ***universal donor*** because they can donate to people of all blood types
- In addition to the *A* and *B* antigens, red blood cells may also have two different configurations of the ***Rhesus (Rh) factor*** surface antigen. Like *A* and *B* antigens, the Rh factor is also autosomal dominant and can elicit an immune response:
  - ***Rh Positive*** – Most common blood type
  - ***Rh Negative*** – Less common, can cause anemia in Rh positive infants with an Rh negative mother

	***AB* Blood**	***A* Blood**	***B* Blood**	***O* Blood**
Antibodies in Plasma	Anti-*A* & Anti-*B*	Anti-*B*	Anti-*A*	None
Antigens on Red Blood Cell	None	*A* Antigen	*B* Antigen	*A* & *B* Antigens
Compatible Donor Blood Types	*AB, A, B, O*	*A, O*	*B, O*	*O*

VESSELS

- Blood vessels carry blood to and from the heart in a closed circulatory system. They are composed of the following layers:
  - ***Tunica Intima*** – Consist of endothelial cells that allow blood to flow smoothly through the lumen
  - ***Tunica Media*** – Consists of smooth muscle that controls vasodilation and vasoconstriction
  - ***Tunica Externa*** – Consists of protective connective tissue that contain collagen and elastin
- ***Arteries*** are vessels that carry blood away from the heart, while ***veins*** carry blood towards the heart
- Most of the time, arteries carry oxygenated blood and veins carry deoxygenated blood. The only exceptions are in pulmonary and fetal circulation. The ***pulmonary*** and ***umbilical veins*** are the only veins that carry oxygenated blood, while the ***pulmonary artery*** is the only artery that carries deoxygenated blood
- Unlike arteries, veins contain valves that prevent back flow. Blood travels through veins via skeletal muscle contractions, called the ***skeletal muscle pump***
- ***Capillaries*** are the smallest blood vessels. Their walls are only one endothelial cell thick and consists of only the tunica intima layer. This allows the simple diffusion of gases and small non-polar molecules. Some capillaries contain holes called ***fenestrations***, allowing even more substances to diffuse across. Capillaries are often organized into a complex branching network called a ***capillary bed***
- A ***portal venous system*** describes a circuit in which blood travels through multiple capillary beds before returning to the heart. Examples include the hypophyseal portal system and hepatic portal system



PATHOLOGIES

- ***Tachycardia*** – Heart rate is abnormally fast
- ***Bradycardia*** – Heart rate is abnormally slow
- ***Fibrillation/Arrhythmia*** – Heart rate is irregular due to defects in the electrical conductive system
- ***Atherosclerosis*** – The narrowing of an artery due to the buildup of plaque
- ***Myocardial Infarction*** – An interruption of the flow of blood to the heart
- ***Anemia*** – Abnormally low concentrations of red blood cells
- ***Hemophilia*** – Inability to form blood clots

CHAPTER 19 | **THE LYMPHATIC SYSTEM**

- Unlike the circulatory system, the human lymphatic system is not a closed circuit. It consists of a network of ***blind-ended*** tubules, meaning they are open at one end

FUNCTIONS

- The lymphatic system has the following main functions:
    - **Drain excess interstitial fluid**
        - Lymphatic tubules begin at capillary beds and drain the excess interstitial fluid that is produced as blood leaks out of the vasculature due to excess hydrostatic pressure
        - The drained fluid is called ***lymph***, and is pumped by smooth muscle contractions and released back into systemic circulation via the subclavian vein
        - Like veins, lymphatic tubules have valves to prevent back flow
        - If the lymphatic system did not exist, blood volume would gradually decrease as all our plasma leaked into the interstitial space
    - **Mount immune defence**
        - Before the lymph is reintroduced into systemic circulation, it passes ***lymph nodes***, which contain B and T cells that can trigger the adaptive immune response
    - **Absorbs fat from food**
        - Fats in the small intestine interact with lipoproteins and form ***chylomicrons***, which are absorbed by lymph vessels called ***lacteals*** located within intestinal villi
        - The fats are released into the systemic circulation via the subclavian vein, and absorbed by tissues in the body at capillary beds

LYMPHATIC TISSUE

- ***Primary lymphatic tissue*** includes the thymus, spleen, and lymph nodes
    - **Thymus** – Location where T cells from the adaptive immune system mature
    - **Spleen** – Filters blood and houses immune cells for early detection of pathogens
    - **Lymph Nodes** – Collects lymph from lymphatic vessels and houses immune cells
- ***Secondary lymphatic tissue*** refers to ***MALT (mucosa-associated lymphoid tissue)***
    - MALT describes small, interspersed regions of lymphoid tissue in the tonsils, appendix, small intestine, thyroid, breast, lung, skin, any many other tissues
    - Regional MALT tissue is named after the tissue it resides in. For example, BALT stands for bronchus-associated lymphoid tissue

PATHOLOGIES

- ***Lymphoedema*** – Swelling (edema) of tissue due to the insufficient clearance of fluids by the lymphatic system

CHAPTER 20 | **THE IMMUNE SYSTEM**

TYPES OF IMMUNITY ☆ HIGH-YIELD

- Components of the immune system can be categorized in three different ways:
  - **Humoral vs Cell-Mediated**
    - Humoral immunity is mediated by molecules in bodily fluids such as antibodies and complement proteins. In contrast, cell-mediated immunity involves leukocytes (aka "white blood cells")
  - **Innate vs Adaptive**
    - Innate immunity describes the body's *non-specific* defences against pathogens, which does not require previous exposure to an antigen. Examples include:
      - Anatomic barriers (skin, cilia, blood-brain barrier, etc.)
      - Chemical or enzymatic defences (low pH of skin, lysozyme in tears, etc.)
      - Mutualistic skin microbiota outcompeting harmful bacteria
      - The complement system
      - The interferon response
      - The inflammatory response
      - Non-specific immune cells (granulocytes, NK cells)
    - Adaptive immunity describes the body's *specific* defences against pathogens, which is acquired after exposure to an antigen. The adaptive immune response increases with additional exposures. Examples include:
      - B cells, T cells, and antibodies
      - Professional antigen-presenting cells (B cells, macrophages, dendritic cells)
  - **Active vs Passive**
    - Active immunity results from an antigen triggering the adaptive immune system and antibodies being produced (i.e. infection or immunization). In contrast, passive immunity results from antibodies naturally or artificially acquired from another source (i.e. newborn infants acquiring antibodies via breast feeding, or an ebola patient getting injected with purified antibodies from another previously sick victim)

CELLS OF THE BLOOD

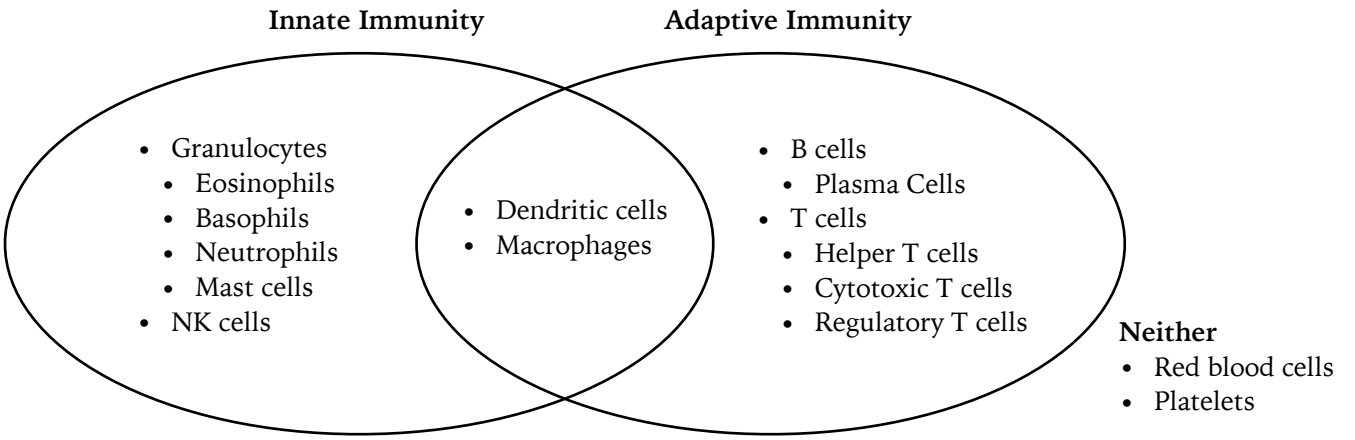
- ***Antigen Presenting Cells (APCs)*** – A cell that presents antigens on MHC I to cytotoxic (CD8+) T cells. All cells have MHC I, so all cells are APCs
- ***Professional Antigen Presenting Cells*** – A cell that presents antigens on MHC II to helper (CD4+) T cells. Includes B cells (most common), macrophages, and dendritic cells
- ***Leukocytes*** – A category of cells known as "white blood cells," that includes all lymphoid cells (B cells, T cells, NK cells) plus some myeloid cells (granulocyte cells and macrophages). All cells involved in the immune response are leukocytes

- ***Lymphocytes*** – A category describing cells that all originated from a common lymphoid progenitor during hematopoiesis. Includes B cells, T cells, and NK cells

  MNEMONIC All the cells with a letter in their name ("B", "T", "NK") are lymphoid

  - ***Natural Killer (NK) Cells*** – Cytotoxic lymphocytes that destroy virus-infected or cancerous cells via perforin (which forms pores in the cell membrane) and granzyme (which triggers apoptosis)
  - ***B Cells*** – Lymphocytes containing antibodies on the cell membrane that bind to antigen epitopes. Once bound, the B cell phagocytoses the antigen and presents a fragment on MHC II. A helper T cell binds and activates the B cell, which undergoes clonal expansion and differentiates into plasma cells and memory B cells. B cells mature in the bone marrow and are professional APCs
    - ***Plasma Cells*** – Produce high volumes of antibodies with variable regions that are complementary to the same epitope that initially activated the B cell. These antibodies hinder pathogen mobility, trigger opsonization (enhanced phagocytosis), and activate the complement system
    - ***Memory B Cells*** – Contain identical surface antibodies to the B cell that was initially activated. They serve as a "reserve" force of cells to mount a faster and stronger immune response incase the body is exposed to a pathogen with the same epitope in the future. This is the basis for immunological memory and the adaptive immunity
  - ***T Cells*** – Lymphocytes containing T cell receptors (TCRs) on the cell membrane. T cells mature in the thymus
    - ***Helper (CD4+) T Cells*** – Activated when its TCR binds with a professional APC's MHC II, an antigen, plus a CD28 co-stimulatory protein. Once activated, the helper T cell undergoes clonal expansion and differentiates into effector helper T cells
      - ***Effector Helper T Cells*** – Release T cell cytokines (such as interleukin) that cause B cell antibody class switching and increased cytotoxic T cell activation. As their name describes, they "help" B cells become activated. Further differentiated into Th1 and Th2 cells
    - ***Cytotoxic (CD8+) T Cells*** – Activated when its TCR binds with an infected or cancerous APC's MHC I, plus an antigen. Upon activation, differentiates into effector cytotoxic T cells and some mature further into memory cytotoxic T cells
      - ***Effector Cytotoxic T Cells*** – Binds with APCs that present the same antigen and kills them via perforin and granzyme
      - ***Memory Cytotoxic T Cells*** – Recognizes the same antigens as the cytotoxic T cell that was initially activated. They serve as a "reserve" force of cells to mount a faster and stronger immune response in the future
    - ***Regulatory T Cells*** – Immune suppressive T cells that down-regulate the induction and proliferation of effector T cells. This regulates the immune system, maintaining tolerance to self-antigens to prevent autoimmune disease

- ***Myelocytes*** – A category describing cells that all originated from a common myeloid progenitor during hematopoiesis. Includes red blood cells, platelets, granulocytes, and macrophages
  - ***Erythrocytes/Red Blood Cells*** – The most abundant cell in blood, which carries four oxygen molecules via a porphyrin ring and one iron molecule. They are anucleate cells (contain no nucleus) and are not involved in immunity
  - ***Thrombocytes/Platelets*** – Fragments of cytoplasm from megakaryocytes that functions to prevent bleeding by forming a blood clot. They are anucleate cells and not involved in immunity
  - ***Granulocytes*** – Phagocytic myelocytes that destroy antigens at the site of injury. They are characterized by the presence of granules in the cytoplasm and multi-lobed nuclei.
    - ***Neutrophils*** – The most abundant leukocytes in blood and often the first responders to inflammatory cytokines. They are specialized to phagocytose and kill bacteria via oxidative/respiratory burst (the release of toxic reactive oxygen species). Neutrophil counts are elevated during acute inflammation and is the main component of pus
    - ***Eosinophils*** – Mainly responsible for allergic and asthmatic responses. Eosinophil counts are elevated during allergic responses or parasitic infections
    - ***Basophils*** – Similar responsibilities as eosinophils, but also mediates histamine release to stimulate local blood vessel dilation
    - ***Mast Cells*** – Same responsibilities as basophils, except residing in tissue instead of blood
  - ***Macrophages*** – Phagocytic myelocytes that destroy pathogens throughout the body. They are professional APCs. Monocytes are the precursors to macrophages. Like neutrophils, monocytes kill bacteria via oxidative/respiratory burst
  - ***Dendritic Cells*** – Phagocytic myelocytes or lymphocytes that destroy pathogens in tissues that interact with the external environment (nasal membrane, lungs, intestines, skin, etc.). Once activated, they migrate to the lymph nodes where they present antigens on MHC II to helper T cells. Dendritic cells are professional APCs



CELLS OF THE BLOOD SUMMARY ☆ HIGH-YIELD

Cell Name	Main Function	Location
NK Cell Ⓛ ⬡	Kills infected/cancerous cells via granzyme and perforin	Circulates in blood and migrates to tissue
B Cell Ⓛ ⌖ ✪	Produce antibodies once activated; Present antigens to helper T cell	Matures in bone marrow; circulates in blood and migrates to 2° lymphoid tissues
T Cell Ⓛ ⌖	Activates B cells; kills infected/ cancerous cells; immunesupression	Matures in thymus; circulates in blood and migrates to 2° lymphoid tissues
Red Blood Cells Ⓜ	Contains hemoglobin which carries oxygen with a porphyrin ring and Fe^{2+}	Matures in bone marrow, spleen, and liver; circulates in blood
Platelets Ⓜ	Activated by thrombin to form blood clots; triggers coagulation cascade	Released by megakaryocytes into blood; stored in spleen
Neutrophils Ⓜ ⬡	Phagocytoses and kills bacteria via oxidative burst	Matures in bone marrow; circulates in blood; migrates into tissues
Eosinophils Ⓜ ⬡	Mediates allergic/asthmatic and parasitic response	Matures in bone marrow; circulates in blood; migrates into tissues
Basophils Ⓜ ⬡	Same as eosinophils, except releases histamine to dilate vessels	Matures in bone marrow; circulates in blood; migrates into tissues
Mast Cells Ⓜ ⬡	Same as eosinophils, except releases histamine to dilate vessels	Resides in tissues
Macrophages Ⓜ ⬡ ⌖ ✪	Phagocytose pathogens; present antigens to helper T cell	Circulates in blood; resides in tissues
Dendritic Cells Ⓜ ⬡ ⌖ ✪	Phagocytose pathogens; present antigens to helper T cell	Resides in tissues that contact external environment; migrates to lymph nodes

Legend

Ⓜ Myeloid Cell
Ⓛ Lymphoid Cell
⬡ Involved in Innate Immunity
⌖ Involved in Adaptive Immunity
✪ Professional APC (MHC II+)

LINES OF DEFENCE

- The immune system is described as having three "lines of defence":
  - ***Fist Line of Defence*** – Physical barriers, which are non-specific (skin, mucociliary escalator, gastric acid, lysozyme, symbiotic bacteria, etc.)
  - ***Second Line of Defence*** – The innate immune system, which is non-specific (complement system, interferon response, inflammatory response, phagocytic cells, NK cells, etc.)
  - ***Third Line of Defence*** – The adaptive immunes system, which is specific and has memory (B cells, T cells, antibodies)

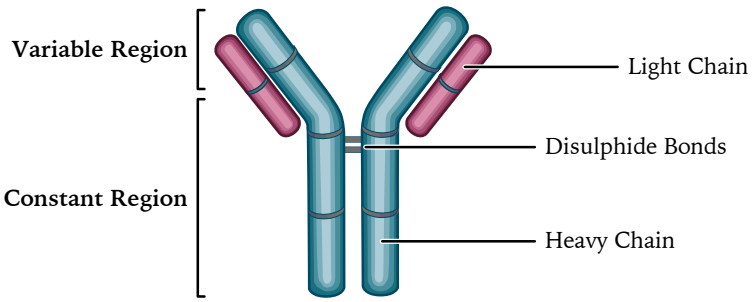
T AND B CELL MATURATION

- Each T cell has a ***T cell receptor (TCR)*** with specificity to a different epitope. The variety of TCR specificities is due to alternative splicing of introns in the genes coding for the TCR's variable region
- In the thymus, developing T cells undergo different types of selection:
  - ***Negative Selection*** – T cells with TCRs that are high in self-reactivity are eliminated
  - ***Positive Selection*** – T cells with TCRs that are low in self-reactivity are kept
    - Cells that interact well with MHC I become cytotoxic (CD8+) T cells
    - Cells that interact well with MHC II become helper (CD4+) T cells
  - ***Goldilocks Selection*** – T cells with TCRs that are intermediate in self-reactivity become regulatory T cells
- B cells mature in a similar process to T cells, except they do not undergo goldilocks selection nor become CD8 or CD4 positive

ANTIBODIES/IMMUNOGLOBULINS

- Unlike T cells, B cells secrete their surface receptors as ***antibodies/immunoglobulins (Ig)***
- The antibodies secreted by a particular B cell are identical and all recognize the same antigen epitope
- Antibodies destroy pathogens by attaching to their surface and hindering mobility, marking them for other cells to phagocytose. This process is called ***opsonization*** and activates the ***complement system***

- **Antibody Structure**
  - Antibodies consist of two large ***heavy chains*** and two small ***light chains*** connected via disulphide bonds
  - The region that recognizes antigens is called the ***variable region (Fab)*** while the region that remains constant is called the ***constant region (Fc)***
  - There are five different types of heavy chains that determine the antibody's ***class/isotype***: IgM, IgD, IgG, IgE, or IgA



- **Class/Isotype Switching**
  - When a B cell is activated by a helper T cell, the T cell secretes interleukin, a cytokine which triggers the B cell to undergo ***class switching***
  - The B cell rearranges its heavy chain constant region genes, converting the antibodies it secretes from IgM/IgD to IgG, IgA, and IgE

THE COMPLEMENT SYSTEM

- The complement system is a group of serum proteins that "complement" other immune defences. It can be activated *directly* by pathogens or *indirectly* by antibody-coated pathogens
- The complement proteins are part of innate immunity and have three major functions:
  - ***Opsonization*** – Pathogens get covered by complement protein 3b (C3b), which binds to compliment receptor 1 (CR1) on phagocytes and triggers phagocytosis
  - ***Cytotoxicity*** – Induces cell lysis through the membrane attack complex (MAC)
  - ***Inflammation*** – Complement protein 3a (C3a) induces inflammation by increasing vascular permeability and attracting phagocytes to the site of infection

THE INTERFERON RESPONSE

- Interferons are antiviral cytokines secreted by infected cells. They are an important component of innate immunity and have three major functions:
  - ***Self Destruction*** – Kills infected cells by triggering apoptosis
  - ***Warning System*** – Signal neighbouring cells to start preparing for a viral attack
  - ***Recruit Phagocytes*** – Interferon gamma mobilizes macrophages and NK cells, which phagocytose infected or cancerous cells

THE INFLAMMATORY RESPONSE

- The inflammatory response is a combination of events that occur in response to pathogen invasion (i.e. bacteria colonizes urinary tract), cellular damage (i.e. twisted ankle), or irritants (i.e. pollen). It is an important component of innate immunity
- Macroscopic signs of inflammation include redness, swelling, heat, pain, and loss of function. Pathologists refer to this as the five ***cardinal signs of inflammation***
- Microscopic signs of inflammation include:
  - ***Histamine Release*** – A molecule released by basophils during allergic reactions or parasite invasion. Histamine increases capillary permeability to allow extravasation of leukocytes (migration out of the vessels and into infected tissues)
  - ***Vasodilation*** – Occurs in response to histamine release. Increases blood flow to infected tissue, allowing faster recruitment of leukocytes
  - ***Phagocyte Recruitment*** – Leukocytes extravasate into infected tissue and phagocytose pathogens. They follow the chemical gradient left by complement proteins

PATHOLOGIES

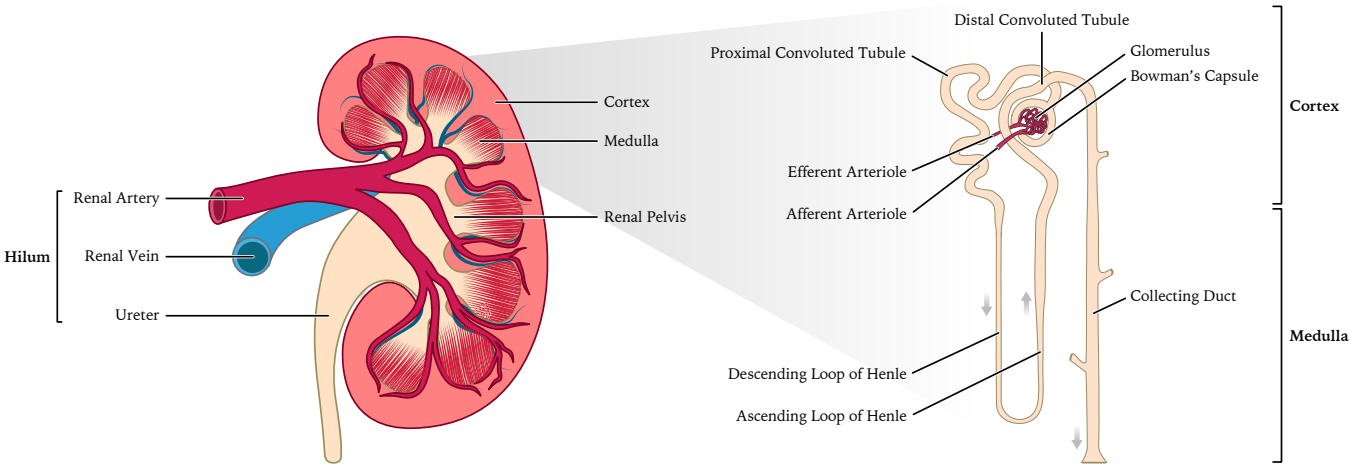
- ***Regulatory T Cell Pathologies***:
  - Too much T cell regulation results in susceptibility to ***cancer***, because the immune system does not adequately fight abnormal cells or small tumours
  - Too little T cell regulation results in the immune system fighting the body, causing ***autoimmune disorders***
- ***Acquired Immunodeficiency Syndrome (AIDS)*** – Caused by infection by the ***human immunodeficiency virus (HIV)***. The disease destroys helper T cells, weakening the immune system and making the body susceptible to ***opportunistic infections***
- ***Type I Diabetes*** – An autoimmune disease where the beta cells of the pancreas are attacked. This results in an insulin deficiency
- ***Rheumatoid Arthritis*** – An autoimmune disease where the synovial membrane of joints are attacked. Unlike osteoarthritis, it is not caused by "wear and tear"
- ***Lupus*** – An autoimmune disease where various healthy tissues are attacked, including the skin, muscles, bones, heart, lungs, kidneys, and eyes
- ***Inflammatory Bowel Disease (IBD)*** – An autoimmune disease where the lining of the intestines are attacked
- ***Hashimoto's Thyroiditis*** – An autoimmune disease where the thyroid gland is attacked. This results in a thyroid hormone deficiency
- ***Asthma*** – A hypersensitivity disease where the bronchioles overreact to stimuli, resulting in spasms

CHAPTER 21 | **THE URINARY SYSTEM**

- The urinary system's main function is to excrete metabolic waste and harmful substances from the body, but it also regulates blood pH, volume, pressure, and osmolarity
- The kidney filters blood to achieve the above functions, but is also involved in gluconeogenesis, hematopoiesis, and activating vitamin D

THE KIDNEY

- Consists of a superficial layer called the ***cortex*** and a deeper layer called the ***medulla***
- The ***nephron*** is the smallest functional unit of the kidney, and consists of a ***renal corpuscle*** located in the cortex and a ***renal tubule***, which extends into the medulla
- Each kidney contains around one million nephrons, which filter blood that is supplied by the renal artery. The blood returns to systemic circulation via the renal vein
- Each nephron empties their filtrate into ***collecting ducts***, which coalesce to from a ***renal calyx***. The renal calyces coalesce at the ***renal pelvis***, eventually becoming the ureter
- The ***hilum*** is the location where the ureter, renal artery, and renal vein enters the kidney
- The ureter eventually drains into the ***bladder***, an expandable organ that stores urine



NITROGENOUS WASTE

- Nitrogen is a waste product from amino acid and nucleic acid metabolism in the liver. Animals excrete nitrogenous wastes as ammonia, urea, or uric acid (listed in order of increasing nitrogen content per molecule and amount of metabolic processing required to produce)
- ***Ammonia*** is highly toxic and can only be tolerated in low concentrations, so a large amount of water is required to dilute when excreted. This is most common in aquatic species. Fish use their gills to excrete NH_4^+ directly into the water, while many invertebrates may use their entire body surface
- ***Urea*** is a less toxic waste product that is produced when the liver combines ammonia with carbon dioxide. This is most common in mammals and allows the organism to conserve water, since less dilution is necessary
- ***Uric acid*** is an even less toxic substance that is non-soluble in water and can be excreted as crystals or a paste. It is the most highly-processed waste product and is common in insects, reptiles, and birds
- In eggs, a sac called the ***allantois*** functions as a reservoir for nitrogenous waste produced by the embryo

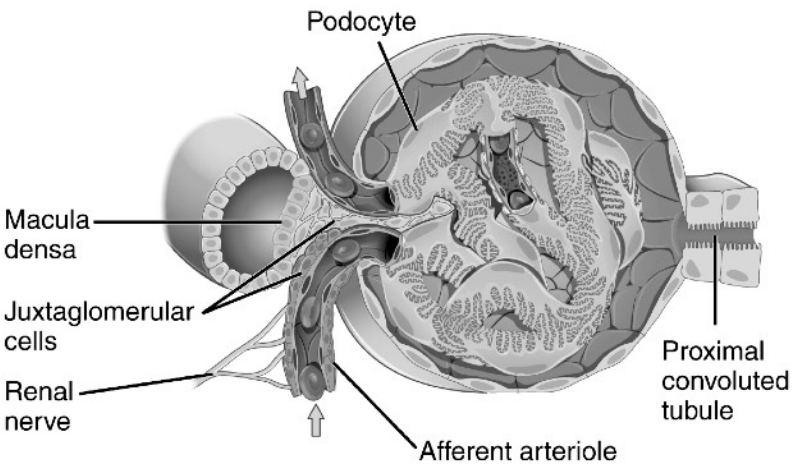
FILTRATION AND ABSORPTION ☆ HIGH-YIELD

- Blood enters the nephron through the ***afferent arteriole*** and leaves through the ***efferent arteriole***. Note that the blood leaving the nephron is still oxygenated
- The efferent arteriole continues and branches in to ***peritubular capillaries***, a network of vessels that supply oxygen to the nephron and reabsorbs useful molecules from the filtrate
- The section of peritubular capillaries near the loop of Henle is called the ***vasa recta***. Unlike the rest of the peritubular capillaries, the vasa recta is straight
- The steps of urine production begin in the ***glomerulus***, a convoluted vessel that exists between the afferent and efferent arteriole:
  1. Due to high hydrostatic pressure, blood plasma in the glomerulus is squeezed through fenestrated endothelial cells and the pedicels of ***podocytes***, ending up within the ***Bowman's capsule***. Ions (Na^+, K^+, Cl^-), glucose, amino acids, small vitamins, and small hormones get filtered into the Bowman's capsule. This is called the ***filtrate***. Large components of blood like cells and proteins are NOT filtered
  2. Filtrate enters the ***proximal convoluted tubule***, where reabsorption occurs:
     - Na^+ is reabsorbed back into luminal cells via active transport by Na^+/K^+ pump
     - Glucose and amino acids are reabsorbed via secondary active transport by symporters
     - Water is reabsorbed via facilitated diffusion by ***aquaporin*** channels
  3. Filtrate enters the ***descending loop of Henle***, which is permeable to water but not ions:

     MNEMONIC Think "waterfall" → descending loop of Henle is water permeable

     - The descending loop of Henle dips into the medulla
     - The medulla's osmolarity is proportional to depth. In other words, the environment becomes increasingly salty (hypertonic) the deeper we travel into the medulla
     - High osmolarity of the medulla reabsorbs water via facilitated diffusion by aquaporin channels
  4. Filtrate enters the ***ascending loop of Henle***, which is permeable to ions but not water:
     - Na^+ is reabsorbed via active transport by Na^+/K^+ pump. This results in the medulla's osmolarity gradient
  5. Filtrate enters the ***distal convoluted tubule***, where further ion reabsorption occurs:
     - Na^+ is reabsorbed via active transport by Na^+/K^+ pump
     - Ca^{2+} and K^+ are reabsorbed via secondary active transport by antiporters and symporters
  6. Filtrate enters the ***collecting duct***, where further reabsorption occurs:
     - Water is reabsorbed via facilitated diffusion by aquaporin channels
     - Na^+ is reabsorbed via active transport by Na^+/K^+ pump
     - Some urea is reabsorbed to maintain renal medulla's osmotic gradient
     - By the time the filtrate reaches the ureter, it has become highly concentrated ***urine***

The Glomerulus



HORMONAL REGULATION

- The osmotic pressure of an organism's fluids is controlled by increasing or decreasing the concentration of urine as needed. This is called ***osmoregulation***
- In humans, this is accomplished by the ***renin-angiotensin-aldosterone system (RAAS)***:
  - RAAS is triggered by three situations:
    1. Low blood pressure detected by ***juxtaglomerular cells***, which release ***renin***
    2. Low sodium detected by ***macula densa cells***, which release ***prostaglandin***
    3. Activation of the sympathetic nervous system
  - Normally, the liver continuously produces ***angiotensinogen***, an inactive peptide hormone
  - When exposed to renin, angiotensinogen is cleaved into ***angiotensin I***
  - Angiotensin I is converted to ***angiotensin II*** by ***angiotensin-converting enzyme (ACE)*** found within the endothelial cells of the lung. Angiotensin II has four effects:
    1. Triggers vasoconstriction of blood vessels
    2. Increases Na^+ reabsorption in the proximal tubules. This in combination with the first effect will raise blood pressure over time
    3. Stimulates ***antidiuretic hormone (ADH)*** production by the ***posterior pituitary gland***
    4. Stimulates ***aldosterone*** production by the ***adrenal gland***
- ***Antidiuretic hormone*** (also called vasopressin) can also be triggered when the hypothalamus detects hypertonicity of the blood plasma. When released by the posterior pituitary, it increases the number of aquaporin proteins in the collecting duct. This allows for greater water permeability, resulting in increased resorption and higher blood volume
- ***Aldosterone*** can also be triggered when stretch receptors in the heart detect decreased blood pressure. When released by adrenal gland, it increases Na^+ reabsorption in the distal convoluted tubule and collecting duct, resulting in higher blood volume

PATHOLOGIES

- ***Diabetes Insipidus*** – Insensitivity to antidiuretic hormone (ADH), resulting in the production of abnormally high quantities of urine. Symptoms include frequent urination, intense thirst, and increased fluid intake

CHAPTER 22 | **THE DIGESTIVE SYSTEM**

- The main function of the digestive system (aka gastrointestinal system) is to mechanically and chemically break down food, absorbing useful nutrients for metabolism and other bodily functions

THE UPPER GI TRACT

- Consists of the following anatomy:
  - ***Oral Cavity***
    - Starts the mechanical digestion of food via ***mastication*** (chewing)
    - Chemical digestion also begins via the secretion of:
      - ***Salivary Amylase*** – Enzyme that breaks down starches into disaccharides and trisaccharides
      - ***Lingual Lipase*** – Enzyme that brakes down triglycerides into partial glycerides and free fatty acids. This important for breast milk digestion in infants
    - After food is chewed into a ***bolus***, the ***swallowing reflex*** occurs, which is partially under voluntary control. After swallowing, movement through the rest of the digestive system is involuntary up until defecation
  - ***Salivary Glands***
    - ***Parotid Glands*** – Located near ears. Activated when eating, produces watery saliva containing mostly amylase
    - ***Submandibular Glands*** – Located near jaw. Activated when eating, produces thicker saliva containing both amylase and mucus
    - ***Sublingual Glands*** – Located under tongue. Activated at rest, produces saliva contains mostly mucus

    MNEMONIC Think "waterfall" → Parotid glands are located the highest and produce the most watery saliva
  - ***Pharynx***
    - During swallowing, the ***epiglottis*** covers the entrance to the larynx (voice box)
    - The bolus travels from the oral cavity and into the pharynx, then into the esophagus
  - ***Esophagus***
    - The bolus is propelled down the esophagus by smooth muscle contractions called peristalsis

THE STOMACH ☆ HIGH-YIELD

- Composed of the ***fundus*** (top), ***body*** (middle), and ***antrum*** (bottom)
  - The fundus and upper body participates in storage and receptive relaxation
  - The antrum and lower body participates in mechanical digestion
- Food enters the stomach via the ***cardiac sphincter***, and leaves the stomach through the ***pyloric sphincter***
- The main function of the stomach is the digestion of food:
  - ***Chemical Digestion***
    - ***Hydrochloric Acid*** – Denatures proteins, kills microbes, stimulates secretion of hormones, and activates pepsinogen. Once the food bolus is mixed with gastric juice, it is called ***chyme***. The stomach itself is protected from HCl by a mucin layer
    - ***Pepsin*** – Pepsinogen is an inactive enzyme that is cleaved into ***pepsin*** in the presence of HCl (low pH). Pepsin is a protease that breaks proteins down into smaller polypeptides
  - ***Mechanical Digestion***
    - Food is mixed via peristaltic (wave-like) and segmental (alternating) contractions, with the pyloric sphincter closed
    - A regulated stream of chyme is let into the small intestine via controlled openings of the pyloric sphincter

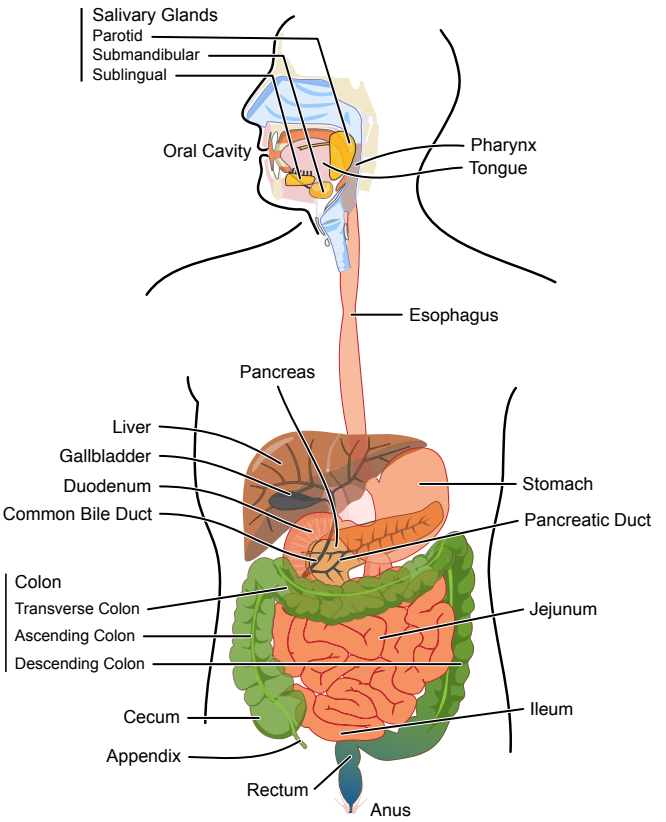
THE SMALL INTESTINE HIGH-YIELD

- The surface of the small intestine is coated with projections called ***villi***, each with many ***microvilli*** to increase surface area for maximum nutrient absorption
- Inside each villi, a lymphatic capillary called a ***lacteal*** absorbs fats and lipid-soluble vitamins (A, D, E, K)
- The small intestine is divided into three sections:
  - ***Duodenum***
    - The most chemical digestion occurs in this portion of the small intestine
    - Pancreatic secretions and bile are mixed into the chyme
    - ***Brush border enzymes*** are produced and released by simple cuboidal epithelial cells in the duodenum. There are four important brush border enzymes:
      - ***Enterokinase*** – Activates trypsin from the pancreas
      - ***Lactase*** – Converts lactose into glucose and galactose
      - ***Sucrase*** – Converts sucrose into glucose and fructose
      - ***Maltase*** – Converts maltose into two glucose molecules
  - ***Jejunum***
    - The most absorption of nutrients occurs in this portion of the small intestine
    - Amino acids and sugars are absorbed into the bloodstream, which is routed directly to the liver via the ***portal vein***. The liver extracts dissolved nutrients from the bloodstream and filters out toxins
    - Dietary fats are emulsified by bile and associate with proteins to form ***chylomicrons***, which are then absorbed into the lymphatic system by vessels called ***lacteals***. When transported to their destination, the bile component of the chylomicron is recycled back to the small intestine
  - ***Ileum***
    - The main function of this portion of the small intestine is to absorb ***vitamin B_{12}*** and continue the absorption of fats and sugars that was initiated in the jejunum
    - Absorption of vitamin B_{12} requires ***intrinsic factor***, which is secreted from parietal cells in stomach
    - The fat soluble vitamins (A, D, E, K) require micelle formation in order to be absorbed. Therefore we need to consume some fat to absorb all our vitamins
    - The water soluble vitamins (B, C) require transporter proteins for absorption

MNEMONIC The order of the intestinal sections is "DJI", the name of the popular drone company

THE LARGE INTESTINE

- Main function is to absorb water from the chyme, forming faeces
- Highly populated by bacteria, which complete nutrient extraction via fermentation
- Chyme travels from the ileum of the small intestine through the ileocecal valve and into the beginning of the large intestine, called the ***cecum***. From there, it travels through the ***ascending colon***, into the ***transverse colon***, down the ***descending colon***, and into the S-shaped ***sigmoid colon***
- The ***rectum*** stores faeces until defecation, during which the skeletal muscles of the ***external anal sphincter*** voluntarily relaxes. Unlike the external anal sphincter, the ***internal anal sphincter*** is composed of smooth muscle and is under involuntary control
- The ***appendix*** is a vestigial extension of the cecum that stores symbiotic bacteria to repopulate the gut flora. In our herbivorous ancestors, the appendix stored cellulose-digesting bacteria



PANCREATIC SECRETIONS ☆ HIGH-YIELD

- Whenever you see a pancreatic enzyme that ends with "-gen" or begins with "pro-", it is the inactivated form
- Inactive enzymes are called ***zymogens***, and they usually have an extra peptide bond that needs to be cleaved before they become active
- ***Exocrine Secretions*** – Secreted into the pancreatic duct
  - ***Bicarbonate*** – Neutralizes HCl from stomach
  - ***Trypsin*** – Secreted as trypsinogen and activated by enterokinase. Trypsin is a protease that activates chymotrypsinogen, procarboxypeptidase, and proelastase
  - ***Chymotrypsin*** – A protease that cleaves non-terminal peptide bonds
  - ***Carboxypeptidase*** – A protease that cleaves C-terminal peptides
  - ***Elastase*** – A protease that cleaves elastin fibres
  - ***Pancreatic Amylase*** – Breaks down starches into disaccharides and trisaccharides. Unlike salivary amylase, pancreatic amylase is active at high pH (alkaline)
  - ***Pancreatic Lipase*** – Breaks down triglycerides into partial glycerides and free fatty acids. Unlike salivary lipase, pancreatic lipase is active at high pH (alkaline)
  - ***Nucleosidase*** – Breaks down a nucleoside into ribose and a base

MNEMONIC "LANCET" → Lipase, Amylase, Nucleosidase, Chymotrypsin & Carboxypeptidase, Elastase, Trypsin

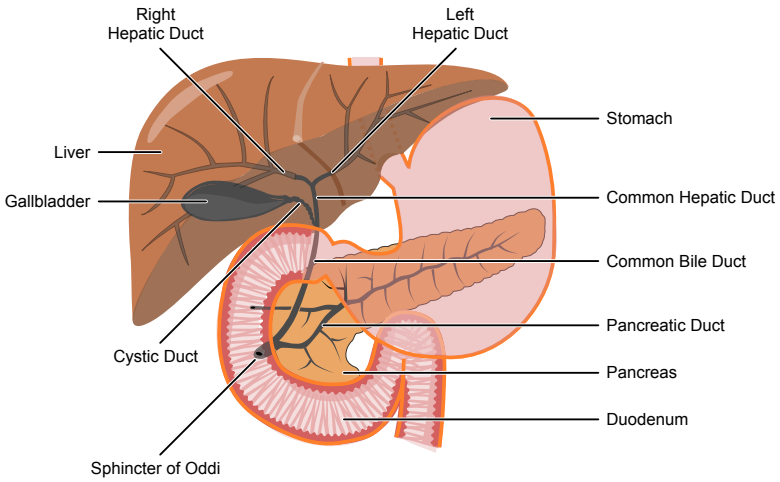
- ***Endocrine Secretions*** – Secreted into the bloodstream
  - ***Insulin*** – Produced by beta cells in the pancreatic islets. Causes glucose absorption from blood into skeletal muscle and adipose tissue
  - ***Glucagon*** – Produced by alpha cells in the pancreatic islets. Causes glucose release from tissue into blood

MNEMONIC "Glucagon" acts when glucose is "gone" from the blood

  - ***Somatostatin*** – Also known as growth hormone inhibiting hormone. Produced by delta cells. Inhibits insulin, glucagon, and growth hormone

BILE

- Hepatocytes in the liver continuously secrete bile into vessels called bile canaliculi, which coalesce to form the right and left hepatic duct, which eventually merge to become the ***common hepatic duct***
- Bile travels through the common hepatic duct and up the ***cystic duct*** to be stored in the gallbladder
- The common hepatic duct and cystic duct merge into the ***common bile duct***, which empties into the duodenum
- ***Cholecystokinin (CCK)*** is a hormone that triggers gallbladder contractions, releasing bile into the duodenum
- Bile is composed of:
  - ***Bile Salts*** – Amphipathic molecules that act as an emulsifier for fat digestion. It creates small lipid droplets called ***micelles*** so pancreatic lipase can work more effectively. The micelles combine with cholesterol and proteins to form a ***chylomicron***, which are absorbed into the lymphatic system
  - ***Cholesterol*** – Works with bile salts to turn micelles into chylomicrons
  - ***Bilirubin*** – A hemoglobin waste product that gives bile its green-yellow colour. Bilirubin is eventually excreted in the faeces



CELLS OF THE DIGESTIVE SYSTEM ☆ HIGH-YIELD

- **Stomach Cells**
  - ***Chief Cells*** – Secrete pepsinogen (which digests proteins)
  - ***Parietal Cells*** – Secrete intrinsic factor (which helps absorption of vitamin B_{12}) and HCl (which activates pepsinogen and lowers pH of chyme)
  - ***G Cells*** – Secrete ***gastrin*** hormone (which promotes HCl secretion by parietal cells) and aids in gastric motility
  - ***Mucus Neck Cells*** – Secrete mucus (which protects the stomach from HCl)
- **Duodenum Cells**
  - ***Enterocytes*** – Epithelial cells with microvilli that function in absorption
  - ***Goblet Cells*** – Secrete mucus (which protects the intestinal wall)
  - ***Paneth Cells*** – Secrete lysozyme (which is anti-microbial)
  - ***S Cells*** – Secrete ***secretin*** hormone (which promotes bicarbonate secretion by pancreatic cells) upon stimulation by low pH
  - ***CCK Cells*** – Secrete ***cholecystokinin (CCK)*** hormone (which promotes gallbladder contractions and bile release) upon stimulation by the presence of fats
- **Pancreatic Cells**
  - Previously discussed under the Pancreatic Secretions section of this chapter
  - ***Alpha Cells*** – Secrete glucagon
  - ***Beta Cells*** – Secrete insulin
  - ***Delta Cells*** – Secrete somatostatin

HORMONAL CONTROL SUMMARY ☆ HIGH-YIELD

Hormone	Produced By	Function
Gastrin	G cells of the stomach	Aids in gastric motility and promotes parietal cells to release HCl
Secretin	S cells of the duodenum	Promotes pancreatic cells to release bicarbonate. Trigger by low pH
Cholecystokinin (CCK)	CCK cells of the duodenum	Promotes gallbladder contractions and bile release. Triggered by presence of fat
Insulin	Beta cells of the pancreas	Promotes glucose absorption by tissues. Triggered by high blood glucose
Glucagon	Alpha cells of the pancreas	Promotes glucose release by tissues. Triggered by low blood glucose
Somatostatin	Delta cells of the pancreas	Inhibits insulin, glucagon, and growth hormone

PATHOLOGIES

- ***Gallstones*** – Bile hardens and blocks flow from the gallbladder into the duodenum. As a result, digestion of fats is disrupted and ***jaundice*** can develop from the buildup of excess bilirubin
- ***Gastroesophageal Reflux*** – Failure of the lower esophageal sphincter to close. Leads to symptoms commonly described as "heartburn"
- ***Peptic Ulcers*** – A break in the inner lining of the stomach, duodenum, or esophagus. Gastric ulcers are commonly caused by a bacterium called *Helicobacter pylori*

CHAPTER 23 | THE NERVOUS SYSTEM

THE CENTRAL NERVOUS SYSTEM (CNS) ☆ HIGH-YIELD

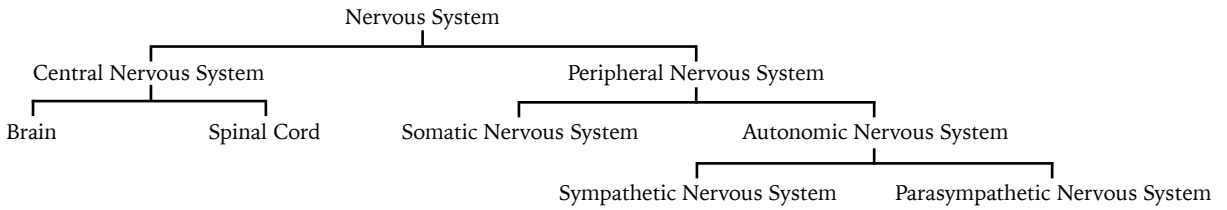
- ***The Brain*** – Controls higher-level executive functions, such as problem-solving and memory. Regions of the human brain include:
  - ***Cerebral Cortex*** – The outer layer (surface) of the brain
    - ***Frontal Lobe*** – Facilitates higher order thinking (problem-solving, memory, logic)
    - ***Parietal Lobe*** – Processes sensory information from various modalities. Includes the primary motor cortex (precentral gyrus) and primary sensory cortex (post central gyrus)
    - ***Occipital Lobe*** – Processes visual sensory information
    - ***Temporal Lobe*** – Processes auditory sensory information; facilitates speech and memory. Includes the primary auditory cortex, Wernicke's area (for understanding language), and Broca's area (for formulating language)
  - ***Corpus Callosum*** – Connection between left and right brain lobes
  - ***Cerebellum*** – Coordinates voluntary motor movements such as hand-eye coordination, balance, and posture. Also involved in muscle memory
  - ***Limbic System*** – Structures involved in motivation, emotion, learning, and memory
    - ***Thalamus*** – Relays motor and sensory signals to the cerebral cortex
    - ***Hypothalamus*** – Produces many endocrine hormones
    - ***Hippocampus*** – Facilitates learning and long term memory formation
    - ***Amygdala*** – Modulates emotions, controlling fear and anger

  MNEMONIC Think of "a hippo wearing a HAT" → Hippocampus Hypothalamus Amygdala Thalamus

- ***The Spinal Cord*** – Conducts afferent and efferent signals to/from the brain, and integrates signals involved in reflexes. Regions of the spinal chord include:
    - ***Midbrain*** – Involved in controlling eye movements, visual and auditory processing. Include the ventral tegmental area (dopamine reward circuit) and substantial nigra (production centre for dopamine)
    - ***Pons*** – Contains many nuclei responsible for integrating signals from the cranial nerves
    - ***Medulla Oblongata*** – Maintains vital functions such as heart rate, breathing, etc.

THE PERIPHERAL NERVOUS SYSTEM (PNS) ☆ HIGH-YIELD

- The PNS relays afferent and efferent signals from the CNS to the rest of the body. The PNS is further subdivided into the following systems:
  - ***Somatic Nervous System (SNS)*** – Under voluntary control (ex: skeletal muscle contraction)
  - ***Autonomic Nervous System (ANS)*** – Under involuntary control (ex: peristalsis)
    - ***Sympathetic ANS*** – Activated in response to stressful or exciting stimuli. It prepares the body for ***"fight or flight"*** by increasing heart rate, decreasing digestion, etc.
    - ***Parasympathetic ANS*** – Activated in absence of stimuli. It prepares the body for ***"rest and digest"*** by conserving energy, increasing blood flow to digestive organs, etc.

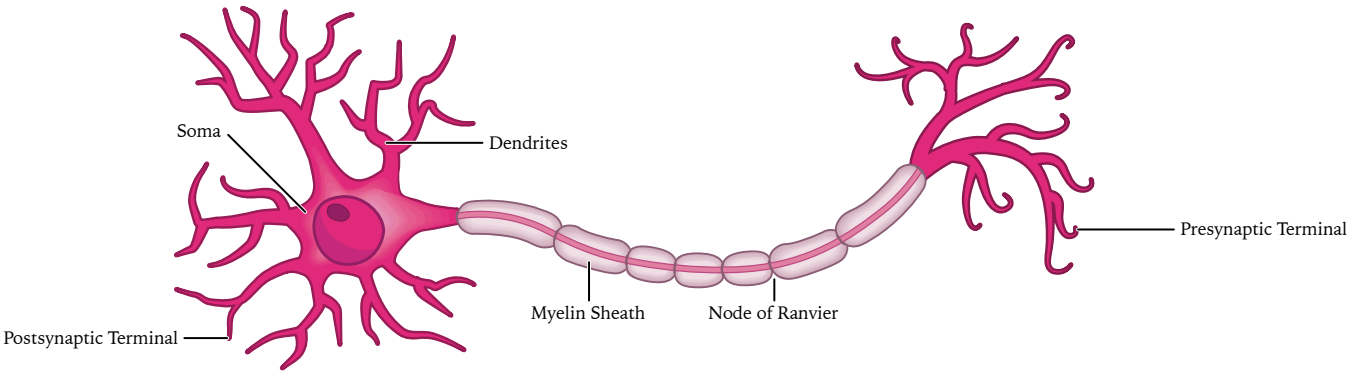


NEURONS ☆ HIGH-YIELD

- Neurons are specialized cells that relay nervous system signals via ***action potentials***. A typical neuron is composed of the following components:
  - ***Soma*** – Cell body containing nucleus and organelles
  - ***Dendrites*** – Multiple cell body extensions that receive action potentials from other cells via its postsynaptic terminals
  - ***Axon*** – A single long extension that conducts and transmits actions potentials to other cells via its presynaptic terminals
- There are three main types of neurons:
  - ***Afferent Neurons (Sensory)*** – Conduct signals from sensory cells to the CNS to cause sensation (ex: vision, hearing, touch). These neurons enter the spinal chord via the ***dorsal root***
  - ***Efferent Neurons (Motor)*** – Conduct signals from CNS to effector cells to cause a response (ex: muscle twitch, release of hormones, exocrine secretions). These neurons exit the spinal chord via the ***ventral root***

MNEMONIC "SAME DAVE" → Sensory Afferent, Motor Efferent, Dorsal Afferent, Ventral Efferent

  - ***Interneurons*** – Integrate afferent data to generate the appropriate efferent response. Located in the CNS (brain and spinal chord)



GLIA

- Glia are the non-neuronal cells of the nervous system. Instead of relaying electrical signals, glia provide support and protection for neurons. There are two major classifications of glia:
  - ***Microglia*** – Specialized macrophages that reside in the CNS and phagocytose pathogens and cellular waste
  - ***Macroglia*** – A group that consists of the following cells:
    - ***Oligodendrocytes*** – Wrap around CNS neurons to produce myelin sheaths. ***Schwann cells*** are glial cells that perform the same function, except in the PNS
    - ***Astrocytes*** – Physically and metabolically supports neurons. It also forms the ***blood-brain barrier***, a selectively permeable membrane that regulates the passage of substances into the brain. Astrocytes are the most abundant type of glial cell. ***Satellite cells*** perform the same function, except in the PNS
    - ***Ependymal Cells*** – Produce ***cerebrospinal fluid***, which fills the skull and the ventricles of the brain, providing mechanical and immunological protection

THE ACTION POTENTIAL ☆ HIGH-YIELD

- At rest, the ***membrane potential*** of a neuron is ***−70mV*** (outside of cell is more positive than inside). This polarization is due to high extracellular Na^+ and intercellular K^+

MNEMONIC "Salty Banana" → Na^+ on the outside, K^+ on the inside

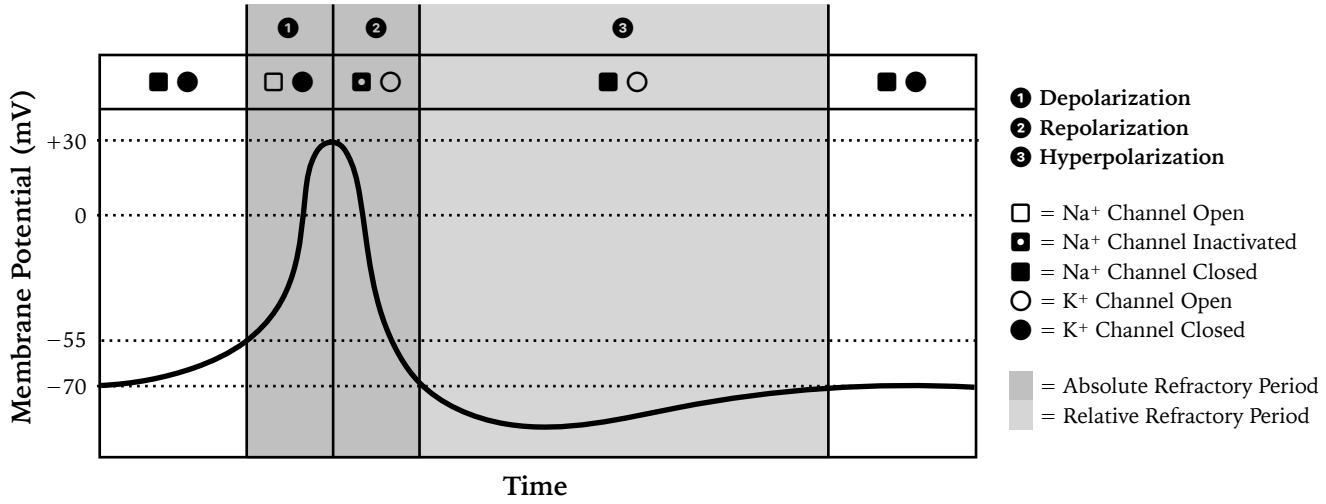
- The difference in ion concentrations is due to:
  - ***Na^+/K^+ Pumps*** – Located on the membrane and use ATP to pump three Na^+ into the cell for every two K^+ it pumps out of the cell
  - ***Selective Membrane Permeability*** – The membrane is naturally permeable to K^+. Since intercellular K^+ is high, K^+ flows out of the cell and makes the inside even more negative
- ***Depolarization*** when the membrane potential increases (becomes more positive)
- ***Repolarization*** is when the membrane potential decreases (becomes more negative)
- ***Hyperpolarization*** is when the membrane potential decreases beyond resting potential
- An ***action potential*** is a transient depolarization of the neuronal membrane that propagates down the length of an axon. After an action potential passes, the membrane is repolarized. An action potential is an ***all-or-nothing*** phenomenon, unlike ***graded potentials***. Once a threshold is reached, a full action potential is initiated

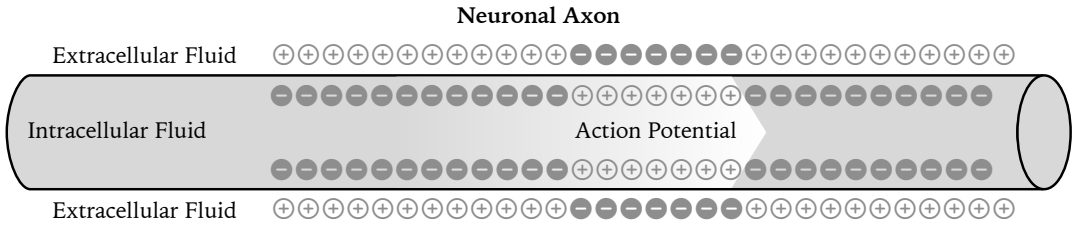
- There are four stages of an action potential:

1. **Depolarization**
   - The cell receives ***graded potentials*** that can be inhibitory or excitatory and can vary in strength (i.e. along a gradient)
     - Excitatory graded potentials depolarize the cell, increasing the cell's membrane potential (making it less negative). Inhibitory graded potentials repolarize or hyperpolarize the cell
     - Graded potentials can be spatially and temporally summated. This means if the cell receives multiple graded potentials at a high frequency or close together, their effects will be additive
   - If enough excitatory graded potentials occur and ***action potential threshold (−50mV)*** is reached, ***voltage-gated Na^+ channels*** on the cell's membrane open and allows an inflow of Na^+ ions down their concentration gradient. This increases membrane potential to around +30mV
   - As Na^+ ions diffuse, they trigger threshold potential in the next portion of the cell membrane, allowing forward propagation of the action potential

2. **Repolarization**
   - The Na^+ channels are inactivated and close, unable to re-open for a short time
   - ***Voltage-gated K^+ channels*** open after a delay, allowing an outflow of K^+ ions down their concentration gradient. This decreases membrane potential

3. **Hyperpolarization**
   - Unlike Na^+ channels, the K^+ channels are slow to close. Therefore the cell repolarizes past the original resting potential, becoming hyperpolarized (−80mV)
   - The concentration gradients of Na^+ and K^+ need to revert back to their original directions. The ***Na^+/K^+ pump*** works to re-establish resting potential
   - Meanwhile, this region of the cell membrane requires more depolarizing stimulation to reach threshold potential due to its hyperpolarized state. This is called the ***relative refractory period***
   - The ***absolute refractory period*** spans the amount of time from depolarization to repolarization. Unlike the relative refractory period, an action potential cannot occur during the absolute refractory period no matter how strong the depolarizing stimulus, since the Na^+ channels are inactivated. This ensures that the action potential propagates only in one direction





MYELINATION AND SALTATORY CONDUCTION

- Most axons are wrapped in a ***myelin sheath***, which are made of fat and electrically insulates the cell
  - In the PNS, myelin is produced by ***Schwann cells***
  - In the CNS, myelin is produced by ***oligodendrocytes***

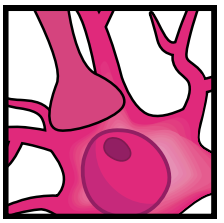
  MNEMONIC "COPS" → CNS Oligodendrocytes, PNS Schwann Cells

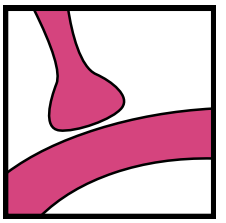
  - Myelinated neurons appear white (called "white matter"), while non-myelinated neurons appear grey (called "grey matter"). This difference in colour allows the neurons to be visually distinguishable at a macroscopic scale. In the brain, grey matter is superficial while grey matter is deep, and vice versa in the spinal chord
- Neurons can conduct action potentials faster either by 1) increasing axon diameter, or 2) insulating their axons with myelin to allow ***saltatory conduction***
- The non-myelinated spaces between each myelin sheath are called ***nodes of Ranvier***
- In saltatory conduction, the action potential "jumps" from node to node

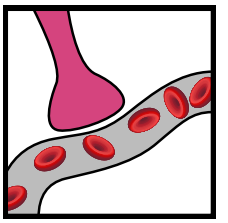
THE SYNAPSE ☆ HIGH-YIELD

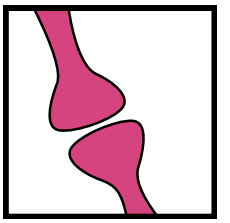
- The synapse is the interface that allows a neuron to transmit an action potential to another neuron or the target cell. It consists of the following major components:
  - ***Presynaptic Terminal*** – The axon terminal of the presynaptic neuron
  - ***Synaptic Cleft*** – The physical gap between the two neurons
  - ***Postsynaptic Terminal*** – The membrane of the postsynaptic neuron or target cell
- In most cells, an action potential of the presynaptic neuron is transmitted chemically (via neurotransmitters) to the postsynaptic neuron. However in some neurons (i.e. in the heart), the action potential is transmitted electrically via channels called ***gap junctions***, which physically connects the cytoplasm of the two cells

- There are four important synapse types:
  - ***Axosomatic*** – Synapse between a presynaptic axon and postsynaptic soma. This usually occurs in inhibitory connections
  - ***Axoaxonic*** – Synapse between a presynaptic axon and postsynaptic axon
  - ***Axosecretory*** – Synapse between a presynaptic axon and blood vessel (ex: hypothalamic neurons directly release neurohormones into a capillary system)
  - ***Axodendritic*** – Synapse between a presynaptic axon and postsynaptic dendrite. There are two subtypes:
    - ***Spine Synapse*** – Connection with projections of the dendrite called spines. Usually occurs in excitatory connections of the brain
    - ***Shaft Synapse*** – Connection with shafts of dendrites, found between spines. Usually occurs in inhibitor connections

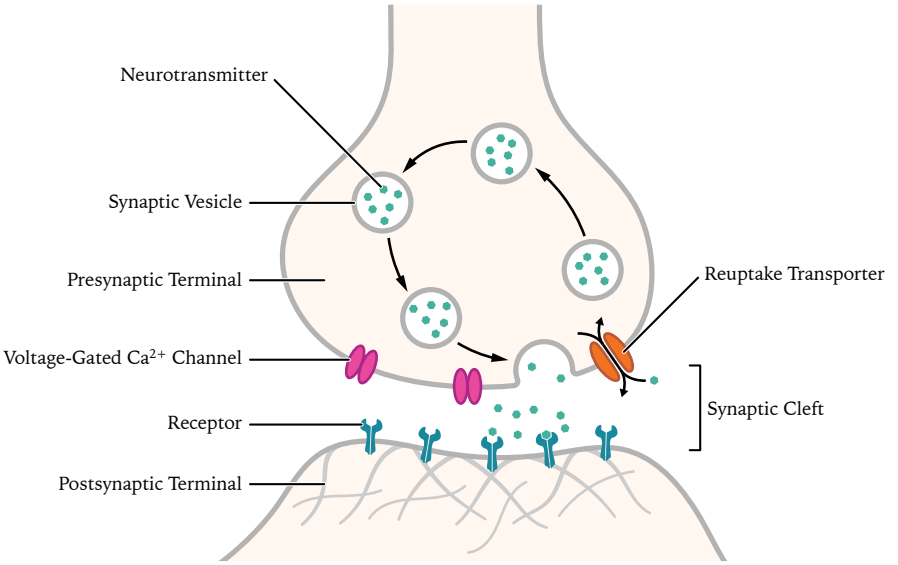

Axosomatic


Axoaxonic


Axosecretory


Axodendritic

- Synaptic transmission occurs through the following mechanism:
  1. Action potential of presynaptic cell reaches the axon terminal and triggers the opening of ***voltage-gated Ca^{2+} channels***, causing a rapid inflow of Ca^{2+} into the cell down its concentration gradient
  2. Ca^{2+} triggers proteins to cause the exocytosis of synaptic vesicles containing ***neurotransmitters***. The neurotransmitters are released into the synaptic cleft
  3. Neurotransmitters contact ***receptors*** on the postsynaptic membrane, which cause either excitation or inhibition of the postsynaptic neuron
     - ***Excitatory postsynaptic potentials (EPSPs)*** open chemically-gated Na^+ channels, causing depolarization (an excitatory graded potential)
     - ***Inhibitory postsynaptic potentials (IPSPs)*** open chemicals-gated K^+ channels, causing hyperpolarization (an inhibitory graded potential)
     - Summation of EPSPs and IPSPs determines if the postsynaptic cell will fire an action potential
  4. Neurotransmitters are degraded by enzymes in the synaptic cleft, or recycled by ***reuptake transporters*** on the presynaptic membrane



COMMON NEUROTRANSMITTERS ☆ HIGH-YIELD

Neurotransmitter	Description
Glutamate Ⓐ	Most common excitatory neurotransmitter in the brain
Gamma Amino-Butyric Acid (GABA) Ⓐ	Most common inhibitory neurotransmitter in the brain
Glycine Ⓐ	Most common inhibitory neurotransmitter in the spinal chord
Epinephrine Ⓜ	Produced in exciting/stressful situations; involved in fight or flight
Norepinephrine Ⓜ	Involved in attention and concentration; involved in fight or flight
Dopamine Ⓜ	Involved in pleasure, addiction, and motivation
Serotonin Ⓜ	Involved in happiness and wellbeing
Acetylcholine Ⓔ	Involved in thought, learning, memory, and muscle contraction

Legend
Ⓐ = Amino Acid Ⓜ = Monoamine Ⓔ = Ester

- ***Monoamines*** are simply amino acids connected to an aromatic ring. They are derived from aromatic amino acids such as tyrosine, phenylalanine, and tryptophan
- Note that acetylcholine is excitatory for skeletal muscles but inhibitory for cardiac muscle. It is also the most common neurotransmitter in the muscular system
- Glutamate is the most common neurotransmitter in the CNS

MNEMONIC If the neurotransmitter starts with the letter "G", it is an amino acid. Every other neurotransmitter is a monoamine, except for acetylcholine

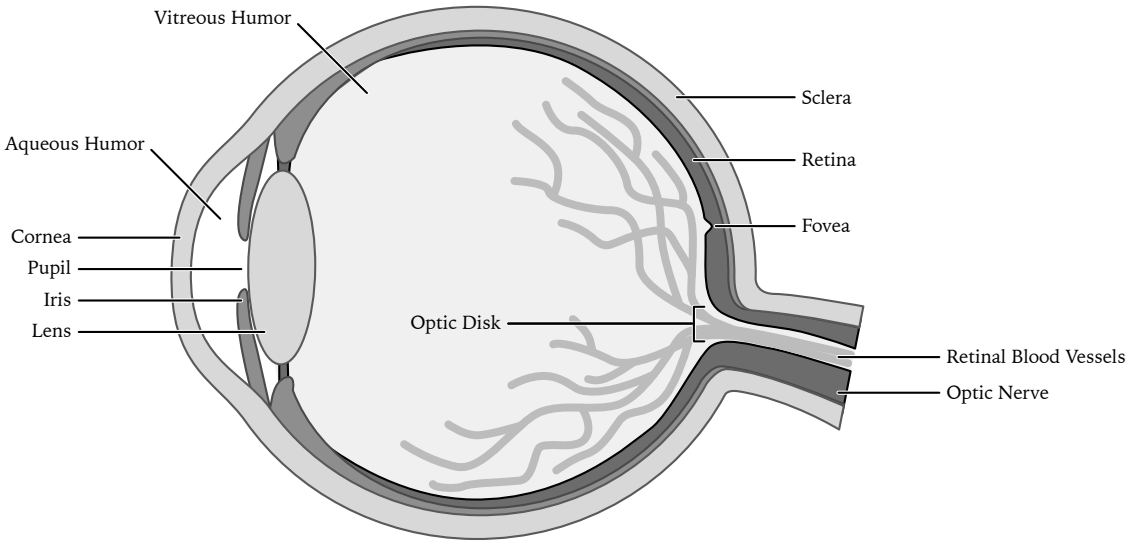
PATHOLOGIES

- ***Alzheimer's Disease*** – A chronic neurodegenerative disorder caused by amyloid or tau proteins that form neurofibrillary tangles or plaques. Symptoms include memory loss, impaired thinking and reasoning skills, difficulty using or comprehending language
- ***Parkinson's Disease*** – A chronic neurodegenerative disorder caused by the death of dopamine secreting neurons in the ***substantia nigra***. Symptoms include impaired motor skills resulting in shaking, rigidity, slowness of movement, and abnormal gait
- ***Creutzfeldt–Jakob Disease*** – A neurodegenerative disorder caused by prions (infectious and misfolded proteins) that cause sponge-like holes in the brain
- ***Multiple Sclerosis*** – An autoimmune disease caused by the destruction of neuronal myelin sheaths. Symptoms include a variety of motor and psychiatric impairments

CHAPTER 24 | **SPECIAL SENSES**

VISION

- The eye is the primary organ of the visual system and consists of the following anatomy:
  - ***Cornea*** – Clear refractive covering that protects the iris and pupil. It helps focus light but has a permanent curvature, unlike the lens
  - ***Aqueous Humour*** – Clear fluid in the anterior chamber of the eye
  - ***Pupil*** – An aperture at the centre of the iris that allows light to enter the eye
  - ***Iris*** – A pigmented muscle that controls the diameter of the pupil
  - ***Lens*** – Highly refractive structure that focuses light on the retina. Unlike the cornea, the lens can change its curvature via ***ciliary muscles***, allowing a change in focal distance
  - ***Vitreous Humour*** – Clear, viscous fluid in the posterior chamber of the eye. Maintains the eye's shape and optical properties
  - ***Retina*** – Layer of light-sensitive cells on the back wall of the eye. These cells can be rods or cones:
    - ***Rods*** – Highly sensitive in low light but cannot detect colour. Numerous everywhere in the retina except the ***fovea***, a region in the centre of the retina that provides the sharpest vision
    - ***Cones*** – Less sensitive in low light but can detect colour. Numerous in the fovea
  - ***Fovea*** – A small indentation in the retina that contains a high density of cones. It is responsible for high-definition vision at the centre of our visual field
  - ***Optic Disk*** – A point in the retina devoid of light sensitive cells, producing a ***blind spot***. It is where ganglion cell axons exit the eye
  - ***Sclera*** – The white outer layer of the eye

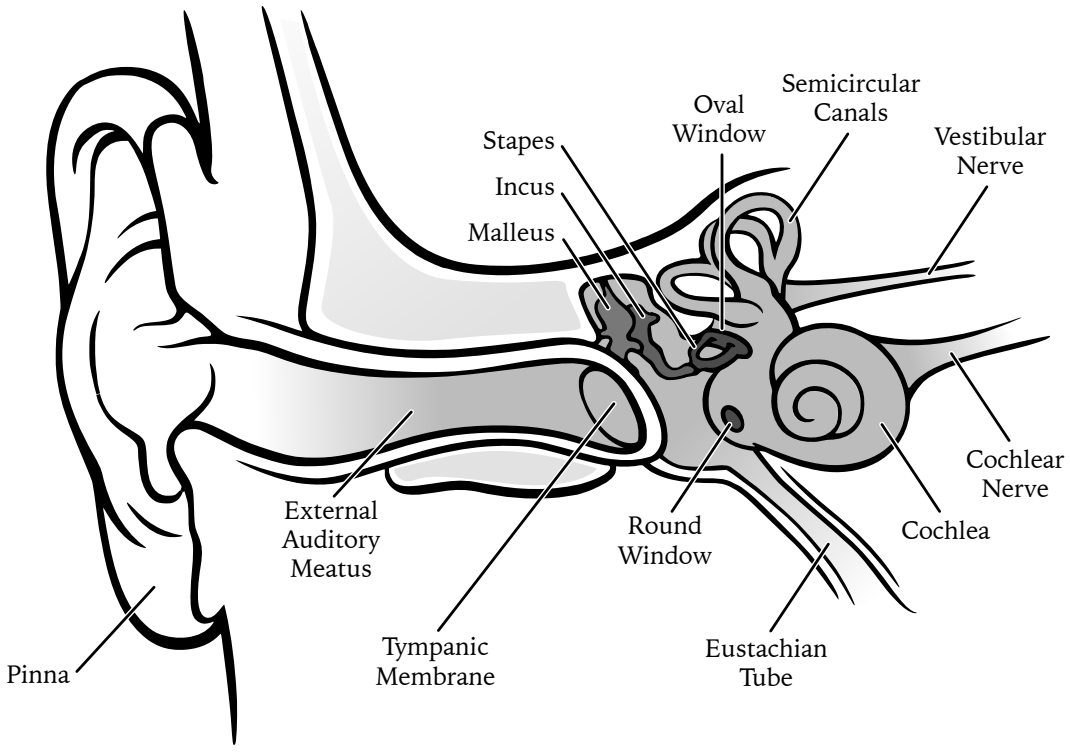


- The eye is able to detect light through the following mechanism:
  1. A photon hits rhodopsin, which causes a change in conformation of a pigment called ***retinal***
  2. The rod or cone cell becomes momentary hyperpolarized. This turns them "off" (they are "on" by default)
  3. The rod or cone synapses with an on-centre and off-centre ***bipolar cell***. The on-centre cell is depolarized while the off-centre cell is hyperpolarized (the opposite occurs in darkness)
  4. Bipolar cells synapse with a ***ganglion cell***, which transports the signal to the brain via the ***optic nerve***

AUDITION

- The auditory system is composed of the following anatomy:
- ***Outer Ear***
  - ***Pinna*** – The visible, external part of the ear
  - ***External Auditory Meatus*** – The tube that funnels sound waves to the tympanic membrane
- ***Middle Ear***
  - ***Tympanic Membrane*** – Also known as the eardrum. Responsible for converting sound waves into vibrations that are transmitted to the ossicles
  - ***Eustachian Tube*** – Connects the middle ear to the nasopharynx
  - ***Ossicles*** – Three bones that amplify the vibrations received from the tympanic membrane
    - ***Malleus*** – Shaped like a hammer. Transmits vibrations from tympanic membrane to the incus
    - ***Incus*** – Shaped like an anvil. Transmits vibrations from malleus to stapes
    - ***Stapes*** – Shaped like an equestrian stirrup. Transmits vibrations to the oval window of the cochlea

    MNEMONIC "MISS" → Malleus Incus Stapes
  - The ***oval window*** separates the middle ear (the ossicle bones) from the inner ear (cochlea and semicircular canals). The ***round window*** functions to relieve the expansion of the cochlear fluid caused by vibrations from the oval window
- ***Inner Ear***
  - ***Cochlea*** – Responsible for auditory sensation. Converts vibrations into neural impulses via hair cells with stereocilia. Transmits auditory information to the brain via the ***cochlear nerve***
  - ***Semicircular Canals*** – Responsible for vestibular sensation. Provides information about balance and spatial orientation via three fluid-filled semicircular tubes in the x, y, and z axes. Fluid motion is detected by ***hair cells***, which send the information to the brain via the ***vestibular nerve***

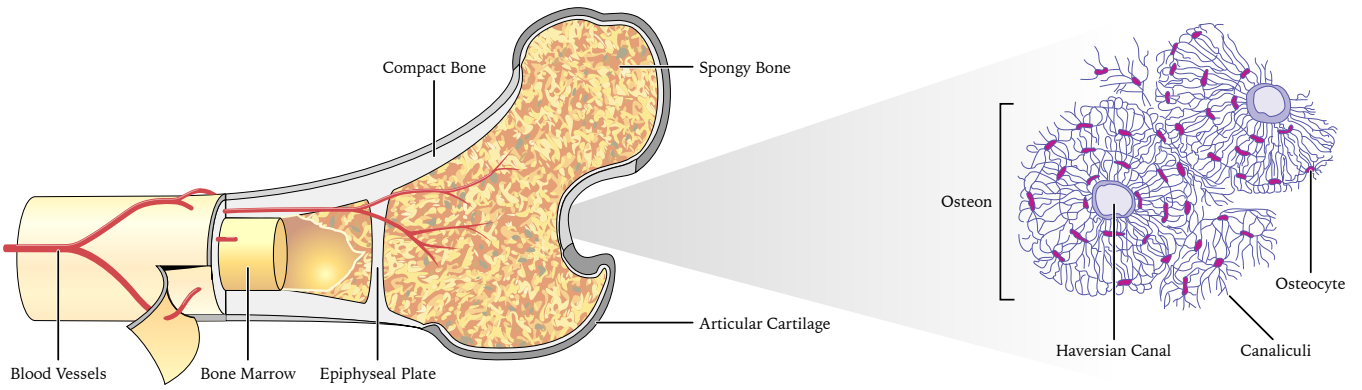


CHAPTER 25 | **THE SKELETAL SYSTEM**

- Some animals (such as arthropods) have their skeleton on the external surface of their body (an ***exoskeleton***), while others have it on the inside of their body (an ***endoskeleton***)
- Humans have an endoskeleton. The bones that form our appendages (arms and legs) make up the ***appendicular skeleton***, while all the other bones make up our ***axial skeleton***. Note that the pelvis, scapula, and clavicle are considered part of the appendicular skeleton

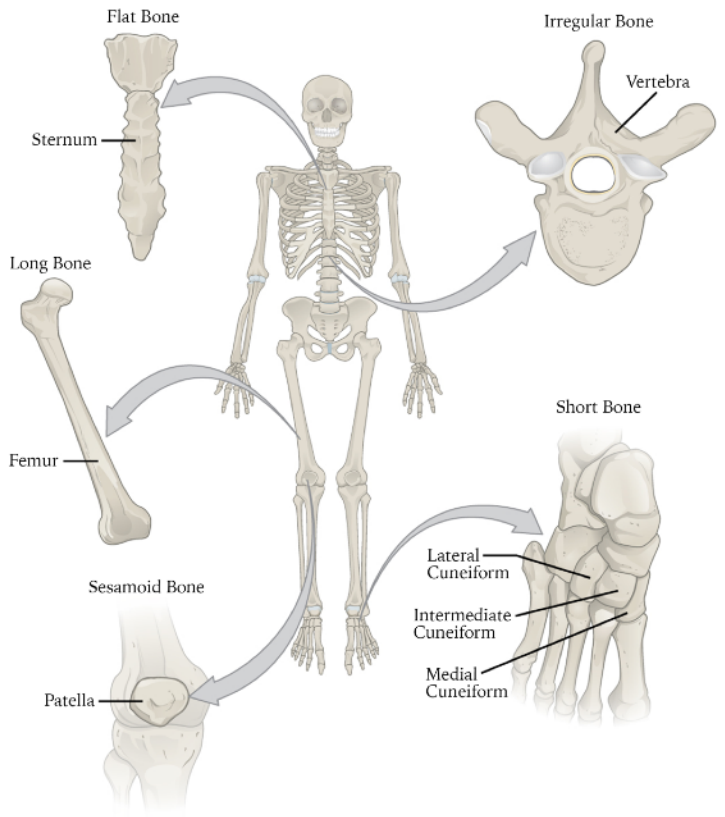
BONE AND CARTILAGE TISSUE ☆ HIGH-YIELD

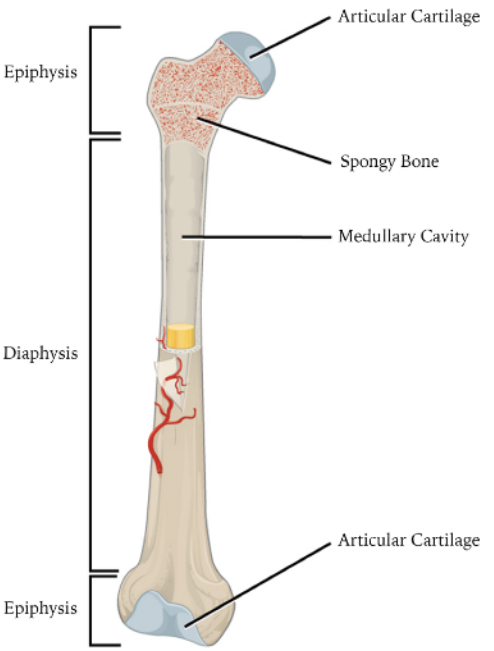
- Bone consists of cells embedded in a mineralized matrix, which is made of organic (collagen, proteoglycans) and inorganic (hydroxyapatite, calcium, phosphate) components. It is a dynamic structure that is constantly remodelled by specialized cells called osteoblasts, osteocytes, and osteoclasts:
  - ***Osteoblasts*** – Synthesize and deposit uncalcified bone matrix called ***osteoid***
  - ***Osteocytes*** – Osteoblasts that become trapped in bone matrix. They are found in small hollow spaces called ***lacunae*** and have cellular extensions that tunnel through channels ***canaliculi*** to communicate and transport nutrients/waste
  - ***Osteoclasts*** – Resorb bone matrix, increasing blood calcium levels
- There are two types of bone tissue:
  - ***Compact/Cortical Bone***
    - Compact bone tissue is found in the cortex of all bones. It consists of columns called ***osteons*** (also known as a ***Haversian system***). Each osteon contains a central ***Haversian canal*** with blood vessels, lymphatic vessels, and nerves. Neighbouring Haversian canals are connected via ***Volkmann's*** canals. Each Haversian canal is surrounded by concentric layers of calcified bone matrix called ***lamellae***, which contain bone-producing cells called osteocytes
  - ***Spongy/Cancellous/Trabecular Bone***
    - Spongy bone tissue is less dense and more vascular than compact bone. It is found at the epiphyses (ends) of long and short bones, and in the middle layer of flat bones. It consists of a porous network of ***trabecula*** surrounded by bone marrow. ***Red bone marrow*** consists of hematopoietic cells and is more plentiful in children, while ***yellow bone marrow*** consists of adipocytes and is more plentiful in adults
- Unlike bone, cartilage is avascular and is not innervated. This is why it takes a long time for cartilage to heal – any nutrients must gain access to the cartilage through slow diffusion. There are three types of cartilage tissue:
  - ***Hyaline Cartilage*** – The most common cartilage in the body. Appears glass-like, and functions to reduce friction, provide support, and reduce shock. Hyaline cartilage found on the articular surfaces of bones is called ***articular cartilage***. Found in the respiratory system, joints, ribs, and growth plates
  - ***Elastic Cartilage*** – Flexible, contains elastin fibres. Found in ears, epiglottis, and larynx
  - ***Fibrous Cartilage*** – Found in high-stress regions such as ligaments, tendons, intervertebral disks, and pubic symphysis



BONE ANATOMY

- There are five major anatomical categories of bones:
  - ***Long Bone*** – Characterized by a long shaft (***diaphysis***) with a rounded head at each end (***epiphysis***).The ***epiphyseal plate*** is where growth occurs. The ***metaphysis*** is located between the diaphysis and epiphysis. Examples of long bones include the femur, tibia, fibula, radius, and ulna
  - ***Short Bone*** – Cube-shaped appearance. Examples include the carpal bones of the wrist
  - ***Flat Bone*** – Thin and usually curved. Examples include the sternum, scapula, and bones of the skullcap
  - ***Sesamoid Bone*** – Embedded within tendons, functioning to increase muscle leverage. Examples include the patella (kneecap) and pisiform bone
  - ***Irregular Bone*** – Bones that do not fit into any of the above categories. Examples include the vertebrae, pelvis, ethmoid, and sphenoid bones of the skull



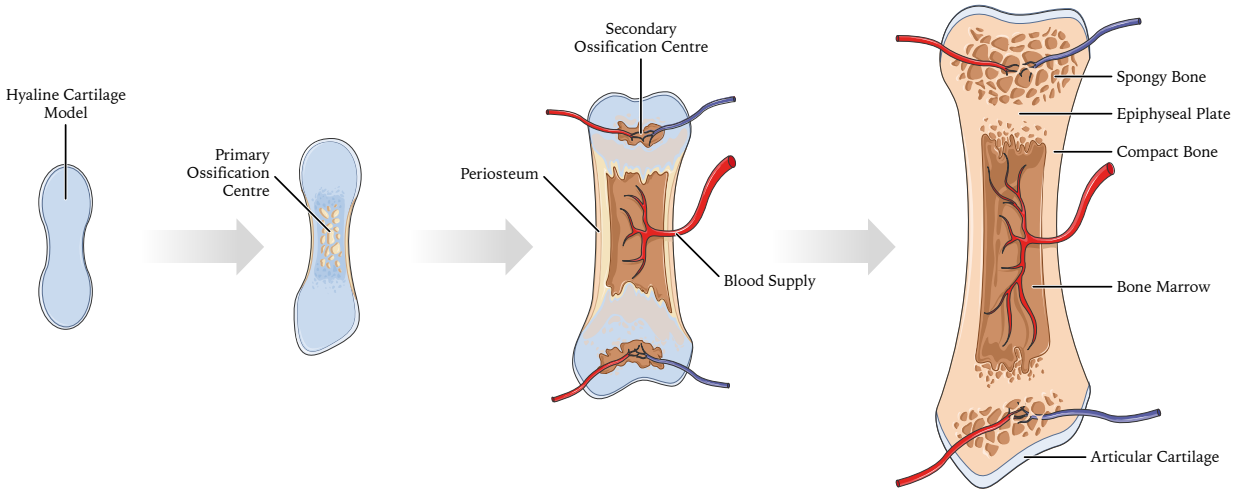


INTRAMEMBRANOUS OSSIFICATION

- Intramembranous ossification occurs in the formation of flat bones. The following steps are involved:
  1. Mesenchymal connective tissue near a blood supply in the fetus differentiates into osteoblasts
  2. Osteoblasts secrete new bone matrix into the connective tissue, forming an ***ossification centre***
  3. Bone matrix is calcified and develops into ***trabeculae***, forming spongy bone. Osteoblasts are trapped in the new calcified matrix, becoming osteocytes
  4. Compact bone develops superficial to the spongy bone, and blood vessels coalesce into red bone marrow

ENDOCHONDRAL OSSIFICATION ☆ HIGH-YIELD

- Endochondral ossification occurs in the formation of long bones and the majority of other bone types
- In contrast to intramembranous ossification, this process contains an intermediate cartilage stage. The following steps are involved:
  1. Mesenchymal connective tissue differentiates into ***chondroblasts***, which form a hyaline cartilage model surrounded by a ***perichondrium***
  2. Blood vessels gather to form the ***primary ossification centre*** at the diaphysis. A ***bony collar*** also develops from the diaphysis, replacing the perichondrium with the ***periosteum***. Meanwhile the cartilage model grows taller (interstitial growth) and wider (appositional growth)
  3. The cartilage matrix is calcified by osteoblasts
  4. Osteoclasts resorb bone from the primary ossification centre to form the ***medullary cavity***
  5. ***Secondary ossification centres*** and ***articular cartilage*** develop at the epiphyses
  6. After birth, endochondral ossification continues at a cartilaginous region between the epiphyses and metaphyses, called the ***epiphyseal plate*** (also known as the growth plate)
  7. Growth terminates when the individual reaches adulthood, and the epiphyseal plate is replaced with a calcified ***epiphyseal line***



EPIPHYSEAL PLATE ZONES

- The epiphyseal plate consists of distinct zones that are visible under a microscope:
  - ***Zone of Reserve*** – Located closest to the epiphyses. Consists of flattened precursor chondrocytes
  - ***Zone of Proliferation*** – Consists of actively dividing chondrocytes secreting cartilage matrix
  - ***Zone of Maturation/Hypertrophy*** – Consists of hypertrophic (enlarged) chondrocytes
  - ***Zone of Calcification*** – Consists of apoptotic chondrocytes and calcifying cartilage matrix
  - ***Zone of Ossification*** – Located closest to the diaphysis. Consists of osteoclasts and osteoblasts, which replace the calcified cartilage with bone

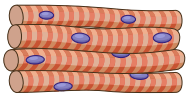
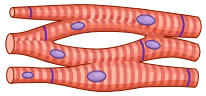
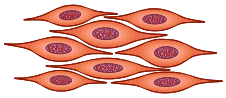
PATHOLOGIES

- ***Osteoporosis*** – Loss of spongy bone due to increased resorption by osteoclasts. This increases the risk of fractures from even minor accidents such as falls
- ***Osteogenesis Imperfecta*** – Abnormal collagen synthesis leading to brittle bones
- ***Rickets*** – Weakened bone in children due to vitamin D deficiency. Patients with this disease usually have legs that are bowed (bent) outwards. The equivalent disease in adults is called ***osteomalacia***
- ***Fibrodysplasia*** – Fibrous tissue (muscle, tendon, and ligament) is spontaneously ossified when damaged, causing joints to become permanently locked in place

CHAPTER 26 | **THE MUSCULAR SYSTEM**

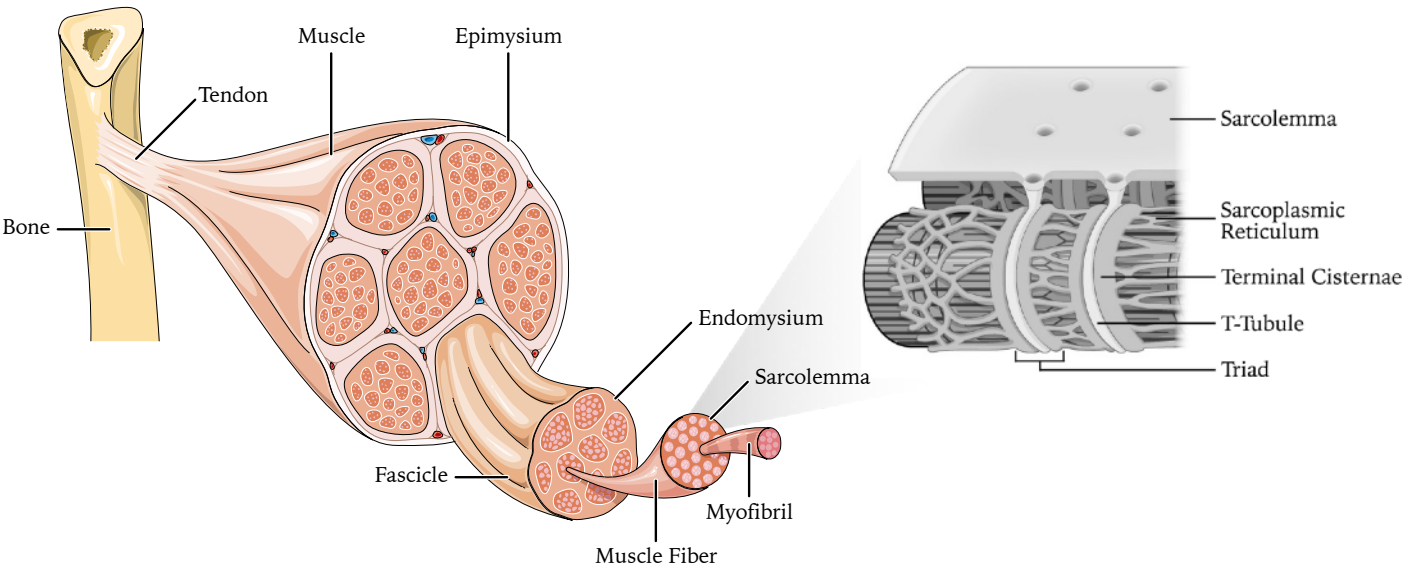
TYPES OF MUSCLE ☆ HIGH-YIELD

- ***Striations*** are a characteristic banding pattern visible under light microscopy due to the parallel organization of myosin and actin proteins
- ***Autorhythmic*** describes a cell that is capable of contracting spontaneously without stimulation
- There are three types of muscle tissue:
  - ***Skeletal Muscle*** – Striated, non-autorhythmic, and multinucleate tissue under voluntary control that functions for posture, locomotion, object manipulation, and venous blood flow. Each muscle fibre consists of a syncytium, a single cytoplasmic mass with several nuclei formed by the fusion of multiple cells
  - ***Cardiac Muscle*** – Striated, autorhythmic tissue under involuntary control that forms the majority of the heart, pumping blood around the body. Each muscle fibre consists of a chain of branching cardiomyocytes joined via ***intercalated disks***
  - ***Smooth Muscle*** – Non-striated, autorhythmic tissue under involuntary control that is found in hollow organs (i.e. stomach, intestines, bladder, uterus), ducts, and tubes. It performs various actions of the autonomic nervous system. Each muscle fibre consists of a single torpedo-shaped smooth muscle cell. Smooth muscle is the only muscle type in which striations are not visible, due to its highly disordered organization of myosin and actin

Type of Muscle	Muscle Fiber	Nuceli	Morphology	Control	Autorhythmic
 Skeletal	Syncytium of Cells	Multinucleate	Striated	Voluntary	No
 Cardiac	Chain of Cells	Mononucleate	Striated	Involuntary	Yes
 Smooth	Individual Cell	Mononucleate	Smooth	Involuntary	Yes

MUSCLE ORGANIZATION ☆ HIGH-YIELD

- Skeletal muscles are connected to bones via ***tendons***. Each muscle is composed of many bundles called ***fascicles***, and is surrounded by a connective tissue layer called the ***epimysium***. Each fascicle is composed of many ***muscle fibres*** and is surrounded by its own connective tissue called the ***endomysium***. Finally, each muscle fibre is composed of many ***myofibrils*** and is surrounded by a cell membrane called the ***sarcolemma***
- The sarcolemma is penetrated by invaginations called ***transverse tubules (T-tubules)***, which allow rapid transmission of an action potential into the cell. The T-tubules associate closely with the ***terminal cisternae*** of the ***sarcoplasmic reticulum***, an organelle that stores calcium ions for initiating a muscle contraction



- Each myofibril consists of repeating protein structures called ***sarcomeres***, which are the smallest functional units of muscle. A sarcomere is composed of the following components:
  - ***Actin Filament*** – Also known as "thin filaments". Consists of two chains of actin protein arranged in a double helix
  - ***Myosin Filament*** – Also know as "thick filaments". Consists of two ATP-dependent myosin proteins twisted around each other, with ATP hydrolysis occurring at its two head domains
  - ***Tropomyosin*** – Protein that twists around actin and covers the actin active sites to prevent myosin head from binding
  - ***Troponin*** – Protein that holds tropomyosin in place. Ca^{2+} ions can bind to troponin and prevent it from holding tropomyosin in place
  - ***Z Disk*** – Serves as an anchor for myosin and actin. Also delineates the borders of a sarcomere
  - ***Titin*** – Large elastic protein attached to either end of the myosin filament, anchoring it to the Z disk and aligning it with the M line. Responsible for the elasticity of muscle

MNEMONIC Titin holds myosin tight

- There are five important features of a sarcomere visible under a microscope:
  - ***I Band*** – Region containing only thin filaments (actin)

  MNEMONIC The I band appears LIGHT under microscopy

  - ***A Band*** – Region containing the entire length of thick filaments (myosin)

  MNEMONIC The A band appears DARK under microscopy

  - ***H Band*** – Region containing only thick filaments (myosin)

  MNEMONIC The H band is composed of only THICK filaments

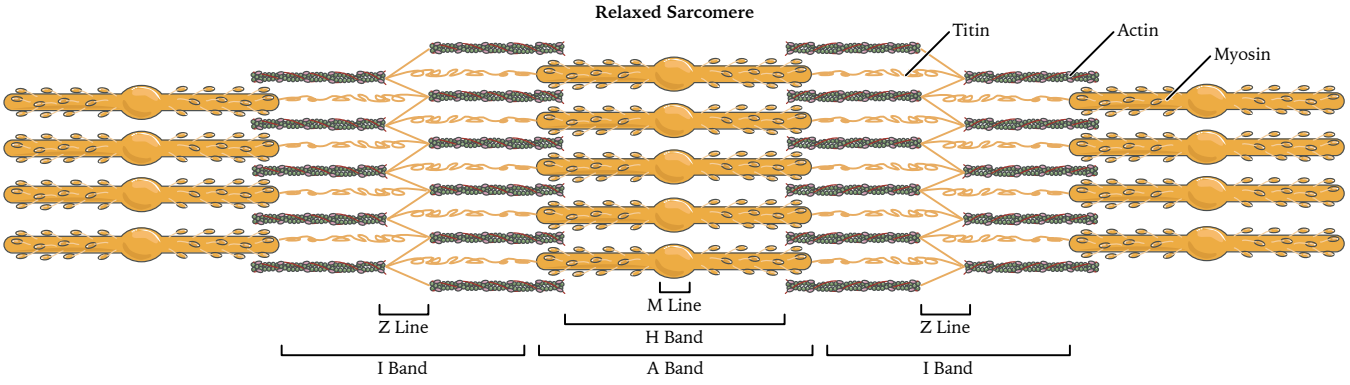
  - ***M Line*** – String of proteins in the middle of the A band that anchors myosin

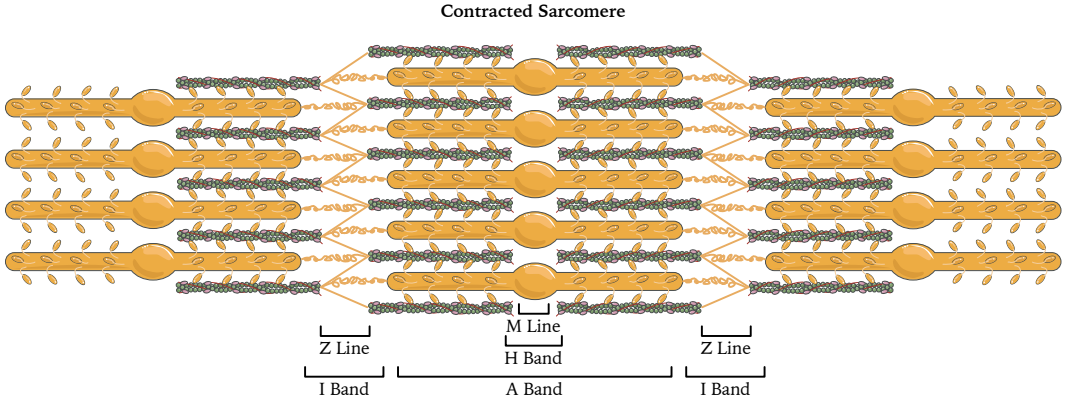
  MNEMONIC The M line is in the MIDDLE

  - ***Z Line*** – Region containing Z disks, which anchor actin and myosin. Delineates the sarcomere's borders

  MNEMONIC The Z line contains Z disks
- The only two bands that change length during a muscle contraction are the H and I bands

  MNEMONIC Say "HI" to muscle contraction

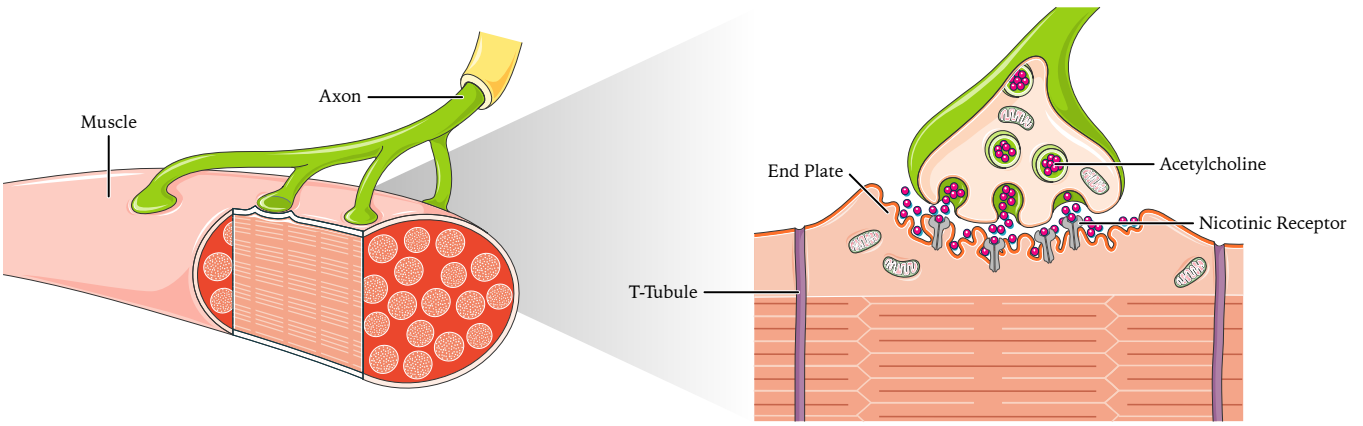




NEUROMUSCULAR JUNCTION

- Skeletal muscles are able to voluntarily contract thanks to synapses between the somatic nervous system and muscles, called ***neuromuscular junctions***. The sum of all muscle fibres that are innervated by one motor neuron is called a ***motor unit***
- Synaptic transmission across a neuromuscular junction occurs via the following mechanism:

1. Action potential reaches the presynaptic terminal of a motor neuron, causing the exocytosis of ***acetylcholine*** into the synaptic cleft
2. Acetylcholine binds to ***nicotinic receptors*** located at the ***end plate*** of a muscle cell. This causes voltage-gated Na^+ channels to open, causing an action potential that is propagated down the T-tubules and to the sarcoplasmic reticulum
3. The sarcoplasmic reticulum releases Ca^{2+}, which triggers muscle contraction

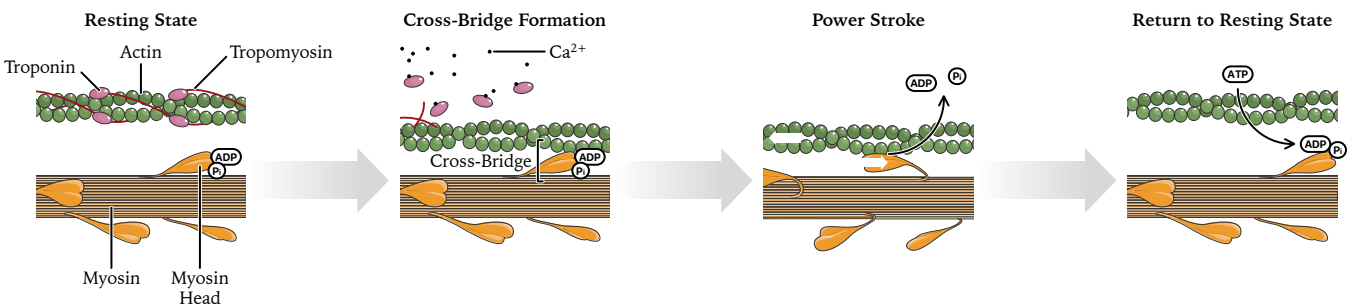


MUSCLE CONTRACTION ☆ HIGH-YIELD

- Muscle contraction is believed to occur via the ***sliding filament model***, in which the length of the sarcomere shortens but the length of individual fibres remains the same. This occurs via the following mechanism:

1. An action potential is received from a motor neuron and spreads from the neuromuscular junction into the individual muscle cells via the T-tubules. This causes Ca^{2+} to be released from the sarcoplasmic reticulum
2. When the muscle is at rest, the myosin head is in a high-energy "cocked" conformation. However, a protein called ***tropomyosin*** blocks actin's active sites, preventing myosin from binding to actin. Tropomyosin is held onto actin by another protein called ***troponin***. When exposed to Ca^{2+}, troponin is released, causing tropomyosin to disassociate from actin. This allows myosin to form a ***cross-bridge*** with actin
3. ADP and P_i are released from the myosin head, returning myosin into its native conformation. This ***power stroke*** pushes the actin and myosin filaments in opposite directions
4. When a new molecule of ATP binds to the myosin head, the cross-bridge is broken and myosin detaches from actin. Dephosphorylation of the new ATP returns the myosin head to the high-energy "cocked" conformation. This cycle repeats until the muscle stops receiving action potentials or all ATP is exhausted

- Note that without a constant supply of fresh ATP, myosin is unable to dissociate from actin. This is what causes ***rigor mortis***, the continued state of muscle contraction and rigidity after death



PATHOLOGIES

- ***Botulism*** – Muscle weakness and paralysis due to bacterial botulinum toxin, which inhibits the release of acetylcholine at the neuromuscular junction
- ***Tetanus*** – Muscle spasms and sustained contraction due to bacterial tetanus toxin, which also inhibits the release of acetylcholine at the neuromuscular junction
- ***Muscular Dystrophy*** – The weakening and atrophy of skeletal muscles over time

CHAPTER 27 | THE INTEGUMENT SYSTEM

FUNCTIONS OF THE INTEGUMENT

- ***Thermoregulation*** – Maintains body temperature homeostasis through dilation/contraction of arterioles leading to capillary beds that facilitate evaporative cooling
- ***Protection*** – The physical barriers of skin are part of the innate immune, and dendritic cells in the epidermis are part of the adaptive immune system
- ***Sensation*** – Sends afferent information about temperature, pressure, and pain to the CNS
- ***Excretion*** – Excess water and ions are excreted through skin
- ***Vitamin D Synthesis*** – UV radiation activates 7-dehydrocholesterol in the skin, a precursor to Vitamin D
- ***Blood Reservoir*** – Vessels in the dermis hold around 10% of the blood in a resting adult

SKIN ANATOMY OVERVIEW ☆ HIGH-YIELD

- Skin consists of two major layers – the ***epidermis*** and ***dermis***. The ***hypodermis*** is technically not part of the skin. It consists of adipose (fat) and connective tissue. The epidermis and dermis each have their own distinct layers. The order of all skin layers from superficial to deep is:
  - Stratum Corneum
  - Stratum Lucidum
  - Stratum Granulosum
  - Stratum Spinosum
  - Stratum Basale

  ] Epidermis

  - Papillary Region
  - Reticular Region

  ] Dermis

  - Hypodermis

MNEMONIC "Come Let's Get Sun Burnt" → Corneum Lucidum Granulosum Spinosum Basale

- There are two types of skin. ***Thick skin*** is found on the palms, soles of the feet, and finger tips. It has a thick epidermal layer and no hair follicles. ***Thin skin*** is found everywhere else on the body. It has a thinner epidermal layer and does contain hair. Note that hair is a unique mammalian structure that functions for thermal insulation, physical protection, and sensation

EPIDERMIS

- The ***epidermis*** is an avascular tissue that depends on the dermis for oxygen and nutrients
- Important epidermal cells include:
  - ***Keratinocytes*** – Precursors to ***corneocytes***, which are waterproof anucleate cells that are routinely sloughed off and replaced. They contain ***keratin*** (a structural protein) and ***lamellar bodies*** (organelles that exocytose lipids, waterproofing the epidermis)
  - ***Melanocytes*** – Cells that produce and transport melanin pigment to keratinocytes
  - ***Langerhans Cells*** – Resident dendritic cells of the skin. They present antigens to helper T-cells
  - ***Merkel Cells*** – Slow-adapting mechanoreceptors with a small receptive field; abundant in highly sensitive areas such as the skin on fingertips

- The epidermis consist of various layers that are visually distinct under the microscope:
  - ***Stratum Corneum*** – The outermost layer. Contains dead corneocytes, keratin protein, and lipids
  - ***Stratum Lucidum*** – Contains additional dead corneocytes for extra protection. Exists only in thick skin
  - ***Stratum Granulosum*** – Contains live keratinocytes migrating up from the stratum spinosum. The keratinocytes contain granules filled with ***keratohyalin***, the precursor to keratin. Lamellar bodies are also secreted in this layer
  - ***Stratum Spinosum*** – Contains live keratinocytes securely bound to each other via desmosomes. This layer is responsible for most of the skin's strength and flexibility
  - ***Stratum Basale/Germinativum*** – Contains stem cells that differentiate into keratinocytes, as well as Merkel cells and melanocytes. This layer sits right above the basal membrane, which delineates the epidermis from the dermis

DERMIS

- The ***dermis*** is a vascular tissue that contains collagen, elastin, hair follicles, glands, adipocytes, and nerves. It contains folds called ***dermal papillae***, which increase the strength of its attachment with the epidermis. The dermis consists of only two layers:
  - ***Papillary Region*** – Superficial 20%. Features dermal papillae, upward projections of the dermis into the epidermis which increase surface area and create our fingerprints
  - ***Reticular Region*** – Deep 80%. Contains dense irregular connective tissue

MNEMONIC "PR" → Papillary Reticular

EXOCRINE GLANDS OF THE SKIN

- ***Sebaceous Glands*** – Found at the base of hair follicles. Sebaceous glands produce oily ***sebum*** to lubricate and waterproof the skin and hair
- ***Sudoriferous Glands*** – Produce ***sweat***. There are two types:
  - ***Eccrine*** – Most common sweat gland, found throughout the body. Eccrine sweat glands secrete a dilute electrolyte fluid over the skin to eliminate urea and regulate body temperature through perspiration
  - ***Apocrine*** – Found only in the armpits, nipples, and public region. Apocrine sweat glands secrete viscous solutions with pheromone-like compounds. Unlike eccrine glands, they secrete directly into the hair follicle
- ***Ceruminous Glands*** – Found in the ear canal. Ceruminous glands produce ***cerumen***, a wax-like material that lubricates, waterproofs, kills bacteria, and traps foreign particles
- ***Mammary Glands*** – Produce ***milk*** to feed newborns after pregnancy

CHAPTER 28 | THE ENDOCRINE SYSTEM

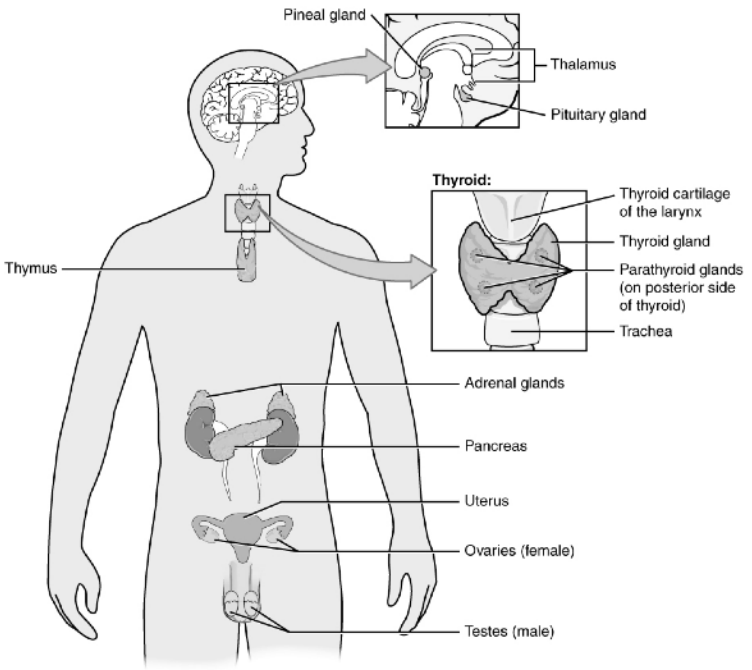
- The endocrine system secretes hormones directly into the blood or extracellular fluid. Hormones function as long-distance chemical signals, affecting only ***target cells*** with the proper ***receptor proteins***

TYPES OF HORMONES

- There are three main categories of hormones:
  - ***Proteins/Polypeptides***
    - Composed of amino acids connected via peptide bonds. They are hydrophilic and cannot cross cell membranes. Thus, their receptors are located in or on the cell membrane. Binding will initiate a ***signalling cascade*** within the cell, composed of ***secondary messengers***. Insulin is a common example
  - ***Steroids***
    - Composed of three cyclohexane rings and one cyclopentane ring, derived from cholesterol. They are hydrophobic and can cross cell membrane. Thus, their receptors are located within the cell nucleus and act as transcription factors. Steroid hormones may combine with a hydrophilic ***carrier protein*** to allow them to be transported via the circulatory system. Examples of steroid hormones include testosterone, estrogen, progesterone, cortisol, and aldosterone
  - ***Monoamines/Tyrosine Derivatives***
    - Monoamines are compounds derived from tyrosine or other aromatic amino acids
    - There are only four monoamine hormones to memorize: the thyroid hormones (T3, T4), and the catecholamines (epinephrine, norepinephrine). Thyroid hormones behave like steroid hormones, while catecholamines behave like protein hormones
- Hormones can also be classified based on the varying distances in which it acts:
  - ***Endocrine Hormones*** – Act at great distances from its source
  - ***Paracrine Hormones*** – Act regionally or at small distances from its source
  - ***Autocrine Hormones*** – Act on or beside the same cell that released it
- A ***neurohormone*** is any hormone that is produced by a neuron, rather than an endocrine cell

ENDOCRINE GLANDS ☆ HIGH-YIELD

- ***Hypothalamus*** – Located under the thalamus and responsible for detecting deviations from ***homeostasis*** and producing special neurohormones (releasing hormones) that signal the pituitary gland to produce hormones
- ***Pituitary Gland*** – Located under the hypothalamus and responsible for producing most endocrine hormones
  - The ***posterior pituitary*** is made of endocrine cells that produce hormones upon receiving electrical signals from the hypothalamus via a special axonal structure called the ***infundibulum***
  - The ***anterior pituitary*** is made of endocrine cells that produce hormones upon receiving neurohormone signals from the hypothalamus via a special capillary system called the ***hypophyseal portal system***
- ***Pineal Gland*** – Located near the thalamus and responsible for regulating the circadian rhythm
- ***Thyroid*** – Regulates overall metabolic rate and blood calcium levels by secreting T3, T4, and calcitonin
- ***Parathyroid*** – Regulates blood calcium levels by secreting parathyroid hormone
- ***Pancreas*** – Regulates blood glucose levels by releasing insulin, glucagon, and inhibin
- ***Adrenal Gland*** – Regulates the autonomic nervous system (ANS), stress, and blood pressure by releasing catecholamines, glucocorticoids (cortisol), and mineralocorticoids (aldosterone)
  - Mineralocorticoids are produced in the ***zona glomerulosa*** of the adrenal cortex
  - Glucocorticoids are produced in the ***zona fasciculata*** of the adrenal cortex
  - Androgens are produced in the ***zona reticularis*** of the adrenal cortex
  - Catecholamines are produced in the adrenal medulla
- ***Gonads*** – The testes and ovaries regulate the development of secondary sex characteristics, in addition to spermatogenesis, ovulation, and pregnancy



THYROID HORMONE SYNTHESIS

- The thyroid hormones ***triiodothyronine (T3)*** and ***thyroxine (T4)*** are produced in a structure called the ***thyroid follicle***, which is composed of multiple follicular cells surrounding a ***colloid-filled lumen***
- The colloid is a gelatinous fluid rich in ***thyroglobulin***, a tyrosine-derived protein secreted by follicular cells
- The follicular cells also actively transport ***iodine*** from nearby capillaries into the lumen, where it attaches to the thyroglobulin to create ***monoiodotyrosine (MIT)*** or ***diiodotyrosine (DIT)***
- The luminal enzyme ***thyroid peroxidase*** then couples MITs and DITs together:
  - MIT + DIT = Triiodothyronine (T3)
  - DIT + DIT = Thyroxine (T4)

PATHOLOGIES

- ***Hyperthyroidism*** – Overproduction of thyroid hormones T3 and T4, resulting in a hyper-metabolic state. Symptoms include high body temperature, weight loss despite increase in appetite, rapid heart rate, hyperactivity, anxiety, insomnia, and osteoporosis
  - Hyperthyroidism can be ***primary*** (due to malfunctioning thyroid) or ***secondary*** (due to malfunctioning anterior pituitary). In primary hyperthyroidism, TSH is low while T3/T4 are high. In secondary hyperthyroidism, TSH and T3/T4 are both high.
  - The most common cause of hyperthyroidism is ***Grave's disease***
- ***Hypothyroidism*** – Underproduction of thyroid hormones T3 and T4, resulting in a hypo-metabolic state. Symptoms include cold intolerance, weight gain, constipation, tiredness, and depression
  - Hypothyroidism can also be primary or secondary. In primary hypothyroidism, TSH is high while T3/T4 are low. This leads to the formation of a ***goiter***. In secondary hypothyroidism, TSH and T3/T4 are both low
  - The most common cause of primary hypothyroidism is ***iodine deficiency***. The second most common cause of primary hypothyroidism is ***Hashimoto's thyroiditis***, an autoimmune disease that destroys the thyroid gland

IMPORTANT HORMONES ☆ HIGH-YIELD

- The next page contains a summary of all the hormones you should be familiar with for the Canadian DAT

MNEMONIC Calci<u>tonin</u> → "<u>Tones</u> down" blood calcium levels. Parathyroid hormone is the opposite

Gland	Hormone	Stimulus	Target	Function
Hypothalamus	**Growth Hormone Releasing Hormone (GHRH)** (P)	Embryonic development, exercise, sleep	Anterior pituitary	Stimulate secretion of human growth hormone from the anterior pituitary
	Growth Hormone Inhibiting Hormone (Somatostatin) (P)	High blood levels of human growth hormone	Anterior pituitary	Inhibit secretion of human growth hormone from the anterior pituitary
	Gonadotropin Releasing Hormone (GnRH) (P)	Low concentrations of estrogen, progesterone, or testosterone	Anterior pituitary	Stimulate secretion of FSH and LH from the anterior pituitary
Posterior Pituitary* *(Produced in Hypothalamus, Stored in Posterior Pituitary)	**Antidiuretic Hormone (ADH)** (P)	Hypertonicity detected by the hypothalamus	Collecting duct of the kidney	Increase water permeability of the collecting duct, resulting in increased blood volume and reduced hypertonicity
	Oxytocin (P)	Skin contact, pressure on uterus opening, sucking of mammary glands	Uterus and mammary glands	Stimulates uterine contractions and milk letdown in women, and ejaculation in men. Stimulates social bonding and reduces anxiety in both sexes
Anterior Pituitary	**Thyroid Stimulating Hormone (TSH)** (P)	Thyrotropin releasing hormone (TRH) from the hypothalamus	Thyroid	Stimulates secretion of triiodothyronine (T3) and thyroxine (T4) from the thyroid. Also stimulates thyroid growth
	Growth Hormone (Somatotropin) (P)	Growth hormone releasing hormone (GHRH) from the hypothalamus	Bone, cartilage, soft tissue	Stimulates growth by increasing metabolism of glucose and other fuels, protein synthesis, and calcium absorption from blood
	Adrenocorticotropic Hormone (ACTH) (P)	Corticotropin releasing hormone (CRH) from the hypothalamus	Adrenal cortex	Stimulates secretion of glucocorticoids (cortisol) and mineralocorticoids (aldosterone) from the adrenal cortex
	Follicle-Stimulating Hormone (FSH) (P)	Gonadotropin releasing hormone (GnRH) from the hypothalamus	Ovaries and testes	Stimulates follicle development and estrogen secretion in females, and spermatogenesis in males. Stimulates inhibin secretion in both sexes
	Luteinizing Hormone (LH) (P)	Gonadotropin releasing hormone (GnRH) from the hypothalamus	Ovaries and testes	Stimulates ovulation in females, and testosterone secretion in males
	Prolactin (P)	Prolactin releasing hormone (PRH) from the hypothalamus	Mammary glands	Stimulates breast development and milk production. Inhibited by dopamine
Pineal Gland	**Melatonin** (M)	Circadian rhythm, absence of light	Brain	Synchronizes the body's biological clock
Thyroid	**Calcitonin** (P)	High blood calcium levels	Bones and kidneys	Stimulates deposition of calcium into bones and decreases calcium reabsorption in kidneys. Leads to overall decrease in blood calcium levels
	Triiodothyronine (T3) and Thyroxine (T4) (M)	Thyroid stimulating hormone (TSH) from the anterior pituitary	Most cells of the body	Increases overall metabolic rate
Parathyroid	**Parathyroid Hormone** (P)	Low blood calcium levels	Bones, kidneys, small intestines	Stimulates release of calcium from bones, increases calcium reabsorption, and activates vitamin D. Leads to overall increase in blood calcium levels
Pancreas	**Insulin** (P)	High blood glucose levels	Liver, muscle, adipocytes	Promotes glucose uptake by cells, decreasing blood glucose levels
	Glucagon (P)	Low blood glucose levels	Liver, muscle, adipocytes	Promotes glucose release by cells, increasing blood glucose levels
Adrenal Medulla	**Epinephrine and Norepinephrine** (M)	Stress, sympathetic nervous system activation	Receptors throughout the body	Activates sympathetic nervous system, triggering "fight or flight" response. Increases blood glucose, reduces blood flow to non-essential organs, etc
Adrenal Cortex	**Cortisol** (S)	Adrenocorticotropic hormone (ACTH), stress	Receptors throughout the body	Increases blood glucose, catabolizes fat, suppresses immune system, decreases bone formation, absorbs sodium, and excretes potassium
	Aldosterone (S)	Adrenocorticotropic hormone (ACTH), low blood sodium levels	Distal convoluted tubule of the kidney	Increases sodium reabsorption in the distal convoluted tubule and collecting duct. Leads to overall increase in blood volume
Ovaries	**Estrogen** (S)	Follicle stimulating hormone (FSH) and leutenizing hormone (LH)	Receptors throughout the body	Regulates menstrual cycle and develops secondary sex characteristics
	Progesterone (S)	Leutenizing hormone (LH) from the corpus leuteum	Receptors throughout the body	Prepares the endometrium for gestation of the embryo
Testes	**Testosterone** (S)	Follicle stimulating hormone (FSH) and leutenizing hormone (LH)	Receptors throughout the body	Stimulates spermatogenesis and develops secondary sex characteristics

SYMBOL LEGEND

(P) = Protein/Polypeptide (S) = Steroid (M) = Monoamine/Tryptophan Derivative

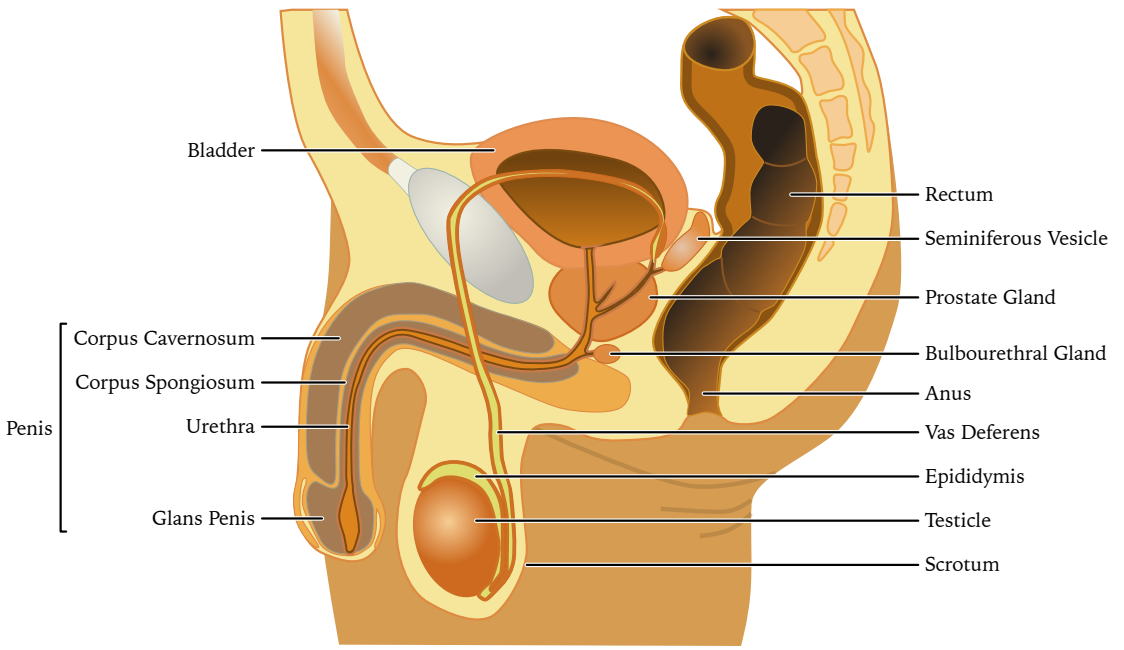
CHAPTER 29 | MALE REPRODUCTIVE SYSTEM

MALE SEX CHARACTERISTICS

- ***Primary sex characteristics*** are features that are present since birth and directly involved in reproduction. For males, this includes the XY chromosome configuration, testosterone, penis, scrotum, and testes
- ***Secondary sex characteristics*** are features that develop after puberty and indicate sexual maturity. For males, this includes abundant facial and body hair, increased muscle mass, broad shoulders, enlarged larynx (Adam's apple), small mammary glands, low body fat, and a deep voice

MALE ANATOMY

- ***Testes*** – The male reproductive gonad, a pair of oval organs housed within an external extension of the abdominal wall called the ***scrotum***. Each testicle produces sperm and androgens such as testosterone
- ***Seminiferous Tubules*** – Tubes located in each testicle that contain cells which create male gametes via spermatogenesis (a specific type of meiosis). Not to be confused with seminiferous vesicles
- ***Epididymis*** – A convoluted tube that sits behind each testicle and stores maturing sperm. It connects the testicle to the vas deferens
- ***Vas deferens*** – A duct that transfers sperm from each epididymis to the ejaculatory ducts and then into the urethra prior to ejaculation
- ***Penis*** – An external structure composed of two ***corpora cavernosa*** and one ***corpus spongiosum***, the latter of which contains the urethra. These three tissue columns become engorged with blood and stiff during erection
- ***Seminiferous Vesicles*** – A pair of accessory glands that secrete the non-sperm components of semen:
  - ***Mucus*** – Increase mobility of sperm by reducing friction
  - ***Fructose*** – Nourish the sperm, which rely entirely on the sugar in semen for energy
  - ***Prostaglandins*** – Suppresses female immune response against foreign semen and stimulates uterine contractions, allowing sperm to reach uterus
- ***Prostate Gland*** – An accessory gland that secretes a white alkaline fluid that helps neutralize the acidity of the vaginal tract. Also secretes proteolytic enzymes, citric acid, and zinc
- ***Bulbourethral Glands*** – A pair of accessory glands that secretes a viscous, mucus-rich fluid (called pre-ejaculate) that lubricates the urethra in preparation for ejaculation



SPERMATOGENESIS ☆ HIGH-YIELD

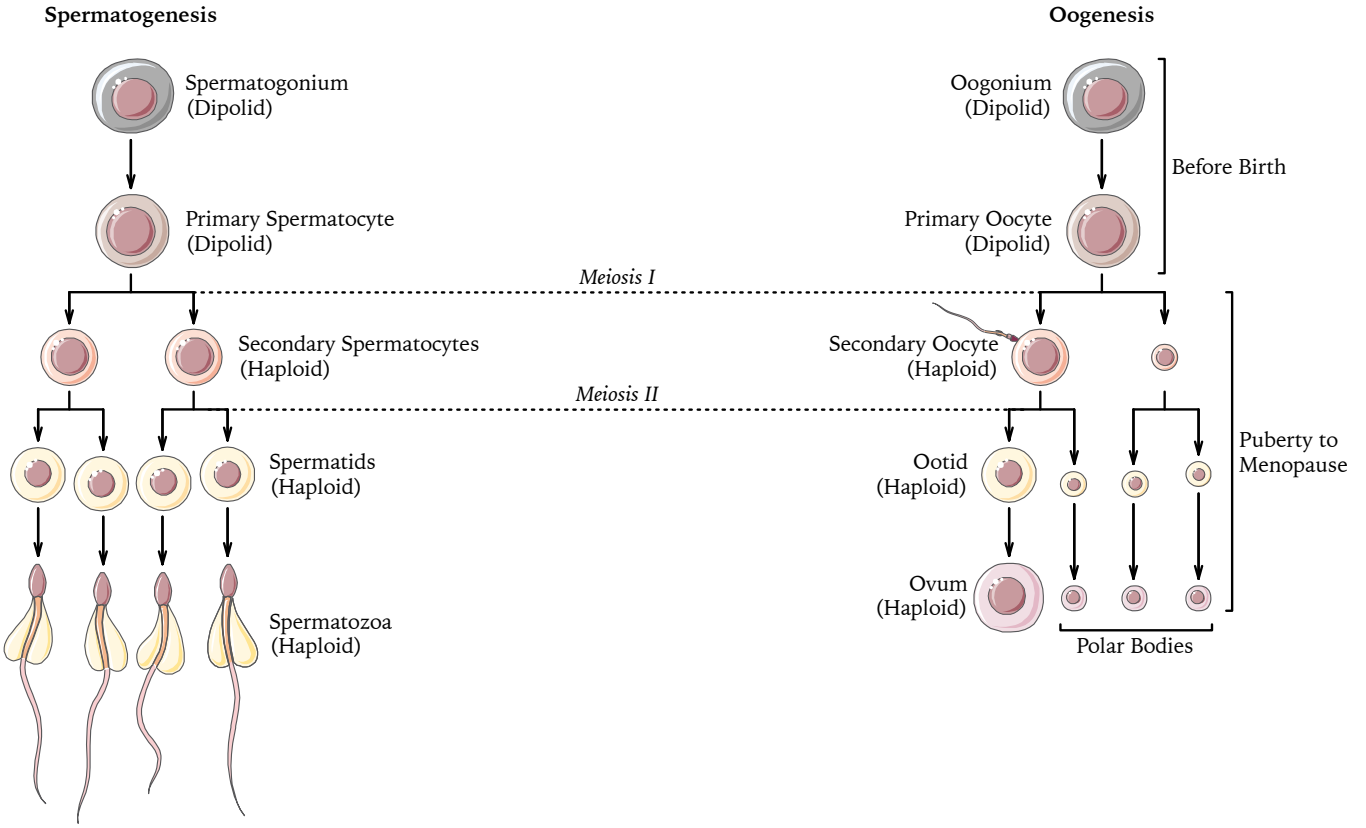
- Spermatogenesis takes place in the seminiferous tubules, which contain three main cell types:
  - ***Leydig Cell*** – Produces ***testosterone*** upon stimulation by ***luteinizing hormone (LH)***

    MNEMONIC Leydig cells are stimulated by Luteinizing Hormone

  - ***Sertoli Cell*** – Supports and provides the nourishment required for ***spermatid*** maturation

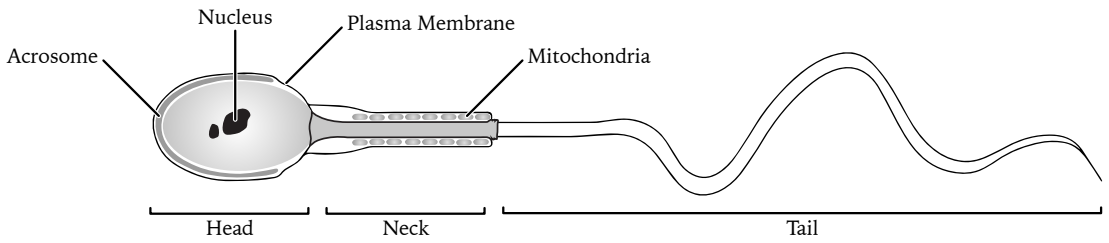
    MNEMONIC Sertoli cells help produce Sperm

  - ***Spermatogonium*** – An undifferentiated germ cell that undergoes mitosis, forming primary spermatocytes
- Spermatogenesis occurs between Leydig cells, which line the circumference of the seminiferous tubule. As the sperm mature, they travel in a luminal direction, eventually ending up in the lumen of the seminiferous tubule
  1. A diploid spermatogonium stem cell undergoes mitosis to produce a diploid ***primary spermatocyte***
  2. Primary spermatocyte undergoes meiosis I to produce two haploid ***secondary spermatocytes***
  3. Secondary spermatocytes undergo meiosis II to produce four haploid ***spermatids***
  4. Spermatids in the lumen are transported to the epididymus, where they complete their maturation to become ***spermatozoa*** (fully-functional sperm)



SPERM ANATOMY

- Spermatozoa are haploid gametes that are composed of a:
  - ***Head*** – Contains the nucleus and ***acrosome***, a cap-shaped organelle derived from the golgi apparatus that contains enzymes needed to penetrate the zona pellucida of the ovum
  - ***Neck*** – Contains mitochondria
  - ***Tail*** – Consists of a long flagellum that provides mobility



HORMONAL REGULATION

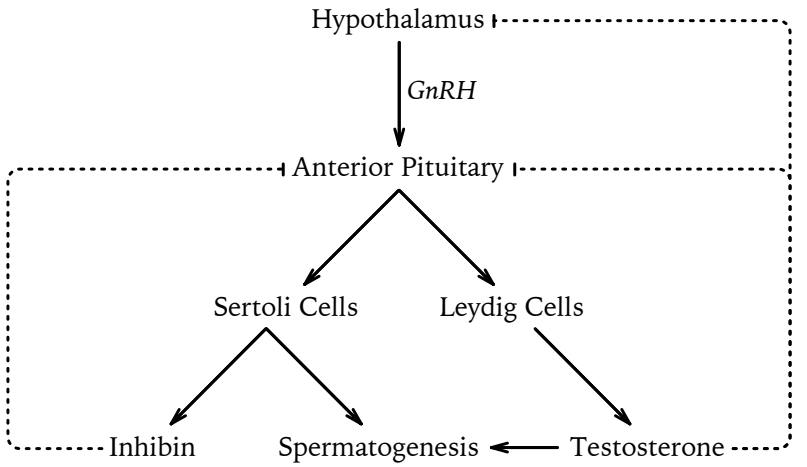
- In males, gamete production begins at puberty and continues until death. However in females, gamete production begins before birth and is paused until puberty, when it resumes and continues until menopause
- There are five hormones involved in the negative feedback loop that regulates spermatogenesis:
  - ***Gonadotropin Releasing Hormone (GnRH)*** – Produced by the hypothalamus and released into the hypophyseal portal system. Promotes the ***anterior pituitary*** to release FSH and LH into systemic circulation
  - ***Follicle-Stimulating Hormone (FSH)*** – Produced by the ***anterior pituitary***. Promotes inhibin release and spermatogenesis by ***Sertoli cells*** in the testes

MNEMONIC Sertoli cells are stimulated by FSH

  - ***Leutenizing Hormone (LH)*** – Produced by the ***anterior pituitary***. Promotes testosterone release by ***Leydig cells*** in the testes

MNEMONIC Leydig cells are stimulated by LH

  - ***Inhibin*** – Inhibits the ***anterior pituitary*** from producing FSH and LH
  - ***Testosterone*** – Promotes spermatogenesis. Inhibits both the ***anterior pituitary*** and the ***hypothalamus*** from producing FSH, LH, and GnRH



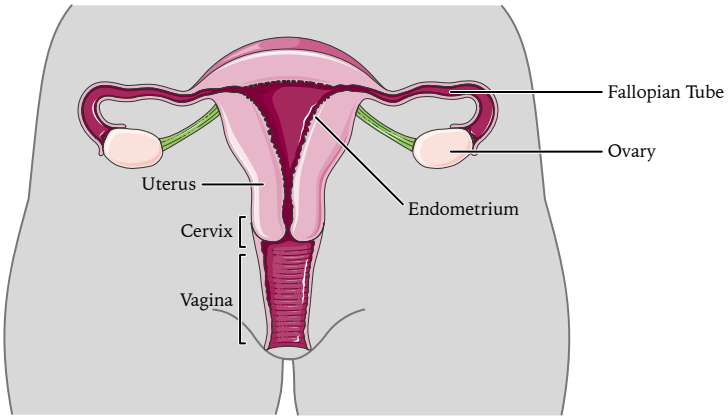
CHAPTER 30 | FEMALE REPRODUCTIVE SYSTEM

FEMALE SEX CHARACTERISTICS

- ***Primary sex characteristics*** are features that are present since birth and directly involved in reproduction. For females, this includes the XX chromosome configuration, estrogen, progesterone, vagina, uterus, and ovaries
- ***Secondary sex characteristics*** are features that develop after puberty and indicate sexual maturity. For females, this includes the menstrual cycle, large mammary glands, and high body fat

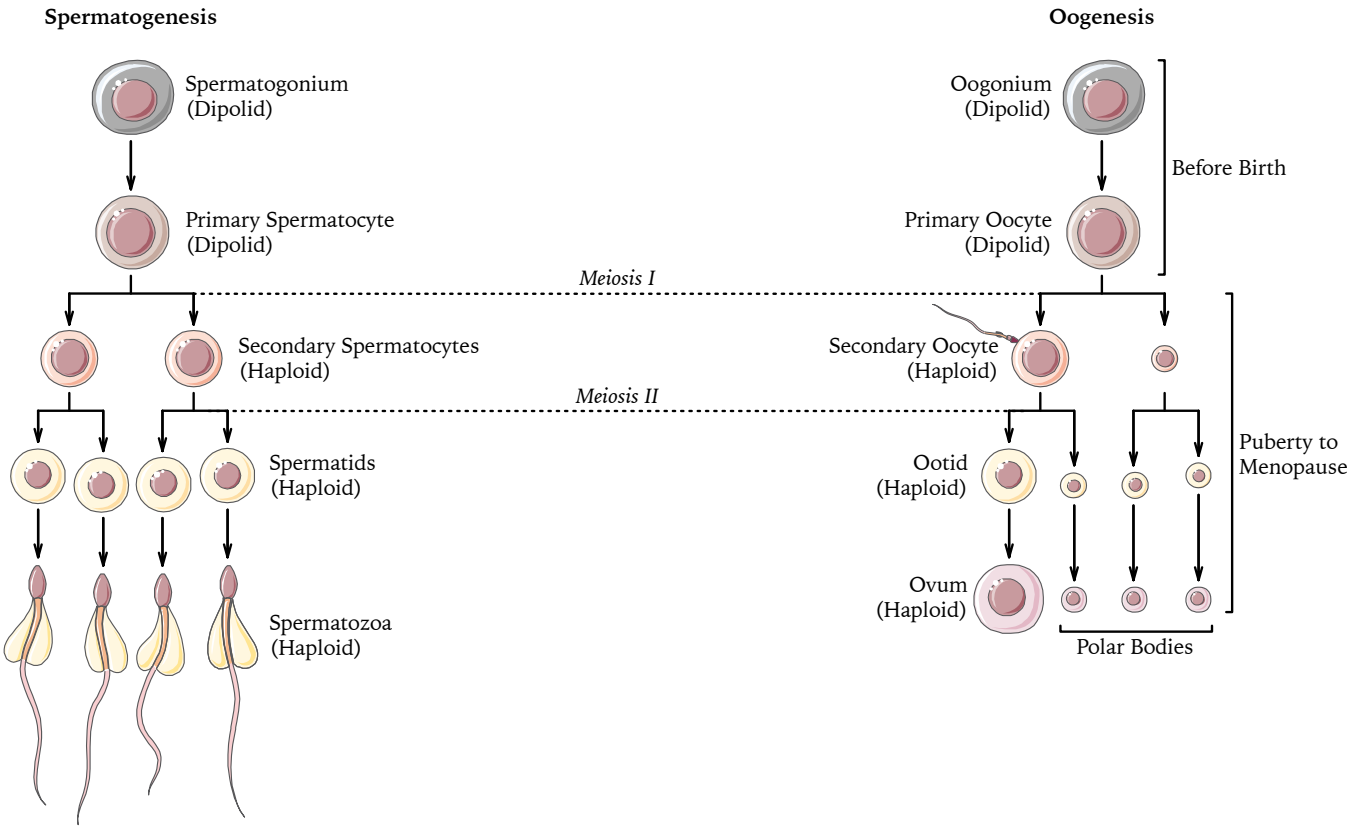
FEMALE ANATOMY

- ***Ovary*** – The female reproductive gonad, a pair of internal, oval organs that store developing eggs
- ***Fallopian Tube*** – Connects the ovaries to the uterus and stores mature eggs for fertilization.
- ***Uterus*** – Muscular organ that contains a dynamic, inner epithelial layer called the ***endometrium***, which changes thickness according to the ***menstrual cycle***. It is also the site of implantation for the fertilized zygote
- ***Vagina*** – A canal that serves as the female reproductive system's only interface with the external environment. It is connected to the uterus by the ***cervix***



OOGENESIS ☆ HIGH-YIELD

- Oogenesis begins before birth, and the eggs remain in the ovaries in an inactive state. During adulthood, a controlled number of these inactive eggs undergo maturation, completing oogenesis
- The maximum number of eggs a female will ever produce has already been determined before her birth. When the supply of inactive eggs is depleted, ***menopause*** occurs
- This is in contrast to spermatogenesis in males, which begins at puberty and continues until death. Therefore, gamete production in males is *continuous* and virtually *unlimited*, while gamete production in females is *interrupted* and *limited*
- Oogenesis takes place in the ovaries:
    1. Prior to birth, a diploid ***oogonium*** undergoes mitosis to produce two diploid ***primary oocytes***
    2. Primary oocytes enter meiosis I, but pause at ***prophase I*** and remain inactive until puberty
    3. From the limited number of primary oocytes produced prior to birth, one primary oocyte resumes meiosis I, producing a haploid ***secondary oocyte*** and a smaller ***polar body***
        - This only occurs once per menstrual cycle. The primary oocyte that resumes meiosis I is surrounding by a transient ovarian structure called the ***follicle***
        - The secondary oocyte pauses again at ***metaphase II*** and remains inactive until fertilized by a sperm
    4. Upon fertilization, the secondary oocyte resumes meiosis II. Another polar body is produced, along with a mature haploid ***ovum***
    5. When the nucleus of the sperm reaches and fuses with the nucleus of the ovum, a diploid ***zygote*** is formed

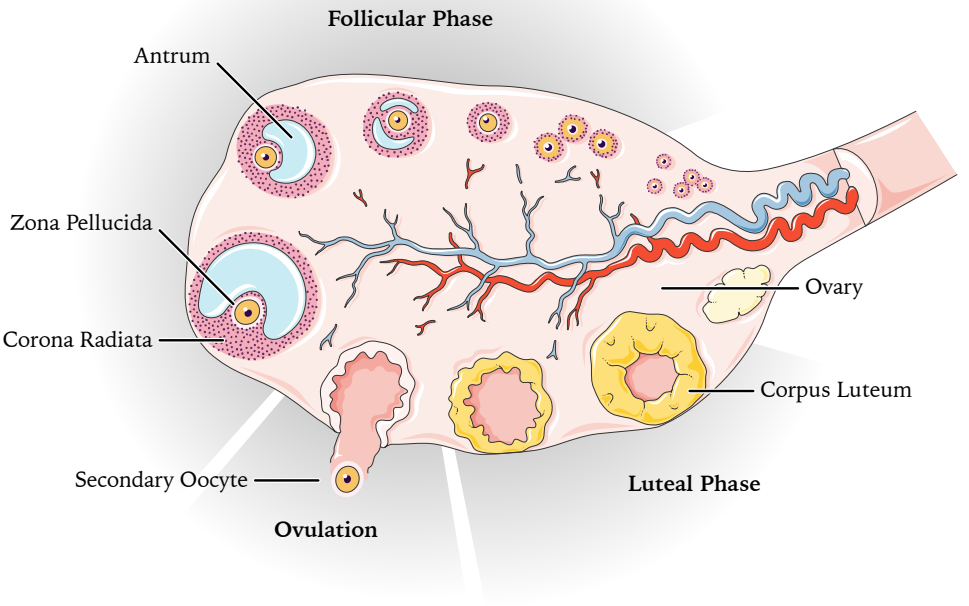


OOCYTE ANATOMY

- An oocyte is a haploid gamete composed of the following components:
  - ***Cytoplasm*** – Contains the nucleus, all the organelles, and lots of mitochondria
  - ***Perivitelline Space*** – Gap between the cytoplasm and the zona pellucida
  - ***Zona Pellucida*** – Glycoprotein layer secreted by the oocyte and follicular cells. Called the ***vitelline layer*** in non-mammalian animals
- The ***corona radiata*** is a layer of special ovarian cells surrounding the egg. These cells are called ***follicular cells*** and are technically not part of the oocyte

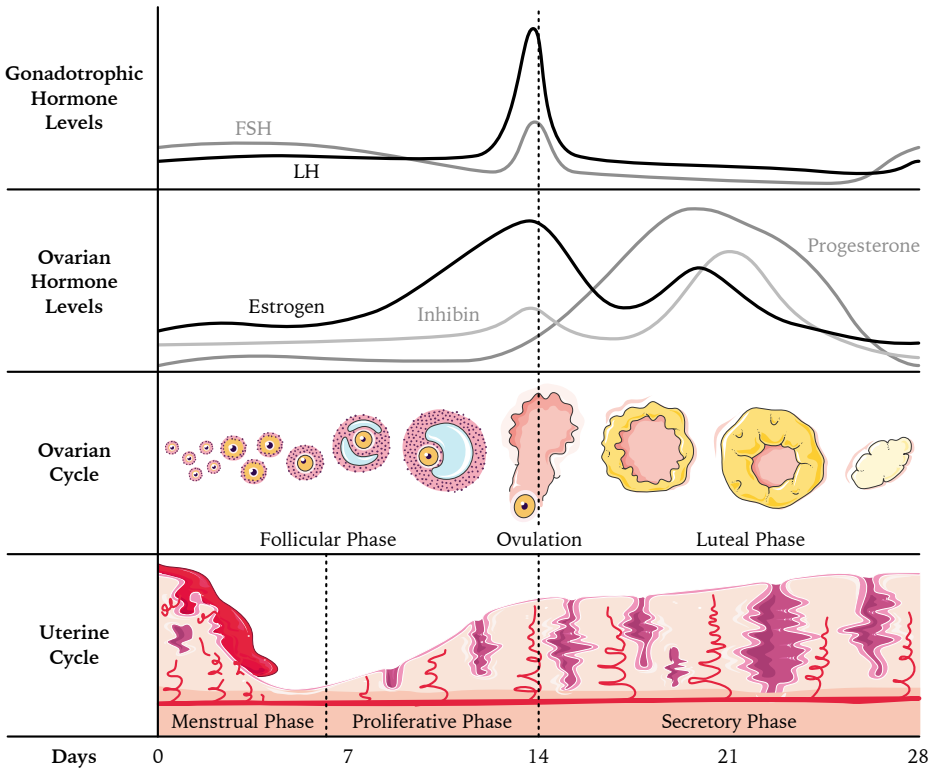
THE OVARIAN CYCLE ☆ HIGH-YIELD

- The ovarian cycle is divided into three phases:
  - ***Follicular Phase*** – The follicle develops and increases the number of ***granulosa cells***, which convert androgens to estrogen. The egg's ***zona pellucida*** also develops during this phase
  - ***Ovulation*** – The process of releasing the secondary oocyte from the ovarian follicle and into the fallopian tubes for fertilization. The remnants of the follicle is called the ***corpus luteum***
  - ***Luteal Phase*** – Granulosa cells of the corpus luteum continue producing estrogen, and begin to produce progesterone and inhibin



THE MENSTRUAL CYCLE ☆ HIGH-YIELD

- The menstrual cycle is also divided into three phases:
  - ***Proliferative Phase*** – The endometrium proliferates and thickens in preparation for implantation of the blastocyst (a structure in early embryonic development)
  - ***Secretory Phase*** – After ovulation, if implantation occurs, estrogen produced by the corpus luteum maintains the thick endometrium
  - ***Menstrual Phase*** – If implantation does not occur, the endometrium is shed in the form of a ***period***



HORMONAL REGULATION ☆ HIGH-YIELD

- We will organize our review of hormonal regulation according to the phases during which they occur:

- **Folicular + Menstrual Phase**
  - If implantation did occur, the blastocyst begins producing ***human chorionic gonadotropin (hCG)***, which is similar to LH in the sense that it prevents the atrophy of the corpus luteum. Commercial pregnancy tests work by detecting hCG levels
  - If implantation did not occur, lack of LH causes the corpus luteum to atrophy, resulting in decreasing estrogen levels. As a result, the following occurs:
    - Low estrogen causes the endometrium to shed
    - Low estrogen and progesterone stimulates the hypothalamus to produce gonadotropin releasing hormone (GnRH) into the hypophyseal portal system
    - GnRH stimulates anterior pituitary to produce follicle stimulating hormone (FSH) and leutenizing hormone (LH) into systemic circulation
    - FSH stimulates follicle development, increasing the number of estrogen-producing granulosa cells

  MNEMONIC The corpus Luteum requires Leutenizing hormone to survive

- **Folicular + Proliferative Phase**
  - Increasing estrogen stimulates thickening of endometrium. It also triggers a ***positive feedback*** mechanism, causing the hypothalamus to produce more GnRH, triggering more FSH and LH production. This leads to an ***LH surge***, which triggers ovulation

  MNEMONIC The Endometrium requires Estrogen to survive

- **Ovulation**
  - Secondary oocyte is released from the ovarian follicle and into the fallopian tubes for fertilization. The remnants of the follicle becomes the ***corpus luteum***

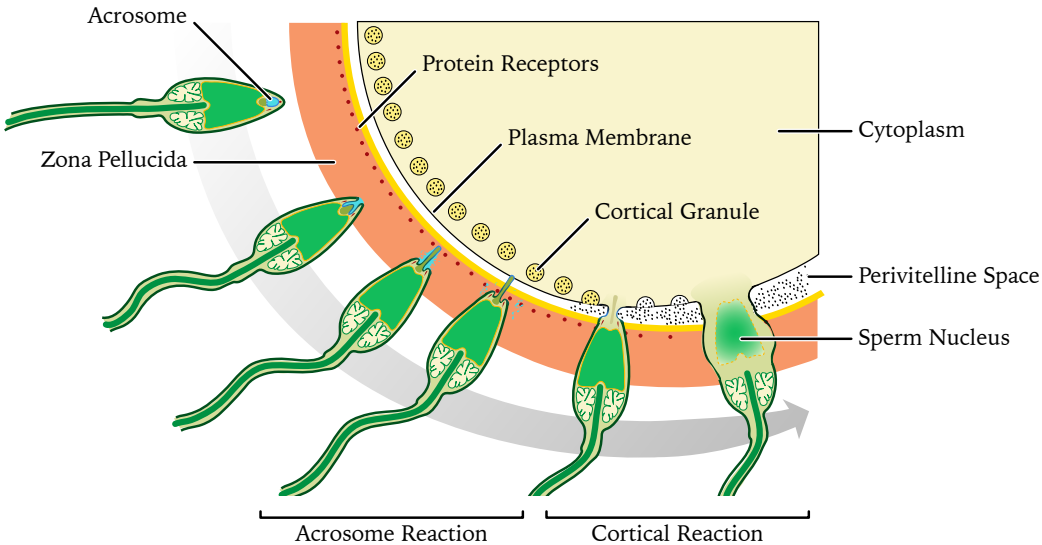
- **Luteal + Secretory Phase**
  - The positive feedback system of estrogen switches back into a ***negative feedback*** system. The corpus luteum begins secreting more inhibin, which inhibits FSH production.
  - If implantation occurs, the corpus luteum continues secreting estrogen and begins secreting ***progesterone***, which maintains the thick endometrium and prepares the uterus for gestation of the embryo. When the placenta develops, it takes over the role of progesterone production and the corpus luteum is degraded

  MNEMONIC Progesterone prepares the uterus for gestation

CHAPTER 31 | EMBRYONIC DEVELOPMENT

FERTILIZATION ☆ HIGH-YIELD

- Fertilization occurs when a sperm and egg meet in the fallopian tube. During fertilization, many sperm burrow through the corona radiata cells surrounding the secondary oocyte. Once a single sperm reaches the zona pellucida, there are two reactions that occur:
  - ***Acrosome Reaction***
    - Sperm binds to glycoproteins of the zona pellucida and releases digestive enzymes from its acrosome
    - Enzymes break down the zona pellucida and allows the sperm and oocyte membranes to fuse
    - Sperm nucleus and centrioles are injected into oocyte cytoplasm, triggering completion of meiosis II
    - The ovum becomes a zygote once the nuclei fuse
  - ***Polyspermy Block***
    - Crucial for preventing the fertilization of an oocyte by multiple sperm, resulting in aneuploidy. There are two methods of blocking polyspermy:
    - ***Fast Block – Electrical***
      - Most common in non-mammals. During the fast block reaction, membrane fusion of the sperm and egg triggers oocyte depolarization, allowing Na^+ to diffuse into the cell down its concentration gradient and increase membrane potential (make it less negative). Additional sperm are blocked due to the repulsion between their positive membranes and the positive egg
    - ***Slow Block – Cortical Reaction***
      - Most common in mammals. During the slow block reaction, membrane fusion triggers release of Ca^{2+} from the endoplasmic reticulum. The Ca^{2+} causes ***cortical granules*** to release the following:
        - ***Proteases*** that destroy sperm binding sites in the zona pellucida
        - ***Peroxidases*** that harden the zona pellucida into an impermeable ***fertilization membrane***
        - ***Glycosaminoglycans*** that attract water into the perivitelline space, increasing the distance of the zona pellucida from the cytoplasm of the ovum
- Note that the mitochondria of sperm do not contribute to the zygote. Instead, all mitochondria come from the egg and are ***maternally inherited***

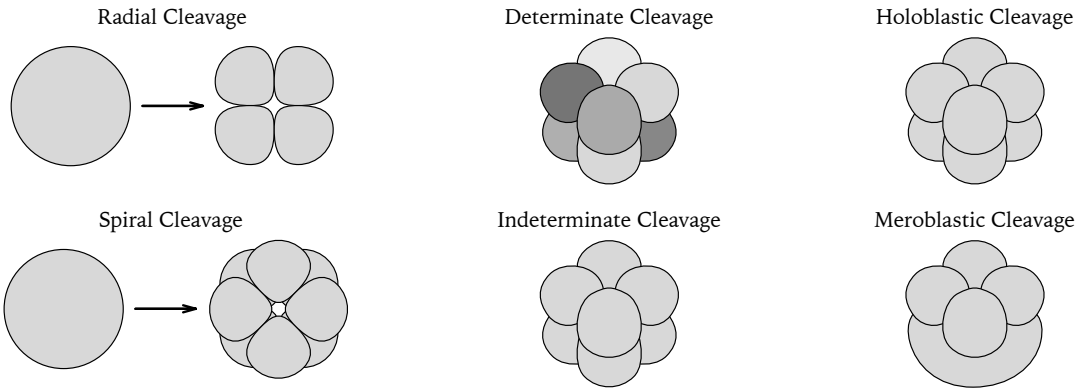


STAGES OF EMBRYONIC DEVELOPMENT ☆ HIGH-YIELD

- After fertilization, the zygote goes through the following developmental phases:
  - ***Cleavage*** – A series of rapid mitotic divisions that increases the number of cells without increasing total volume. The daughter cells of the zygote are called ***blastomeres***
  - ***Morulation*** – The development of blastomeres into a solid, berry-shaped ball of eight cells called a ***morula***
  - ***Blastulation*** – The formation of a hollow cavity called the ***blastocoel***
  - ***Gastrulation*** – The development of the embryonic gut (***archenteron***), ***coelom***, and three ***germ layers***
  - ***Organogenesis*** – The development of organs from the three germ layers (includes ***neurulation***)
- We will spend the rest of the chapter exploring the important phases in more detail

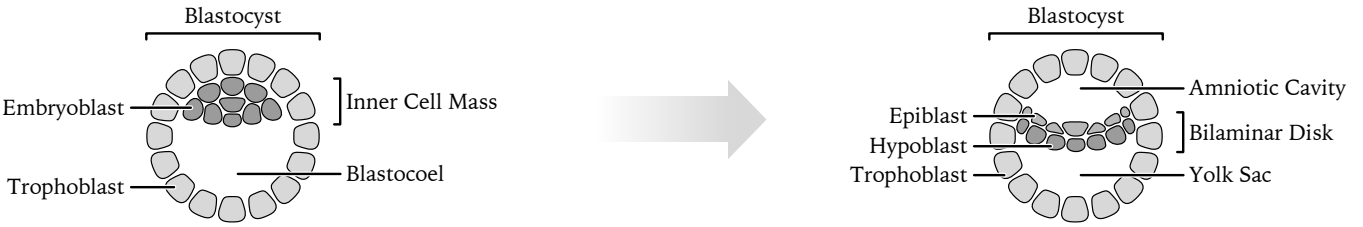
CLEAVAGE

- During cleavage, the zygote undergoes mitotic divisions without increasing cytoplasmic volume. Each daughter cell is called a ***blastomere***, and all blastomeres add up to the same volume as the pre-cleavage zygote
- There are various types of ***cleavage patterns***, which can be categorized based on:
  - **Axis of Cleavage**
    - ***Radial Cleavage*** – Blastomeres are vertically aligned after division. Occurs in deuterosomes
    - ***Spiral Cleavage*** – Blastomeres are vertically misaligned after division, forming a spiral pattern. Occurs in protostomes
  - **Developmental Fate**
    - ***Determinate/Mosaic Cleavage*** – Blastomeres lose ***totipotency*** (the ability to differentiate into all cell types). In other words, blastomeres undergoing determinate cleavage gain a developmental fate. This is characteristic of protostomes. Separation of blastomeres at this stage in development would result in incomplete and dysfunctional embryos
    - ***Indeterminate/Regulative Cleavage*** – Blastomeres retain totipotency and remain unspecialized. This is characteristic of deuterosomes. Separation of blastomeres at this stage in development would result in complete and functional embryos
  - **Yolk Quantity**
    - All embryos have yolk concentrated toward one pole of the zygote, called the ***vegetal pole***. The non-yolk pole is called the ***animal pole***
    - ***Holoblastic Cleavage*** – Zygote contains little yolk, resulting in complete penetration of the cleavage furrow. Occurs in mammals, amphibians, annelids, and echinoderms
    - ***Meroblastic Cleavage*** – Zygote contains lots of yolk, resulting in incomplete penetration of the cleavage furrow. Only the non-yolk regions undergo cleavage. Occurs in birds, reptiles, fish, and insects



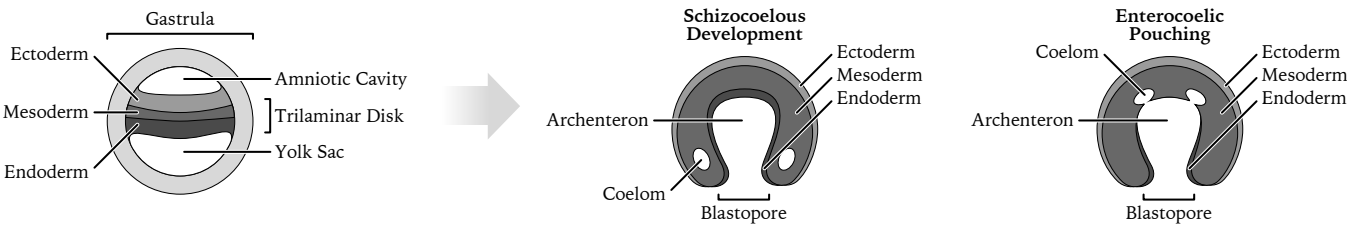
BLASTULATION

- At this stage in embryonic development, liquid begins to accumulate in a hollow cavity called the ***blastocoel***, which later becomes the ***yolk sac***. The embryo is now called a ***blastocyst*** and becomes implanted in the endometrium of the uterus
- Cells of the blastocyst differentiate into:
  - ***Trophoblasts*** – Cells that eventually develop into the placenta
  - ***Embryoblasts*** – A solid lump of cells called the ***inner cell mass***, which eventually develops into the embryo
- Later during blastulation, the inner cell mass differentiates into a structure called the ***bilaminar disk***, which separates the ***amniotic cavity*** from the yolk sac. The bilaminar disk is composed of:
  - ***Epiblasts*** – Cells that face the amniotic cavity. The human embryo develops almost entirely from epiblasts
  - ***Hypoblasts*** – Cells that face the yolk sac



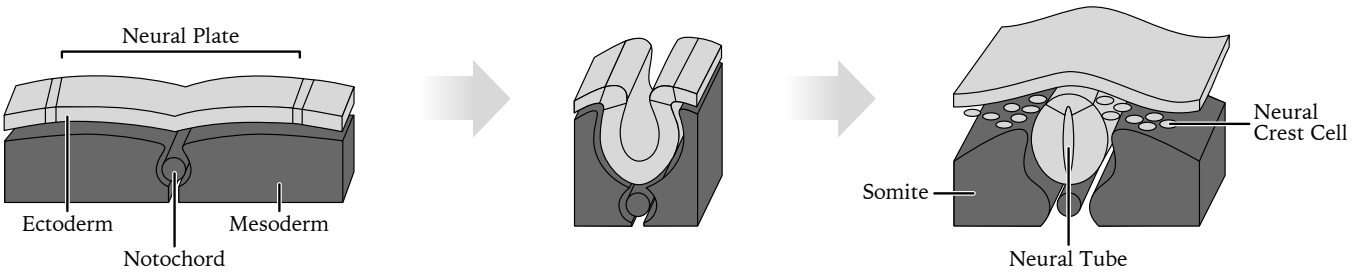
GASTRULATION

- During gastrulation, the epiblast layer starts to invaginate, forming a fold called the ***primitive streak***
- Cells migrate into the primitive streak, turning the bilaminar disk into a ***trilaminar disk***. This three-layered embryo is now called the ***gastrula***, and contains the three ***embryonic germ layers***:
  - ***Endoderm*** – Develops into the pharynx, trachea and bronchi (epithelial parts), digestive system, liver, pancreas, bladder, lungs, thyroid, and parathyroid. Note that the endoderm does *not* include the mucosal linings of the mouth, nostrils, and anus
  - ***Mesoderm*** – Develops into the musculoskeletal system, circulatory system, spleen, lymphatic system, notochord, genitourinary system, and dermis
  - ***Ectoderm*** – Develops into the nervous system, hair, nails, sweat glands, and epidermis. The ectoderm also includes the mucosal linings of the mouth, nostrils, and anus
- An embryonic gut called the ***archenteron*** is created from the invagination of the blastula (picture how a balloon invaginates as it wraps around a closed fist)**.** The opening to the archenteron is called the ***blastopore***
- ***Coelom*** formation also occurs during the gastrulation stage can occur via one of two mechanisms:
  - ***Schizocoelous Development*** – Solid mass of mesodermal cells simply split to form the coelom. This mechanism occurs in protostomes
  - ***Enterocoelic Pouching*** – The archenteron folds into pouches, forming mesodermal cells that form the coelom. This mechanism occurs in deuterosomes



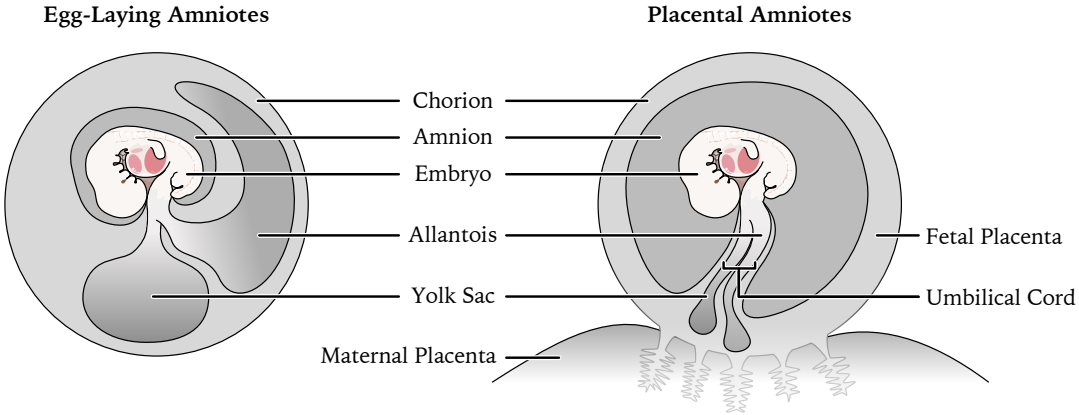
NEURULATION

- ***Neurulation*** describes the formation of the brain and spinal cord. It is a major component of ***organogenesis***, the development of organs from the three embryonic germ layers
- During neurulation, cells of the mesoderm arrange themselves to form the ***notochord***. At maturity, the notochord becomes the ***intervertebral disks*** (do not confuse this with the bony vertebra)
- Cells of the ectoderm differentiate to form the ***neural plate***. This plate invaginates towards the notochord to form the ***neural tube***, which gives rise to the central nervous system (brain and spinal chord)
- In vertebrates, cells near the neural tube also differentiate into the ***neural crest*** (which gives rise to the peripheral nervous system) and repeating blocks called ***somites*** (which organize the segmented structures in vertebrates and gives rise to the bony vertebra)

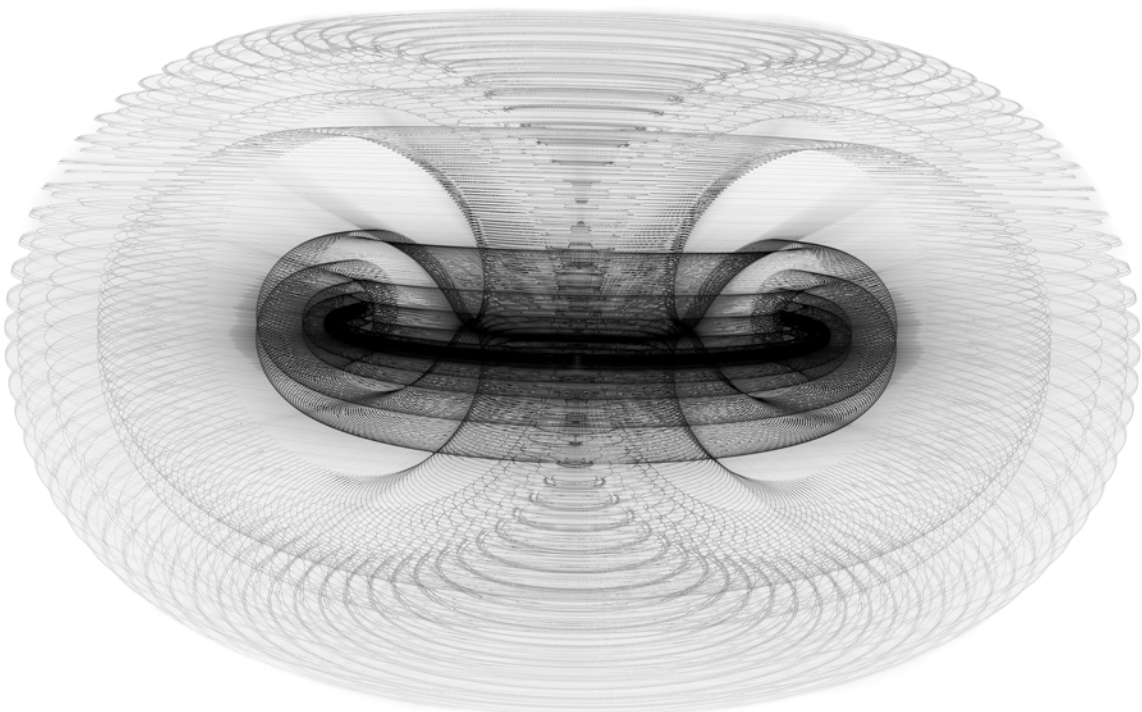


EXTRAEMBRYONIC MEMBRANES

- Extraembryonic membranes are special structures that are unique to ***amniotes*** (reptiles, birds, and mammals). These structures are adaptations for terrestrial reproduction. They also function to physically protect and provide nutrients for the embryo:
  - ***Amnion*** – Innermost membrane forming the ***amniotic cavity***, which contains the embryo and is filled with ***amnionic fluid***. This adaptation protects the developing embryo from physical shocks
  - ***Allantois*** – A sac derived from the embryonic gut (archenteron), located between the amnion and chorion. In egg-laying amniotes, it functions as a reservoir for nitrogenous waste produced by the embryo. In humans, it develops into the umbilical chord
  - ***Chorion*** – Surrounds the amnion, allantois, and yolk sac. In egg-laying amniotes (reptiles and birds), it functions for gas exchange. In humans, it mediates implantation into the endometrium and later develops into the placenta
  - ***Yolk Sac*** – A nutrient reservoir that is larger in egg-laying amniotes than in humans. In mammals, it functions as an early circulatory system and is eventually absorbed into the embryonic gut (archenteron)



SECTION 3 CHEMISTRY



CHAPTER 1 | **PRINCIPLES OF DAT CHEMISTRY**

MINDSET

30 of the 70 questions in the Survey of Natural Sciences (SNS) section will be based on general chemistry. These questions will always come after the 40 biology questions. The chemistry questions on the Canadian DAT tend to be 50% theory-based and 50% calculation-based, with the latter being more time-consuming on average. Keeping this in mind, you should aim to spend around 40 seconds on theory questions and 80 seconds (double) on calculation questions.

Compared to the American DAT, the cDAT focuses more on fundamental concepts covered in high school and introductory university chemistry courses. The cDAT is only based on general chemistry and does not test organic chemistry. Also note that you will not have access to a calculator at any point during the cDAT. Most answer choices will be presented in their raw or uncalculated form. For example, 0.25 will be written as (¼). Because of this, it is recommended that you perform any math by writing out numbers and the operations that will be performed on them, but not carrying out the operations. For instance, given the following information:

$$a = bc^2;\ b = 3 \text{ and } c = 2$$

We will write the final answer as:

$$a = (3)(2)^2$$

And *not* as:

$$a = 12$$

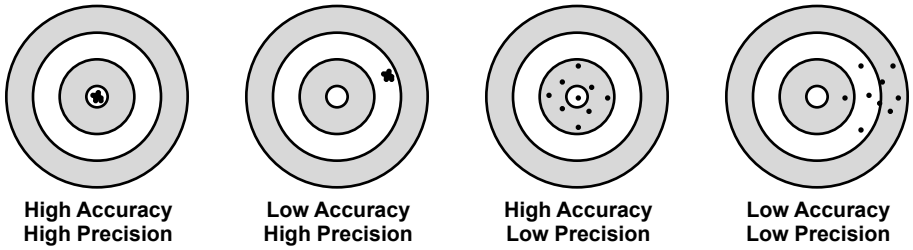
STUDY STRATEGY

We recommend focusing on the content labeled with the ☆ HIGH-YIELD tag if you are low on time. However, to earn an outstanding score in the chemistry part of SNS, you will need to be familiar with *all* the content in this section of the textbook. When performing your content review, make sure to study these chapters in the order that they are presented. Each chapter builds on knowledge from previous chapters, so skipping around may cause you to miss important concepts. Pay extra attention to the worked example problems to ensure that you understand the problem solving behind each question type. The equations, constants, and conversion factors in this section all may appear in questions on the cDAT, so make sure to memorize them. Focusing on why the relationships between certain variables exist will make equations easier to understand and harder to forget. This way, even if you forget an equation, you can always use your knowledge of how the variables behave and interact to reconstruct the relationship. Finally, it is important to practice different types of chemistry problems as you finish the corresponding content review. This will solidify your understanding of the topic and uncover any knowledge gaps that prevent you from reaching an answer.

CHAPTER 2 | **THE LABORATORY**

ACCURACY VS PRECISION

- ***Accuracy*** describes how close a measurement is to reality
  - For example, if a scale measures the mass of a standard 1 kg block to be 1.1 kg, it has higher accuracy than a scale that measures 0.6 kg
- ***Precision*** describes how reproducible a measurement is
  - For example, if we use different scales to measure the mass of a 1kg block four times, 1.1, 1.2, 0.9, 0.8 would be more precise than 1.8, 0.2, 1.6, 0.4



ERROR

- ***Random Error*** – An unpredictable deviation from the true value caused by uncontrollable inconsistencies of the experiment (ex: minor fluctuations in room temperature, mass of glassware used, etc.)
- ***Systemic Error*** – A consistent, repeated deviation from the true value. In other words, all measurements will deviate from the true value by the same amount. This usually occurs due to incorrectly calibrated instruments (ex: using an un-tared electronic balance for all mass measurements, placing a thermometer in the wrong location for the entire experiment, etc)
- ***Gross Error*** – An unpredictable deviation from the true value caused by experimenter carelessness. They typically result in outliers and are discarded before statistical analysis of the data

SIGNIFICANT DIGITS

- The precision of a measurement is proportional to its number of ***significant digits***
- To determine the number of significant digits in a measurement, follow these rules:
  - All non-zero digits are significant
  - Any zeros between two significant digits are also significant
  - Trailing zeros are significant only if they occur after the decimal
  - Leading zeros in a decimal are not significant

Example

Which measurement has the most significant digits?

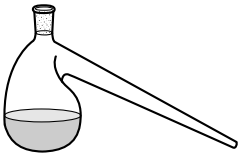
A) 99.30 B) 5.20×10^{23}
C) 0.000021 D) 92002

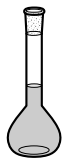
Worked Solution

Option A: 99.30	Let's look at option A first. 9 and 3 are both non-zero digits, therefore they are significant. 0 is also significant because it comes after the decimal. Thus, option A has four significant digits
Option B: 5.20×10^{23}	Next let's look at option B. 5 and 2 are significant. 0 is also significant because it comes after the decimal. We ignore the multiplication component in scientific notation. Thus, option B has three significant digits
Option C: 0.000021	Next let's look at option C. 2 and 1 are significant. The leading zeros are not significant. Thus, option C has two significant digits
Option D: 92002	Finally lets look at option D. 9 and 2 are significant. The two zeros between the non-zero digits are also significant because they are between two significant digits. Thus, option D has five significant digits and is the correct answer

LABORATORY GLASSWARE

- Glass is used instead of plastic because it is strong, inert, transparent, and heat resistant
- Most lab glassware are ***uncalibrated*** because they are only used for mixing, storing, and reacting chemicals
- Any volume markings on uncalibrated glassware are approximations only and cannot be used for measuring
- In contrast, ***calibrated*** glassware can contain a single marking (volumetric) or multiple markings (graduated) that is accurate within a given temperature range for measuring volumes
    - Calibrated glassware include: graduated cylinders, burets, graduated pipettes, volumetric pipettes, and volumetric flasks
- Note that beakers, Erlenmeyer flasks, and transfer pipettes/droppers are *not* calibrated, despite featuring markings along their sides
- When measuring using calibrated glassware, a concave ***meniscus*** will form due to the adhesion/capillary action of water. Measurements are always made from the bottom of the meniscus, reading at eye level
- The following page contains a summary of all calibrated and uncalibrated laboratory glassware

Glassware	Image	Description	Calibrated?
Beaker		Used for mixing, heating, stirring, and reacting	No
Erlenmeyer Flask		Smaller opening, unlike beakers. Often used in titrations. Better for mixing solutions because its cone shape prevents spillage. Can be capped or corked	No
Boiling Flask/ Round Bottom Flask		Used for mixing and heating. Must be clamped, usually to a retort stand	No
Test Tube		Hold small volumes. Used for reacting and observing. Can be capped or corked	No
Retort		Used for distillation of substances from a mixture. Long neck acts as a condenser	No
Extraction Flask/ Separatory Funnel		Used in liquid-liquid extractions, in which an organic and aqueous phase is used to isolate a compound based on solubility	No
Transfer Pipette/ Dropper		Used to transfer a small quantity of liquid	No
Graduated Cylinder		Used for measuring a volume of liquid. Contains volume markings along the side	Yes

Glassware	Image	Description	Calibrated?
Buret		Used for dispensing a volume of liquid. Often used in titrations to contain the known concentration of acid/base. Contains volume markings along the side	Yes
Graduated Pipette		Used for measuring a volume of liquid. Contains volume markings along the side	Yes
Volumetric Pipette		Same as a graduated pipette except has only one marking and a large bulb. Used for measuring a volume of liquid	Yes
Volumetric Flask		Used to measure or store a larger volume of liquid. Contains only one marking	Yes

NON-GLASSWARE EQUIPMENT

- ***Bunsen burners*** produce an open flame from a natural gas source and are used to heat and sterilize materials. A collar is used to adjust airflow; more oxygen produces a bluer flame. It must be ignited using a match or spark lighter
- ***Electronic balances*** measure the mass of a sample. They must be zeroed or tared against any weighing paper or weigh boats used before a measurement is made
- ***Analytical balances*** are hyper-accurate electronic balances that can measure masses in the sub-milligram range. They have transparent doors on all sides to prevent measurement error from air currents
- ***pH meters*** measure pH using electrodes. They must be calibrated against reference solutions before use
- ***Centrifuges*** spin a sample at high speeds so individual components can be separated based on density. After centrifugation, the solid material at the bottom is called the ***pellet*** and the liquid at the top is called the ***supernatant***. The supernatant can be removed via decanting (pouring) or pipetting
- ***Calorimeters*** measure the amount of heat transferred during a physical process or chemical reaction. They are usually insulated and may be sealed in water (i.e. a bomb calorimeter)

LABORATORY PROCEDURES

- ***Distillation*** – Used to separate liquids based on boiling point
  - ***Simple Distillation*** – Ideal for separating liquids with large (>25°C) differences in boiling point. Molecules of the mixture undergo evaporation and condensation once (at their respective boiling point) and are collected in a flask
  - ***Fractional Distillation*** – Ideal for separating liquids with small (<25°C) differences in boiling point. Molecules of the mixture undergo multiple evaporation and condensation cycles, due to beads in the condenser column. Each cycle increases the purity of the distillate such that the final condensation results in a much better separation compared to simple distillation
  - ***Vacuum Distillation*** – Ideal for separating liquids with extremely high boiling points (>150°C). The lower pressure decreases the boiling point such that lower temperatures can be used
- ***Filtration*** – Used to separate non-dissolved solids from liquids
  - Vacuum Filtration – Special type of filtration in which a vacuum is attached to a flask and used to generate the force that draws water across the filter paper
- ***Crystallization*** – Used to purify solids based on differences in solubility. The solid is added to a solvent at high temperature, then the solution is cooled in an ice bath. Impurities remain in solution, while the pure solid forms large crystals that can be collected. Pure solids have a narrower and higher melting point range, while impure solids have a wider and lower melting point range
- ***Chromatography*** – Used to separate liquids based on polarity
  - ***Liquid Column Chromatography*** – A chromatography tube is filled with polar beads. A solution is poured through, and the more polar components will stick to the beads, while the non-polar components will not and thus flow faster. Therefore the non-polar components will have a lower elution time
  - ***Paper Chromatography*** – A solution is "spotted" onto a paper strip, which is dipped in a non-polar organic solvent. The solution's more polar components will stick to the paper, while the more non-polar components will not and thus flow faster
  - ***Thin-Layer Chromatography*** – Same as paper chromatography except a silica gel coated glass plate is used instead of a paper strip. The polar components will stick to the polar silica, while the more non-polar components will not and thus flow faster
- ***Liquid-liquid Extraction*** – Used to separate solutes based on relative solubilities in a polar ***aqueous phase*** and a non-polar ***organic phase***. The liquids are placed in an extraction flask/separatory funnel and agitated via shaking. This allows each solute to migrate into the solvent in which it is more soluble. When the funnel is kept stationary after agitation, the organic phase rises to the surface, allowing the separation of solutes
- ***Calorimetry*** – Used to measure the amount of heat generated, absorbed, or transferred via chemical or physical processes. The reaction occurs inside an insulated container filled with water

CHAPTER 3 | **PERIODIC PROPERTIES**

THE PERIODIC TABLE ☆ HIGH-YIELD

- In the period table, each element is sorted by ***atomic number*** (the number of protons) from smallest to largest
- The columns of the periodic table are called ***groups/families*** and the rows are called ***periods***
- Each group/family has a specific name and unique properties:
  - ***Group 1 – Alkali Metals***
    - Does not include hydrogen
    - Lower density than most metals
    - Highly reactive due to low ionization energy and large atomic radius
    - Can easily lose valence electrons to form cations
    - Commonly form salts and 1^+ cations during chemical reactions
  - ***Group 2 – Alkaline Earth Metals***
    - Easily lose their two valence electrons to form 2^+ cations during chemical reactions
    - Lower electronegativities than predicted by periodic trends, due to completely filled *s* subshells
  - ***Groups 3 to 12 – Transition Metals***
    - Hard and lustrous metals with high melting points (except mercury)
    - Electrons involved in metallic bonds in the *d* subshell are highly mobile, resulting in high malleability and electrical conductivity
    - May exist in a variety of oxidation states
    - Ions may form complexes with water and non-metals. These complexes absorb specific frequencies of light, forming coloured aqueous solutions
    - Group 7 and 12 transition metals have lower electronegativities than predicted by periodic trends, due to their relatively stable half-filled or completely filled *d* subshells
  - ***Groups 13 to 16 – Metalloids and Non-Metals***
    - Metalloids are elements at the transition of metals and non-metals. They have properties of both (ex: silicon is a semi-conductor)
    - Non-metals are brittle, poor electrical conductors, and have high electronegativities
  - ***Group 17 – Halogens***
    - Highly reactive non-metals due to proximity to the noble gas configuration
    - Commonly form salts and -1 anions during chemical reactions
    - Fluorine is the most electronegative element of the entire periodic table
  - ***Group 18 – Noble Gases***
    - Non-reactive due to stable electron configuration and no valence shell
    - Weak intermolecular interactions and therefore low boiling points
- There are also two periods that make up the ***inner transition metals***: ***period 6 – lanthanides*** and ***period 7 – actinides***. These elements are out of the scope of the Canadian DAT

DIATOMIC GASSES

- There are seven elements in the periodic table that always exist as *pairs* of atoms in the gaseous state
- This is important to consider when calculating molar mass. For example, the molar mass of oxygen gas is 32 g/mol and not 16 g/mol, because oxygen is diatomic
- There are seven ***diatomic gasses***:

MNEMONIC Have No Fear Of Ice Cold Beer → Hydrogen Nitrogen Fluorine Oxygen Chlorine Bromine

- The seven diatomic gasses also make a "7" figure on the periodic table

PERIODIC TRENDS ☆ HIGH-YIELD

Effective Nuclear Charge (Z_{eff}) – Net positive charge from the nucleus experienced by an electron

- Effective nuclear charge increases as you move from left to right on the periodic table because the number of protons in the nucleus increases and exerts a greater pull on the electrons. Effective nuclear charge decreases as you move from top to bottom on the periodic table because the number of electron shells increase, which sterically shields the outer electrons from the positive pull of the nucleus

Electronegativity (EN) – Measure of an atom's attraction for bonding electrons

- Electronegativity increases as you move from left to right on the periodic table because the effective nuclear charge increases, which exerts a stronger pull for electrons. Electronegativity decrease as you move from top to bottom on the periodic table because the effective nuclear charge decreases, resulting in a weaker electron pull

Ionization Energy – The energy absorbed when an electron is removed from a neutral atom in its gaseous state/ this value is usually written as a positive number, to signify energy absorbed (endothermic)

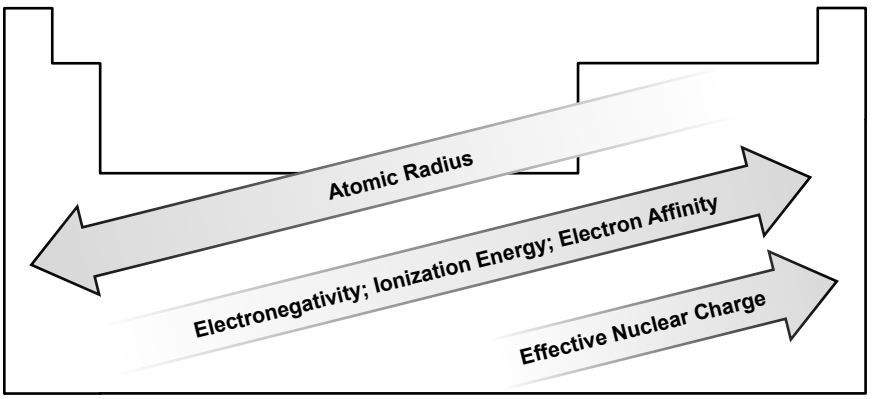
- Ionization energy has no clear, exact trend due to inherently stable half-filled subshells. However, it tends to increase as you move from left to right on the periodic table because electronegativity increases. Ionization energy tends to decrease as you move from top to bottom on the periodic table because electronegativity decreases
- The reason why actual ionization energies don't always follow the trend of increasing across periods is because different subshells are being filled. A perfectly half-filled subshell is more stable than a subshell that is just a little over halfway filled

Electron Affinity – The energy released when an electron is added to a neutral atom in its gaseous state. This value is usually written as a negative number, to signify energy released (exothermic)

- Like ionization energy, there is no exact trend for electron affinity. However, the magnitude of electron affinity tends to increase as you move from left to right on the periodic table because electronegativity increases. The magnitude of electron affinity tends to decrease as you move from top to bottom on the periodic table because electronegativity decreases

Atomic Radius – Distance from the centre of the nucleus to the boundary of the valence electron shell

- Atomic radius decreases as you move from left to right on the periodic table because the number of proteins in the nucleus increases and exerts a greater pull on the electrons, pulling them closer. Atomic radius increases as you move from top to bottom on the periodic table because the number of electron shells increase, adding more "layers" on top of the nucleus and producing a larger radius



CHAPTER 4 | **ATOMIC STRUCTURE**

DALTON'S ATOMIC THEORY

- ***John Dalton*** proposed the first theory that described matter and its properties on the basis of atoms
- The following knowledge served as the foundation for his theory:
  - ***Law of Conservation of Mass*** – In an isolated system, total mass remains constant because matter cannot be created nor destroyed. The mass of reactants and products must be equal
  - ***Law of Constant Composition*** – A chemical compound always contains its constituent elements in the same ratio. For example, a molecule of methane always consists of one carbon and four hydrogens (CH_4)
- Based on these two laws, Dalton proposed the following:
  1. All matter is made of atoms, which are indivisible
  2. All atoms of a given element are identical in mass and property, which differ from that of other elements
  3. Compounds are composed of atoms from more than one element, in simple whole-number ratios
  4. A chemical reaction is a rearrangement of atoms
- Dalton's theory needed to be revised because it had the following limitations:
  - ***J.J. Thomson's*** cathode ray experiments discovered that all atoms contain small negatively charged subatomic particles (referred to as ***electrons*** in modern chemistry)
  - Experiments with mass spectrometers discovered atoms of the same element that had different masses (referred to as ***isotopes*** in modern chemistry)
- J.J. Thomson later proposed the ***plum pudding model*** of the atom, in which electrons "float" in a volume of positive charge, like plums in pudding
  - However, this was later proved to be incorrect thanks to ***Ernest Rutherford's*** discovery that atoms are mostly made of empty space
- These limitations led to the development of the ***Rutherford atomic model***

RUTHERFORD'S ATOMIC MODEL

- ***Ernest Rutherford*** tested the plum pudding model through his ***gold foil experiment***, in which alpha particles (He^{2+}) are shot at a thin sheet of gold foil
  - His prediction was that all the alpha particles would travel straight through the gold, based on the plum pudding model
  - The result was that most alpha particles traveled straight through, but every 1 in 20,000 alpha particles were deflected at large angles
- This led to the following two discoveries:
  - The centre of each atom contained a tiny, dense, and positively charged mass
  - Most of the atom is made of empty space
- Based on the results of the gold foil experiment, Rutherford proposed the following:
  1. All atoms contain a tiny, dense, and positively charged nucleus
  2. The nucleus is surrounded by a cloud of orbiting, negatively charged electrons
- Rutherford's model needed to be revised due to the following limitations:
  - Did not explain why hydrogen emitted a series of spectral lines when excited with high voltage (hydrogen emission spectrum). The emission spectrum of hydrogen consisted of spectral lines in visual wavelengths (***Blamer series***), ultraviolet wavelengths (***Lyman series***), and infrared wavelengths (***Paschen series***)
- These limitations led to the development of the ***Bohr atomic model***

BOHR ATOMIC MODEL

- Based on data from the hydrogen emission spectrum, ***Niels Bohr*** proposed the following:
    1. Electrons orbit the nucleus in concentric circles, like how planets orbit the sun
    2. The energy of electrons in orbitals is ***quantized*** (can only exist in discrete values and is non-continuous), so each orbital can be assigned an integer index from lowest to highest energy (n = 1, 2, 3, etc.)
    3. Electrons in their lowest energy orbital (ground state) can absorb energy and "jump" to a higher energy orbital (excited state)
    4. The excited state is unstable, and electrons eventually return to their ground state by releasing light with a wavelength (λ) corresponding to the difference in energy
- Although the Bohr model was successful at explaining the existence of hydrogen's emission spectrum, it needed to be revised due to the following limitations:
    - Did not explain how electrons can remain perpetually in orbit without falling into the nucleus
    - Did not explain why orbitals are quantized
    - Did not predict the emission spectrum of elements with more than one electron
    - Did not explain why the spectral lines of hydrogen were split (consist of two closely spaced lines), as later discovered
- These limitations lead to the development of the ***quantum mechanical model***

QUANTUM MECHANICAL MODEL

- Electrons were discovered to exhibit ***particle-wave duality*** (behaves as both a particle and wave) through ***Thomas Young's double-slit interference experiment***:
    - A visible-spectrum laser is fired at a screen with two slits spaced closely together, and a pattern is observed on a wall behind the screen
    - If photons behaved as particles, we expect to see two bright spots on the wall
    - However, the result was an interference pattern, due to the photons diffracting as they pass through the slits. This means photons can behave as waves
- ***De Broglie*** later discovered that electrons also exhibit this particle-wave duality
- ***Schrödinger*** realized that electrons can be modelled as standing waves with an integer number of nodes (like harmonics on a guitar string). This explains why Bohr's orbitals were quantized. Schrödinger also developed an equation that predicted the wave functions of electrons and explained all emission spectra
- The principles of the quantum mechanical model will be discussed in the remainder of this chapter

QUANTUM NUMBERS ☆ HIGH-YIELD

- The ***Heisenberg uncertainty principle*** states that it is impossible to know both the exact location and exact velocity of an electron. The accuracy of each measurement is inversely proportional. Thus, we use quantum orbitals to model electron distribution in atoms
- ***Quantum orbitals*** are three dimensional fields that describe the probability of finding an electron at that particular location in the atom
- ***Quantum numbers*** are used to describe the state of an electron in an atom. There are four quantum numbers:
    - ***Principle Quantum Number (n)*** – Describes the energy and size of an orbital. Higher n values represent orbitals with higher size and energy. It can only assume positive integer values. Orbitals with the same n form a ***shell***
    - ***Azimuthal/Angular Quantum Number (l)*** – Describes the shape of an orbital. It can only assume integers in a range from 0 to $n - 1$. Orbitals with the same n and l form a ***subshell***
        - $l = 0 \rightarrow$ ***s orbital*** (sphere shaped)
        - $l = 1 \rightarrow$ ***p orbital*** (dumbbell shaped)
        - $l = 2 \rightarrow$ ***d orbital***
        - $l = 3 \rightarrow$ ***f orbital***

- ***Magnetic Quantum Number (m_l)*** – Describes the orientation of an orbital relative to the x, y, and z axis. It can only assume integers in a range from $-l$ to $+l$
- ***Spin Quantum Number (m_s)*** – Describes the direction of an electron's spin within an orbital. A single orbital can hold a maximum of two electrons, which can exist in only two possible spin states: up ($m_s = +½$) and down ($m_s = -½$). This causes each electron to have a magnetic orientation
  - Elements with unpaired electrons are ***paramagnetic***, interacting with magnetic fields
  - Elements with no unpaired electrons are ***diamagnetic*** and do not interact with magnetic fields

  DAT TIP An easy way to remember this is that paramagnetic elements align their electron spin parallel with a magnetic field, resulting in attraction/repulsion forces

  - If a neutral element has an odd number of valence electrons, it must be paramagnetic
  - If a neutral element has an even number of valence electrons, it may be diamagnetic or paramagnetic, depending on whether or not all electrons are paired up within orbitals

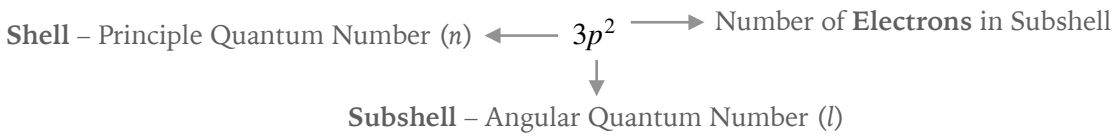
- The following table is a summary of all four quantum numbers:

Quantum Number	Description	Range (Inclusive)
Principle Quantum Number (n)	Size and energy level of a shell	1 to n
Angular Quantum Number (l)	Shape of a subshell	0 to $(n - 1)$
Magnetic Quantum Number (m_l)	Orientation of an orbital	$-l$ to $+l$
Spin Quantum Number (m_s)	Spin of an electron	$+½$ to $-½$

- The maximum electron capacity of a shell is simply the sum of the maximum electron capacity of all its subshells. This can be calculated using the formula: $2n^2$
  - Note that elements in the third row of the periodic table and higher can have an ***expanded octet***, which is more than 8 valence electrons. The extra electrons are accommodated by their d orbitals
- The maximum electron capacity of a subshell can be calculated using the formula: $4l + 2$

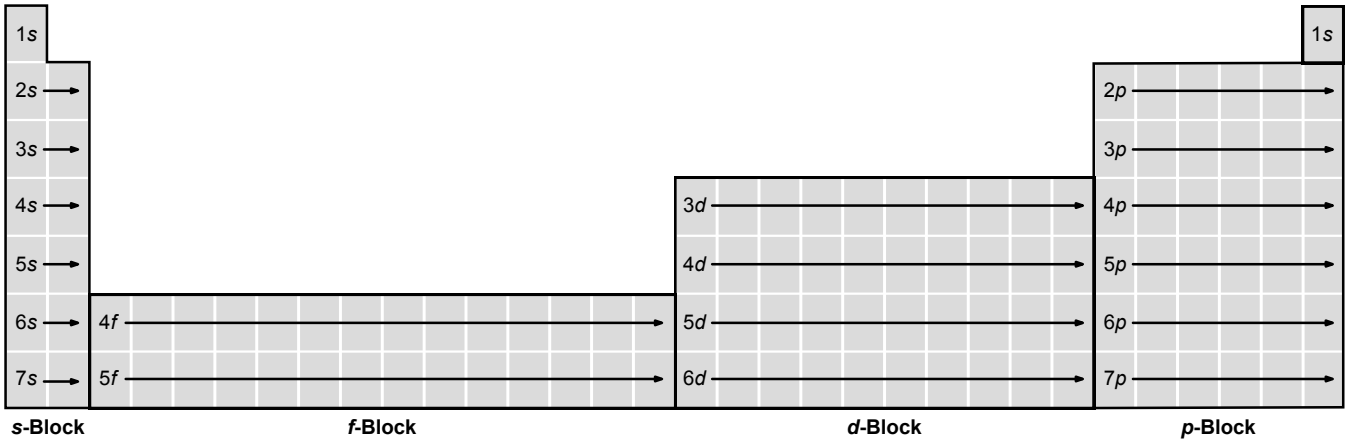
ELECTRON CONFIGURATIONS ☆ HIGH-YIELD

- All neutral elements have a unique ***electron configuration***
- An electron configuration is a list of quantum numbers that describes the distribution of electrons in an atom in terms of shells and subshells. Each element in the list will look like the following notation:



- In the above example, the notation tells us that this atom contains two electrons in the p subshell ($l = 1$) of the third shell ($n = 3$)
- Electron configurations are always listed from lowest energy to highest energy shells and subshells
  - For example, sodium's *full* electron configuration is: $1s^2$, $2s^2$, $2p^6$, $3s^1$
- Long electron configurations can be abbreviated by using a noble gas to represent lower shells and subshells
  - For example, sodium's *abbreviated* electron configuration is: [Ne], $3s^1$

- We can use the periodic table as a tool for writing the electron configurations of neutral elements
  - Each row of the table represents a principle quantum number (Ex: $n = 2$, or the second row), increasing in energy as we move down. For the s and p blocks, the principle quantum number (n) is equal to the row number. Note that for the d block, n is equal to the row number minus one. For the f block, n is equal to the row number minus two
  - We also divide the table into ***blocks***. Each block represents an angular quantum number (ex: $l = 2$, or the d block). Note that helium belongs in the s block



TECHNIQUE **Electron Configurations for Neutral Elements**

1. Locate the element in the periodic table
2. Start "filling in" subshells with electrons from the upper left corner of the periodic table and moving from left to right (like reading a book)
3. Go to the next shell (one row down) and continue filling subshells left to right until you reach the element you located in step one

Example

What is the full electron configuration for aluminum?

A) $1s^2, 2s^2, 2p^6, 3s^1$ B) $1s^2, 2s^2, 2p^6, 3s^2, 3p^6$
C) $1s^2, 2s^2, 2p^6, 3s^2, 3p^1$ D) $1s^2, 2s^2, 2p^6, 3s^2, 3p^1$

Worked Solution

$1s^2$	Start at row one ($n = 1$) and fill the 1s subshell with the maximum number of electrons it can hold: $4(0) + 2 = 2$
$1s^2, 2s^2, 2p^6$	Go to row two ($n = 2$) and fill the 2s and 2p subshells with the maximum number of electrons they can hold: $4(0) + 2 = 2$ and $4(1) + 2 = 6$
$1s^2, 2s^2, 2p^6, 3s^2, 3p^1$	Go to row three ($n = 3$) and fill the 3s and 3p subshells until you reach aluminium. Since it is a neutral element, this is our final answer

- All elements in the same column as chromium and copper are important exceptions to this technique
  - In chromium, one 4s electron is promoted to the 3d subshell such that both the 4s and 3d subshells are exactly half-filled. This results in a more stable configuration:
    [Ar], $4s^2$, $3d^4$ → [Ar], $4s^1$, $3d^5$
  - In copper, one 4s electron is promoted to the 3d subshell such that the 3d subshell is full. This results in a more stable configuration:
    [Ar], $4s^2$, $3d^9$ → [Ar], $4s^1$, $3d^{10}$

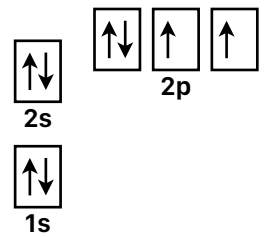
TECHNIQUE **Electron Configurations for Ions**

1. Start by writing the electro configuration for the neutral atom
2. Make changes depending on the ion type:
   - For anions, add electrons to higher orbitals until the correct negative charge is reached. For example, to make Zn^{2-}, [Ar], $4s^2$, $3d^{10}$ becomes [Ar], $4s^2$, $3d^{10}$, $4p^2$
   - For cations, remove electrons from the ***valence subshell*** (the subshell with the highest n) until the correct positive charge is reached. For example, to make Zn^{2+}, [Ar], $4s^2$, $3d^{10}$ becomes [Ar], $3d^{10}$

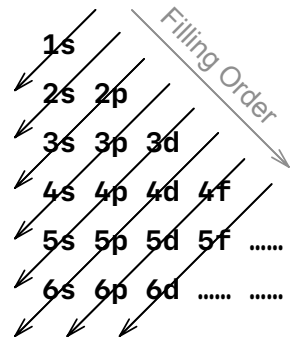
- If two species have the same electron configuration, they are said to be ***isoelectronic***

ORBITAL DIAGRAMS

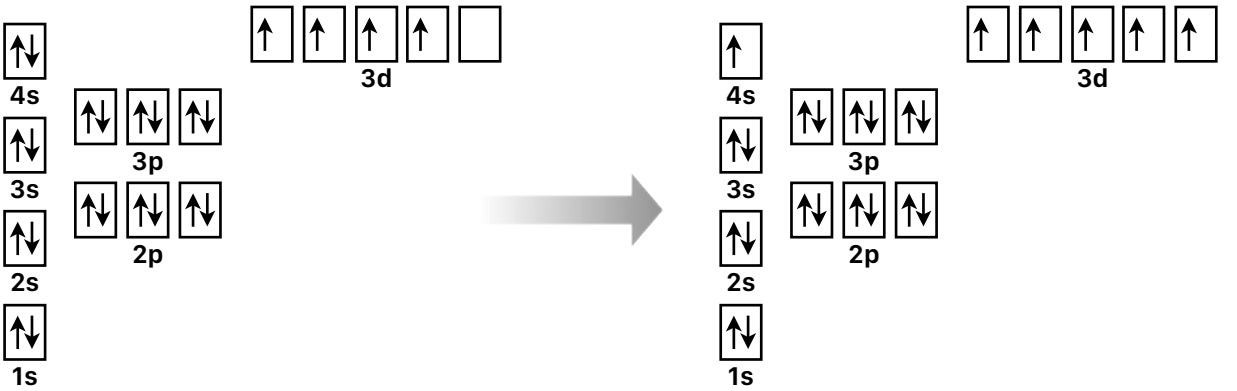
- An orbital diagram is a visual representation of the electrons in each of an atom's orbitals
- Electrons are represented as arrows. The direction of the arrow corresponds to the spin (m_s) of the electron
- Orbitals are represented by rectangles or underlines. Higher energy orbitals are drawn above lower energy orbitals. The following example is an orbital diagram for oxygen:



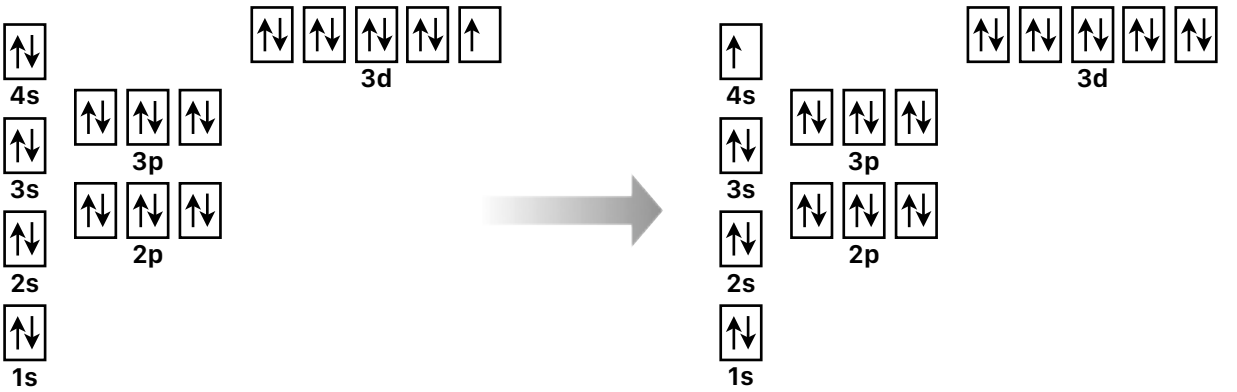
- When drawing orbital diagrams, we must follow these rules:
  - ***Pauli Exclusion Principle*** – No two electrons can have identical quantum numbers. In other words, two electrons in the same orbital must have opposite spins
  - ***Hund's Rule*** – Within a subshell, all orbitals must be half-filled before electrons pair up
  - ***Aufbau Principle*** – Orbitals must be filled from lowest to highest energy level (n). Note that since n is not equal to the row number for the d and f block, the energy level of 4s is actually lower than 3d, and that of 6s is lower than 4f. Visually, this can be represented as follows:



- Remember that all elements in the same column as chromium and copper are important exceptions
  - In chromium, one 4s electron is promoted to the 3d subshell such that both the 4s and 3d subshells are exactly half-filled. This results in a more stable configuration:



  - In copper, one 4s electron is promoted to the 3d subshell such that the 3d subshell is completely full. This results in a more stable configuration:



CHAPTER 5 | **MOLECULAR STRUCTURE**

TYPES OF BONDS ☆ HIGH-YIELD

- ***Ionic bonds*** are formed as a result of electrons being donated/accepted between two elements. This usually occurs between a metal and nonmetal
- ***Covalent bonds*** are formed as a result of the sharing of electrons between two elements. This usually occurs between two nonmetals. If the shared electron pair comes from only one of the two atoms involved in the bond, then it is called a ***coordinate covalent bond***. After formation, a coordinate covalent bond is indistinguishable from a regular covalent bond
- ***Metallic bonds*** are formed as a result of the loose sharing of electrons between multiple nuclei, forming an "electron sea". The loose nature of these bonds allows the nuclei to easily slip across each other, resulting in the high malleability and ductility of metals. This is also responsible for the high conductivity of metals

BOND PROPERTIES ☆ HIGH-YIELD

- ***Bond Order*** – Number of electron pairs involved in a covalent bond (single, double, or triple bond)
- ***Bond Length*** – The distance between the nuclei of two bonding atoms. It is inversely proportional to bond order and bond energy
- ***Bond Energy*** – The energy required to break the bond. It is directly proportional to bond order and inversely proportional to bond length
- ***Bond Polarity***
  - Moderate differences in electronegativity ($2.0 > \Delta EN > 0.5$) between two elements in a covalent bond results in an uneven electron distribution and the development of a ***dipole (δ)***
  - Carbon-hydrogen bonds are too similar in electronegativity to be considered polar
  - Multiple dipoles may cancel each other out to form a non-polar molecule (ex: CO_2) or they may add together to form a polar molecule with a ***net dipole*** (ex: H_2O):

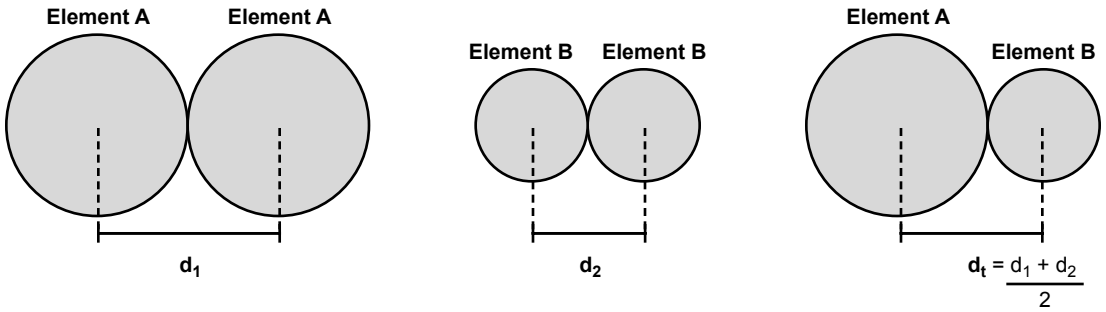


  - In the above example, the carbon-oxygen bonds in CO_2 are polar, but the linear shape of the molecule results in the dipoles cancelling out

Electronegativity Difference (ΔEN)	EN < 0.5	0.5 < EN < 1.7	1.7 < EN
Type of Bond	Non-Polar Covalent	Polar Covalent	Ionic

CALCULATING BOND LENGTHS

- The bond length between two elements is simply equal to the average bond length of the two pure elements
- For example, the bond length for C-H is the average of C-C and H-H bond lengths



- Bond length is inversely proportional to the number of shared electrons within the bond. Therefore, single bonds are the longest while triple bonds are the shortest

INTERMOLECULAR FORCES ☆ HIGH-YIELD

- ***Intermolecular forces*** occur *between* molecules and are much weaker than intramolecular forces (ionic and covalent bonds) occurring *within* molecules
- The relative strengths of intermolecular and intramolecular forces are:

London Dispersion < Induced Dipole < Dipole-Dipole < Hydrogen Bond < Covalent Bond < Ionic Bond

Van der Waals Forces

Intermolecular Forces

- ***Van der Waals forces*** are the weakest intermolecular forces and consist of London dispersion, induced dipole interactions, and dipole-dipole interactions
  - ***London dispersion*** is the weakest Van der Waals force and occurs between non-polar molecules
    - The random distribution of electrons in a non-polar molecule allows a momentary polarization to occur, forming a transient dipole
    - These transient dipoles can induce the polarization of surrounding non-polar molecules, creating a short-lived attraction
    - The greater a molecule's surface area, the easier it is to polarize. Therefore, most large molecules have stronger dispersion forces than smaller molecules
  - Polar molecules participate in ***dipole-dipole interactions***, in which opposite poles attract and identical poles repel. These interactions are significant in solid and liquid phases, but negligible in the gas phase due to lack of proximity between molecules
  - ***Dipole-induced dipole interactions*** occur between the dipole of a polar molecule and and the transient, induced dipole of a non-polar molecule
- A ***hydrogen bond*** is an extremely strong dipole-dipole interaction between a partially positive hydrogen atom and a nearby electronegative atom
  - On the DAT, this occurs when hydrogen is covalently bonded with nitrogen, oxygen, or fluorine
  - Although hydrogen bonds are so strong that they may resemble a covalent bond, they are still intermolecular forces and not true bonds
  - Molecules with hydrogen bonding have higher boiling points compared to molecules with a similar mass that do not exhibit hydrogen bonding. This is because hydrogen bonds help hold the molecules together
  - Hydrogen bonding is important for the existence of organic molecules and thus life on Earth

Example

List the following chemicals in order of weakest to strongest intermolecular interaction:
Ne, HF, CH_3, C_4H_{10}

A) $Ne < C_4H_{10} < CH_3 < HF$ B) $Ne < C_4H_{10} < CH_3 < HF$
C) $Ne < CH_3 < C_4H_{10} < HF$ D) $HF < Ne < CH_3 < C_4H_{10}$

Worked Solution

Ne < _ < _ < _	Neon is non-polar. Therefore the only intermolecular force it will experience is London dispersion. Eliminate D)
Ne < _ < _ < HF	HF has a polar hydrogen-fluorine bond and therefore will experience hydrogen bonding. Eliminate B)
$Ne < CH_3 < C_4H_{10} < HF$	C_4H_{10} and CH_3 are both non-polar and will only experience London dispersion forces. However, C_4H_{10} is larger than CH_3 and therefore experiences stronger dispersion forces. The correct answer is C)

LEWIS STRUCTURES ☆ HIGH-YIELD

- ***Lewis structures*** (also known as ***Lewis dot diagrams***) visually represent the change in valence electron configurations of molecules during a chemical reaction
- The symbol of an element is drawn surrounded in dots, each representing a valence electron. For example, here is the lewis structure for elements in the second row of the periodic table:

Element	Lithium	Beryllium	Boron	Carbon	Nitrogen	Oxygen	Flourine	Neon
Lewis Structure	·Li	·Be·	·B·	·C·	·N·	·O:	·F:	:Ne:

- Note that elements in the same group or column of the periodic table will have the same number of valence electrons and thus dots
- Lines are used to represent the sharing of electrons between two atoms, forming a covalent bond. One line denotes a single bond, while two lines denote a double bond, and so on. Lewis structures are often simplified such that only the bonds (lines) are shown, not the electrons (dots)
- The ***octet rule*** states that an atom can only have a maximum of eight electrons in its valence shell. This is true for most elements. However, there are many exceptions to the octet rule:
  - ***Hydrogen (H), Helium (He), and Lithium (Li)*** – Can have a maximum of only two valence electrons
  - ***Beryllium (Be)*** – Can have a maximum of only four valence electrons
  - ***Boron (B) and Aluminium (Al)*** – Need only six valence electrons, but can have up to eight
  - ***Phosphorus (P), Sulphur (S), Chlorine (Cl), Argon (Ar), and Beyond*** – Can have an expanded octet (>8 electrons) due to the d subshell
- Often, the number of valence electrons of a bonded atom is different from its number of valence electrons as an isolated element. This difference is called the ***formal charge*** and can be calculated with the following equation:

$$\text{Formal Charge} = \text{Valence Electrons} - \frac{1}{2}(\text{Bonding Electrons}) - \text{Nonbonding Electrons}$$

- Or in the context of a lewis diagram:

$$\text{Formal Charge} = \text{Valence Electrons} - \text{Number of Sticks} - \text{Number of Dots}$$

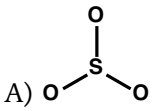
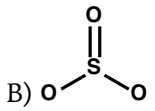
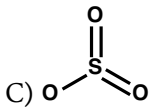
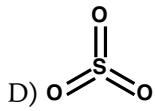
- Formal charges are always minimized in the Lewis structure of a compound. However, the octet rule always trumps formal charges when there is a conflict
- If a Lewis structure contains negative formal charges, they will usually be located on the more electronegative atoms. This is more stable and thus a more favourable configuration
- The sum of formal charges in a compound must always equal the overall charge of the compound
- Formal charges are denoted with the sign placed in front of the number (ie: +1) rather than behind the number as in actual charges (ie: 1+)

TECHNIQUE **Drawing Lewis Structures**

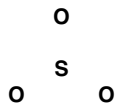
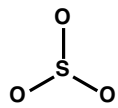
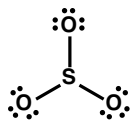
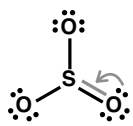
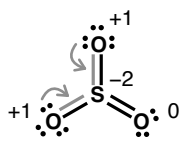
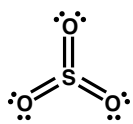
1. Determine the number of valence electrons for each atom. This is equal to the element's column number on the periodic table, plus or minus any charges
2. Determine the total number of valence electrons for the molecule by adding up the number of valence electrons for each atom
3. Draw the least electronegative atom in the centre of the lewis structure, surrounded by all other atoms
4. Draw single bonds between the central and surrounding atoms
   - If the compound contains both hydrogen and oxygen, they usually exist together as a hydroxide (OH) group. You should be familiar with the structure of other common functional groups such as NH_3
5. Fill the octets of surrounding atoms by adding valence electrons, keeping in mind the exceptions to the octet rule. Place the remaining electrons on the on the central atom
6. If the central atom has an incomplete octet, use lone pairs to form double or triple bonds
7. Minimize formal charges by forming double or triple bonds. If the central atom is in the third period or higher, it can have an expanded octet

Example

What is the correct lewis structure for SO_3?

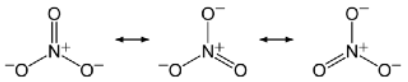
A)  B)  C)  D) 

Worked Solution

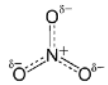
Valence Electrons $= 6 + 3(6) = 24$	First we find the total number of valence electrons. Sulphur has 6, and each oxygen has 6, making a total of 24
	Sulphur is the least electronegative atom, so we draw it in the centre and surround it with the oxygen atoms
	Next we draw single bonds between the central and surrounding atoms
	We have 24 valence electrons minus the 6 electrons that we used for the three single bonds. This leaves us with 18 remaining electrons, which in this case perfectly fills the octets of the surrounding oxygens
	The central atom does not have a complete octet, so we will use a lone pair to form a double bound
	Now we check formal charges. Two oxygens have a formal charge of $+1$ and one oxygen has a formal charge of 0. The sulphur has a formal charge of -2. We can minimize the number of formal charges by forming two double bonds
	Now, all atoms have a formal charge of 0. Sulphur can have an expanded octet because it is in the third row of the periodic table. Since the formal charges have been minimized and all atoms have a full octet, this is our final Lewis structure

RESONANCE STRUCTURES

- In certain situations, two or more equivalent Lewis structures can be drawn for a single molecule. Each of these equivalent structures are equally likely to exist and are called ***resonance structures***
- Molecules do not actually "resonate" between these different structures. Instead, the molecule exists as a blend of all resonance structures, called a ***resonance hybrid***
- For example, nitrate has three equivalent resonance structures:



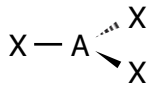
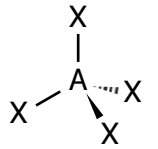
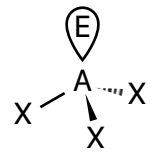
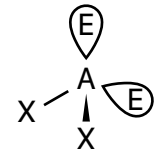
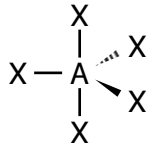
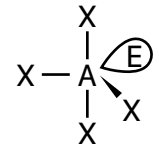
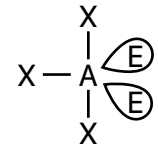
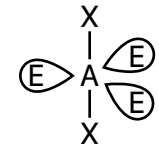
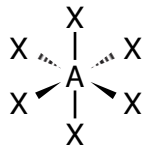
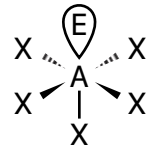
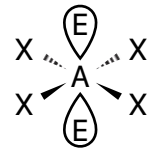
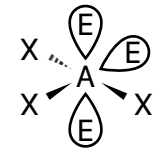
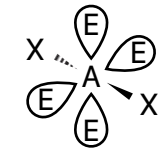
- The actual nitrate molecule exists as a hybrid, with $1\frac{1}{3}$ bonds and partial charges:



- Note that resonance can make a molecule symmetrical (and thus non-polar) by ***delocalizing*** (spreading out) charges that would otherwise result in a net dipole

VSEPR THEORY ☆ HIGH-YIELD

- ***VSEPR*** stands for ***valence shell electron pair repulsion*** theory. It allows us to use Lewis diagrams to predict the three dimensional molecular geometry of covalent compounds
- In text form, a VSEPR configuration can be represented using ***AXE notation***, where ***A*** represents the central atom, ***X*** represents the bonding atoms that surround the central atom, and ***E*** represents lone pairs
- The number of surrounding atoms or lone pairs is denoted in subscript. For example, AX_3E represents three surrounding atoms (X) and one lone pair (E)
- The next page summarizes all the possible VSEPR configurations

# of Electron Domains	Zero Lone Pairs	One Lone Pair	Two Lone Pairs	Three Lone Pairs	Four Lone Pairs
2	 Linear (AX_2) 180°				
3	 Trigonal Planar (AX_3) 120°				
4	 Tetrahedral (AX_4) 109.5°	 Trigonal Pyramidal (AX_3E) 107.3°	 Bent (AX_2E_2) 104.5°		
5	 Trigonal Bipyramidal (AX_5) 90°, 120°	 Seesaw (AX_4E) 90°, 104.5°, 180°	 T-Shaped (AX_3E_2) 90°, 180°	 Linear (AX_2E_3) 180°	
6	 Octahedral (AX_6) 90°	 Square Pyramidal (AX_5E) 90°, 180°	 Square Planar (AX_4E_2) 90°, 180°	 T-Shaped (AX_3E_3) 90°, 180°	 Linear (AX_2E_4) 180°

DAT TIP This table is very high-yield. You should understand how to arrive at each molecular geometry given the number of surrounding atoms (X) and lone pairs (E). You will be able to answer VSEPR questions even faster if you commit the entire table to memory

DAT TIP You can predict a structure's molecular geometry without going through the tedious and time-consuming process of drawing the lewis structure. Here is an easy shortcut:

1. Determine the number of valence electrons
2. Count the number of atoms that bond to the central atom and multiply by 8 to account for full octets on all atoms involved (except for hydrogen, which requires only 2 valence electrons)
3. Find the number of electrons on the central atom by subtracting the number of valence electrons on bonded atoms (step 2) from the total number of valence electrons (step 1)
4. Divide the number of electrons on the central atom by 2 to get the number of lone pairs
5. Use the VSEPR table to predict molecular geometry

Example

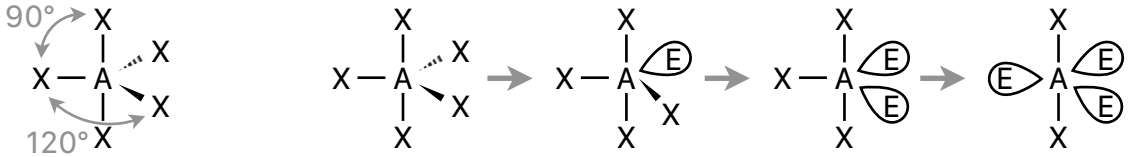
What is the molecular geometry of SF_4?

A) Trigonal Bipyramidal B) Octahedral C) Seesaw D) T-Shaped

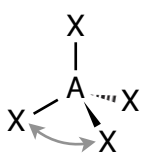
Worked Solution

$6 + 4(7) = 34$	SF4 has a total of 34 valence electrons
$4(8) = 32$	Sulphur is the least electronegative element, so it is the central atom. It will have 4 surrounding atoms, using up a total of 32 electrons
$34 - 32 = 2$	We have 2 electrons left for the central atom
$\frac{2}{2} = 1$	Therefore the central atom will have one lone pair
$X = 4, E = 1$	According to the VSEPR table, the molecular geometry for an AX_4E configuration is seesaw

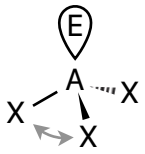
- Note that lone pairs (E) will always have stronger electron repulsion than a bonding atom (X), due to higher electron density. Therefore, lone pairs will always adopt the most spread-out configuration
  - Since trigonal bipyramidal configurations are not rotationally symmetrical (unlike tetrahedral or octahedral configurations), the ***axial*** positions experience greater electron repulsion than the ***equatorial*** positions. This is because axial positions experience three 90° repulsions instead of the two 90° repulsions in equatorial positions. Therefore, lone pairs will always occupy the equatorial positions of a trigonal bipyramidal configuration



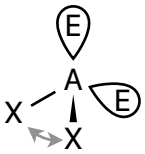
- When lone pairs are present, the angle between bonding atoms decreases. This is because E-E and E-X repulsions are stronger than X-X repulsions



Tetrahedral Bond Angle:
109.5° (Zero Lone Pairs)



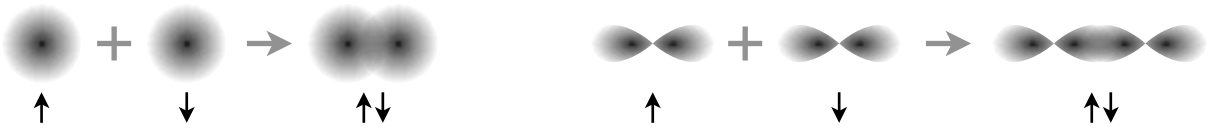
Trigonal Pyramidal Bond Angle:
107.3° (One Lone Pair)



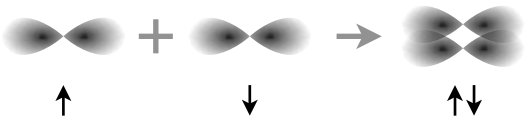
Bent Bond Angle:
104.5° (Two Lone Pairs)

MOLECULAR ORBITAL THEORY

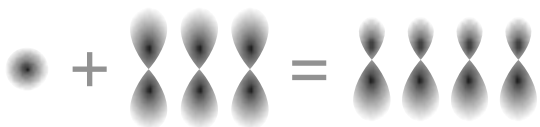
- ***Molecular orbital theory*** states that covalent bonds are formed from the overlapping of two valence atomic orbitals, forming a ***molecular orbital*** that consists of two antagonistic components:
  - ***Bonding Orbital*** – From the constructive interference (in phase) of the two atomic orbitals
  - ***Anti-bonding Orbital*** – From the destructive interference (out of phase) of the two atomic orbitals
- The number of orbitals is always conserved, meaning the total number of atomic orbitals before bonding must be the same as the total number of molecular orbitals after bonding
- There are two types of covalent molecular bonds:
  - ***Sigma Bond (σ)*** – Direct, "head-on" overlap of atomic orbitals which allows ***free rotation*** around the bond axis. Here are examples of σ bonds (between s orbitals on the left, and between p orbitals on the left):



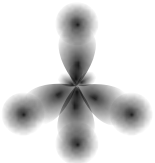
  - ***Pi Bond (π)*** – Parallel, "side-on" overlap of atomic orbitals which does not allow free rotation. A π bond is weaker than a σ bond. S orbitals cannot form π bonds. Here is an example of a π bond between p orbitals:



- These two fundamental covalent molecular bonds can exist in different combinations to form:
  - ***Single Bonds*** – Consist of a single σ bond
  - ***Double Bonds*** – Consist of a σ bond and a π bond
  - ***Triple Bonds*** – Consist of a σ bond and two π bonds
- S orbitals can merge with p orbitals to form ***hybridized atomic orbitals***
  - This phenomenon allows carbon to form up two four single bonds. If hybridization did not occur, carbon could only form two single bonds since its valence shell contains two unpaired electrons ($1s^2$, $2s^2$, $\underline{2p^2}$)
  - In order to participate in four single bonds, carbon hybridizes one s and three p orbitals to form four ***sp^3*** hybrid orbitals. Each sp^3 hybrid orbital has 25% s character and 75% p character:

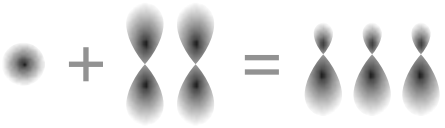


1 *s* + 3 *p* = 4 sp^3

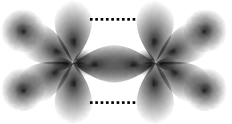


4 σ bonds

  - Carbon can also participate in two single bonds and one double bond. It hybridizes one s and two p orbitals to form three ***sp^2*** hybrid orbitals. The unhybridized p bond participates in the double bond as a π bond. Each sp^2 hybrid orbital has 33% s character and 66% p character:



1 *s* + 2 *p* = 3 sp^2

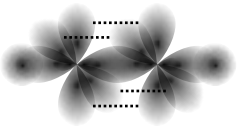


3 σ bonds, 1 π bond

- Carbon can also participate in one single bond and one triple bond. It hybridizes one s and one p orbital to form two ***sp*** hybrid orbitals. The two unhybridized p bonds participate in the triple bond. Each sp hybrid orbital has 50% s character and 50% p character:



1 *s* + 1 *p* = 2 *sp*



2 σ bonds, 2 π bonds

- A general rule-of-thumb for hybridization is:
  - Atoms with four regions of electron density (bonds or lone pairs) are sp^3 hybridized
  - Atoms with three regions of electron density are sp^2 hybridized
  - Atoms with two regions of electron density are sp hybridized

POLYATOMIC IONS

- Some ions are made of multiple elements. Common polyatomic ions such as ammonium or nitrate are important to know, but the more complex ions are not high-yield
- To simplify the many polyatomic ions that exist, it is only necessary to memorize the "***-ate***" form and then use standard nomenclature to convert to the other forms:
  - The prefix "***hypo-***" means one *less* oxygen then the "-ite" form
  - The suffix "***-ite***" means one *less* oxygen than the "-ate" form
  - The prefix "***per-***" means one *more* oxygen than the "-ate" form
- So in general, remember that "hypo-" < "-ite" < "-ate" < "per-"
  - For example, if we know that chlorate is ClO_3^-, then chlorite is ClO_2^-, hypochlorite is ClO^-, and perchlorate is ClO_4^-
  - Two exceptions to this nomenclature are chromite (CrO_2^-) and permanganate (MnO_4^-)
- The prefix "***hydrogen-***" means you add a hydrogen and remove a negative charge
  - For example, if we know that carbonate is CO_3^{2-}, then hydrogen carbonate is HCO_3^-
  - Note that hydrogen carbonate is more commonly called bicarbonate

+1 Charge	−1 Charge	−2 Charge	−3 Charge
NH_4^+ (Ammonium)	NO_3^- (Nitrate)	CO_3^{2-} (Carbonate)	AsO_3^{3-} (Arsenate)
H_3O^+ (Hydronium)	ClO_3^- (Chlorate)	SO_4^{2-} (Sulfate)	PO_4^{3-} (Phosphate)
	BrO_3^- (Bromate)	O_2^{2-} (Peroxide)	
	IO_3^- (Iodate)	S_2^{2-} (Disulphide)	
	CH_3COO^- (Acetate)		
	CN^- (Cyanide)		
	OH^- (Hydroxide)		
	CrO_2^- (Chromite)	CrO_4^{2-} (Chromate)	
	MnO_4^- (Permanganate)	MnO_4^{2-} (Manganate)	

MNEMONIC "NICK the CAMEL ate a CLAM for SUPPER in PHOENIX"
The first letter of each word represents Nitrate, Carbonate, Chlorate, Sulphate, and Phosphate
The number of vowels in each word represents the number of negative charges
The number of consonants in each word represents the number of oxygens

CHAPTER 6 | **STOICHIOMETRY**

MOLES AND AVOGADRO'S CONSTANT ☆ HIGH-YIELD

- A ***mole (n)*** is a unit of measurement that is equal to 6.02×10^{23} particles. This number is called ***Avogadro's constant***. In general, the word "mole" can be used to represent Avogadro's constant in the same way that a "dozen" represents 12. One mole of something refers to 6.02×10^{23} of those items
- For example, one mole of carbon would equal 6.02×10^{23} C atoms. However one mole of carbon dioxide would equal 6.02×10^{23} CO_2 molecules
- One mole can also be defined as the number of atoms in exactly 12 grams of carbon-12

Example

How many oxygen atoms are in 1.5 moles of glucose ($C_6H_{12}O_6$)?

A) 9 B) 6.02×10^{23} C) $6(6.02\times10^{23})$ D) $9(6.02\times10^{23})$

Worked Solution

$n = 6\left(\frac{3}{2}\right) = 9$ mols	Since there are 6 oxygen atoms for every molecule of glucose, there are 6 moles of oxygen for every mole of glucose
Molecules $= 9(6.02 \times 10^{23})$	Since one mole is equal to 6.02×10^{23} particles, we can multiply Avogadro's number by 9 to get the total number of oxygen atoms

MOLAR MASS AND MOLECULAR MASS ☆ HIGH-YIELD

- ***Molecular mass*** is defined as the mass of an entire molecule, expressed in atomic mass units (AMU). This can be calculated by adding together the individual ***atomic masses*** of each constituent atom
- ***Molar mass (MM)*** is defined as the mass of one mole of a substance, expressed in g/mol. This can be calculated by dividing the mass of the substance by the number of moles of that substance
- The atomic masses of each element are listed on the periodic table. This value is numerically the same as the molar mass of that element

Example

What is the mass of two moles of $Al(NO_3)_3$?

A) 213 g B) 426 g C) 639 g D) $\frac{1}{213}$ g

Worked Solution

$MM = 27 + 3(14 + 3(16)) = 213$ g/mol	First we find the molar mass of $Al(NO_3)_3$ by adding together the atomic masses of each element
$m = 2$ mol $\times$ 213 g/mol $= 426$ g	We can multiply the number of moles by the molar mass to get the number of grams

MOLE FRACTION AND MOLE PERCENT HIGH-YIELD

- ***Mole fraction*** is used to describe the number of moles of one species (element, compound, etc.) divided by the total number of moles in a given mixture:

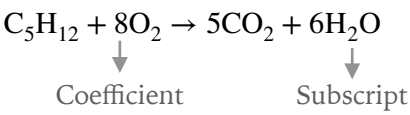
$$X = \frac{\text{Number of Moles}}{\text{Total Number of Moles}}$$

- ***Mole percentage*** is simply the percentage form of mole fraction:

$$Mole\ \% = \frac{\text{Number of Moles}}{\text{Total Number of Moles}} \times 100\,\%$$

BALANCING CHEMICAL EQUATIONS HIGH-YIELD

- Chemical equations contain two types of numbers:
  - **Coefficients** – Indicate the number of each species involved in the reaction
  - **Subscripts** – Indicate the number of each element that exists in a species



- The ***law of conservation of mass*** states that the mass of any element in the reactants of a reaction must be equal to its mass in the products. Therefore, the stoichiometric coefficients in every chemical equation must be ***balanced***, meaning the number of every element must be the same on the left and right sides:



TECHNIQUE **Balancing Chemical Equations**

1. Identify an element that appears in multiple species. Then, make the quantities of this element equal on the left and right sides by multiplying the sociometric coefficients. Treat polyatomic ions as a single unit
2. Repeat step one for the remaining elements
3. Balance hydrogens and oxygens last, as their quantities tend to depend on other elements
4. Eliminate any fractional coefficients by multiplying every species by the common denominator
5. Check your work

Example

What are the correct coefficients for the following equation when balanced?

$$Fe + H_2O \rightarrow Fe_3O_4 + H_2$$

A) 3, 4, 1, 4 B) 4, 3, 1, 4 C) 3, 4, 4, 1 D) 4, 1, 4, 3

Worked Solution

$\mathbf{3}Fe + H_2O \rightarrow Fe_3O_4 + H_2$	Start by balancing the Fe atoms. There are 3 on the right and 1 on the left, so multiply the left side coefficient by 3
$3Fe + \mathbf{4}H_2O \rightarrow Fe_3O_4 + H_2$	Next we balance the O atoms. There are 4 on the right and 1 on the left, so multiply the left side coefficient by 4
$3Fe + 4H_2O \rightarrow Fe_3O_4 + \mathbf{4}H_2$	Finally, we balance the H atoms. There are 8 on the left and 2 on the right, so multiply the right side coefficient by 4
$3Fe + 4H_2O \rightarrow Fe_3O_4 + 4H_2$	After double-checking that both sides have the same number of each element, we arrive at the coefficients of 3, 4, 1, 4

MOLAR RATIOS

- ***Molar ratios*** exist between different elements within a compound and also different molecules in an equation
- We can use molar ratios to calculate the number of moles of an unknown element, if given the number of moles of any other element in the same compound:

Example

When 21.6 g of element X is burned in excess oxygen, 40.8 g of X_2O_3 are formed.
How many moles of X are formed?

A) $\frac{57}{32}$ B) $\frac{19}{16}$ C) $\frac{38}{48}$ D) 19

Worked Solution

$4X + 3O_2 \rightarrow 2X_2O_3$	Write out the balanced equation
$m_{(X_2O_3)} = 40.8\text{ g}$ $m_{(X)} = 21.6\text{ g}$ $m_{(O)} \approx 40 - 21 = 19\text{ g}$	Due to the law of conservation of mass, the mass of X in the reactants must equal the mass of X in the products. Thus we can find the mass of O in X_2O_3
$n_{(O)} = \frac{19}{16}\text{ mol}$	Find the number of moles of O by dividing by its molar mass
$n_{(X)} = n_{(O)} \times \frac{2}{3} = \frac{19}{16} \times \frac{2}{3} = \frac{38}{48}\text{ mol}$	Find the number of moles of X by multiplying by the molar ratio of X to O. Therefore the answer is C)

- We can also use molar ratios to calculate the number of moles of an unknown molecule, given a balanced chemical equation and the number of moles of another molecule:

Example

Given the following equation, if 2 moles of S_8 is reacted with excess F_2, how much SF_6 is produced?

$S_8 + 24F_2 \rightarrow 8SF_6$

A) 8 mol B) 2 mol C) 16 mol D) 0.25 mol

Worked Solution

$n_{(SF_6)} = n_{(S_8)} \times \frac{8}{1} = 2 \times 8 = 16 \text{ mol}$	To find the number of moles of SF_6, multiply the number of moles of S_8 with the molar ratio of SF_6 to S_8

- We can even use molar ratios to calculate the number of moles of an element, given the number of moles of the molecule it is part of:

Example

How many moles of oxygen are in 3 moles of $Ca_3(PO_4)_2$?

A) 24 mol B) 12 mol C) 6 mol D) 4 mol

Worked Solution

$n_{(PO_4)} \times 4 = 3 \times 4 = 12 \text{ mol}$	There are 4 moles of O for every 1 mole of PO_4, so multiply the moles of oxygen by 4
$n_{(O)} = 12 \times 2 = 24 \text{ mol}$	There are 2 moles of PO_4 for every 1 mole of $Ca_3(PO_4)_2$, so multiply the moles of oxygen by 2

- An ***equivalent*** is a measure of the amount of a substance that reacts with one mole of another substance in a chemical reaction (ex: H^+, OH^-, e^-, etc.)

Example

For the following reaction, what is the gram equivalent weight of H_2SO_4?

$$H_2SO_4 + 2NaOH \rightarrow 2H_2O + NaSO_4$$

A) 196 g/eq B) 98 g/eq C) 49 g/eq D) 2 g/eq

Worked Solution

$\mathbf{H_2}SO_4 + 2Na\mathbf{OH} \rightarrow 2H_2O + NaSO_4$	Looking at the molar ratios, we see that 1 mol of H_2SO_4 contains two H^+, while 1 mole of NaOH contains one OH^-. This means that ½ mol of H_2SO_4 reacts with 1 mol of NaOH. In other words, this equation involves the reaction of ½ equivalents of H_2SO_4
$m_{gram\ eq} = \left(98 \text{ g/mol}\right)\left(\frac{1}{2} \text{ mol}\right) = 49 \text{ g/eq}$	To calculate the gram equivalent weight of H_2SO_4, simply multiply its molar mass by ½

EMPIRICAL AND MOLECULAR FORMULAS ☆ HIGH-YIELD

- A compound's ***molecular formula*** consists of the elements and subscripts that make up that compound (ex: $C_6H_{12}O_6$ is the molecular formula for glucose)
- A compound's empirical formula is the lowest whole-number ratio of the molecular formula (ex: CH_2O is the empirical formula for glucose. Note that we simply divided all the subscripts by the common denominator 6)
- ***Percent composition*** (also known as mass composition) describes the mass percentage of a specific element in a given compound. The equation for percent composition is:

$$\%\ \text{Composition} = \frac{\text{Mass of Element in Compound}}{\text{Mass of Compound}} = \frac{\text{Molar Mass of Element in Compound}}{\text{Molar Mass of Compound}}$$

TECHNIQUE **Calculating Empirical Formula from Mass Composition**

- Using the following steps, we can determine a compound's empirical formula if given its percent composition:

1. Assume we have 100 g of the compound
2. Use mass composition to find the mass of each element in the compound
3. Find the number of moles of each element
4. Find the lowest whole-number ratio between the elements
5. Write the empirical formula using this ratio

Example

A compound contains 18.50% nitrogen, 2.22% hydrogen, 37.02% carbon, and 42.26% oxygen by mass. What is its empirical formula?

A) $NH_{1.6}C_{2.3}O_2$ B) $N_3H_5C_7O_6$ C) $N_2H_{3.2}C_{4.6}O_4$ D) $N_6H_{10}C_{14}O_{12}$

Worked Solution

$m_{(N)} = 18.50\% \times 100 = 18.50\ \text{g}$
$m_{(H)} = 2.22\% \times 100 = 2.22\ \text{g}$
$m_{(C)} = 37.02\% \times 100 = 37.02\ \text{g}$
$m_{(O)} = 42.26\% \times 100 = 42.26\ \text{g}$

Assuming 100 g of the compound, we determine the mass of each element within the compound

$$n_{(N)} = \frac{18.50\ \text{g}}{14.01\ \text{g/mol}} = 1.320\ \text{mol}$$
$$n_{(H)} = \frac{2.22\ \text{g}}{1.01\ \text{g/mol}} = 2.20\ \text{mol}$$
$$n_{(C)} = \frac{37.02\ \text{g}}{12.01\ \text{g/mol}} = 3.082\ \text{mol}$$
$$n_{(O)} = \frac{42.26\ \text{g}}{16.00\ \text{g/mol}} = 2.641\ \text{mol}$$

Find the number of moles of each element by dividing their mass by the corresponding molar mass

$\text{ratio}_{(N)} = \frac{1.320\ \text{mol}}{1.320\ \text{mol}} = 1;\ 1 \times 3 = 3$	
$\text{ratio}_{(H)} = \frac{2.20\ \text{mol}}{1.320\ \text{mol}} = 1.67;\ 1.67 \times 3 = 5$	To find the lowest whole-number ratio between the elements, we must divide each value by the smallest number of moles. Then, multiply the ratio by a common factor until no decimals remain
$\text{ratio}_{(C)} = \frac{37.02\ \text{mol}}{1.320\ \text{mol}} = 2.335;\ 2.335 \times 3 = 7$	
$\text{ratio}_{(O)} = \frac{42.26\ \text{mol}}{1.320\ \text{mol}} = 2.001;\ 2.001 \times 3 = 6$	
Empirical Formula = $N_3H_5C_7O_6$	Use the ratio as subscripts in the empirical formula

TECHNIQUE **Calculating Empirical Formula from Combustion Analysis**

- Using the following steps, we can determine the empirical formula of a hydrocarbon undergoing a combustion reaction with excess oxygen, if given the mass of the hydrocarbon and products (H_2O, CO_2):

1. Write out the combustion reaction equation
2. Find the number of moles of the products (H_2O and CO_2)
3. Find the number of moles of H and C in the products
4. Find the mass of H and C in the products
5. Use the law of conservation of mass to find the mass of O in the products
6. Find the number of moles of O
7. Find the lowest whole-number ratio between C, H, and O
8. Write the empirical formula using this ratio

Example

A compound contains only carbon, hydrogen, and oxygen. When 1.60 g of the compound is burned in excess oxygen, 2.20 g of carbon dioxide and 1.80 g of water are produced. What is the compound's empirical formula?

A) CH_2O B) $C_{0.5}H_2O_{0.5}$ C) C_2H_3O D) CH_4O

Worked Solution

$C\_H\_O\_ + O_2 \rightarrow CO_2 + H_2O$	First we write out the combustion reaction equation
$n_{(CO_2)} = \frac{2.20\ \text{g}}{44.0\ \text{g/mol}} = 0.05\ \text{mol}$ $n_{(H_2O)} = \frac{1.80\ \text{g}}{18.00\ \text{g/mol}} = 0.100\ \text{mol}$	We can find the number of moles of products produced by dividing by their molar mass
$n_{(C)} = 0.05\ \text{mol} \times 1 = 0.05\ \text{mol}$ $n_{(H)} = 0.100\ \text{mol} \times 2 = 0.200\ \text{mol}$	Next, use molar ratios to determine the number of moles of carbon and hydrogen
$m_{(C)} = 0.05\ \text{mol} \times 12.01\ \text{g/mol} = 0.601\ \text{g}$ $m_{(H)} = 0.200\ \text{mol} \times 1.01 = 0.200\ \text{g}$	Multiply by molar mass to find the mass of carbon and hydrogen

$m_{(O)} = 1.60 - 0.601 - 0.200 = 0.799$ g	According to the law of conservation of mass, the amount of carbon and hydrogen in the products must equal the amount in the reactants. Therefore, we can calculate the mass of oxygen in the unknown compound
$n_{(O)} = \frac{0.799 \text{ g}}{16.0 \text{ g/mol}} = 0.0500 \text{ mol}$	Divide by molar mass to find the number of moles of oxygen in the unknown compound
$\text{ratio}_{(C)} = \frac{0.0500 \text{ mol}}{0.0500 \text{ mol}} = 1$ $\text{ratio}_{(H)} = \frac{0.200 \text{ mol}}{0.0500 \text{ mol}} = 4$ $\text{ratio}_{(O)} = \frac{0.0500 \text{ mol}}{0.0500 \text{ mol}} = 1$	Finally, find the lowest whole-number ratio between the elements in the unknown compound by dividing each value by the smallest number of moles
Empirical Formula = CH_4O	Use the ratio as subscripts in the empirical formula

TECHNIQUE **Calculating Molecular Formula with Molar Mass**

- Using the following steps, we can determine a compound's molecular formula if given its empirical formula and molar mass:

1. Find the molar mass of the compound's empirical formula
2. Find the ratio between the actual molar mass and the empirical formula's molar mass
3. Multiply the subscripts in the empirical formula by this ratio

Example

The empirical formula of a compound is CH_2O. If the molar mass for the same compound is 180.15 g/mol, what is its molecular formula?

A) CH_2O B) $C_2H_4O_2$ C) $C_3H_6O_3$ D) $C_6H_{12}O_6$

Worked Solution

$MM_{(CH_2O)} = 12.01 + 2(1.01) + 16.00 = 30.03$ g/mol	First we find the molar mass of the empirical formula
$\text{ratio} = \frac{180.15 \text{ g/mol}}{30.03 \text{ g/mol}} = 5.999 \approx 6$	Next, we find the ratio between the actual molar mass and the empirical formula molar mass
Molecular Formula = Empirical Formula $\times 6 = C_6H_{12}O_6$	Finally, we multiply the subscripts of the empirical formula by this ratio

LIMITING REAGENTS ☆ HIGH-YIELD

- A ***limiting reagent*** is a reactant that is present in an amount that is unable to react completely with all other reagents in the chemical reaction
- Once the limiting reagent is consumed, the reaction stops. The remaining reactants that are "left over" are called the ***excess reagents***. The maximum amount of product that can be produced is thus dependent on the amount of limiting reagent, and completely independent of the amount of excess reagents

⚙ TECHNIQUE **Determining the Limiting Reagent**

1. Write out the balanced chemical reaction equation
2. Calculate the number of moles for each reactant
3. Divide the number of moles of each reactant by its corresponding stoichiometric coefficient
4. The reactant with the lowest resulting quotient is the limiting reagent

Example

How many grams of CO_2 would be produced from the combustion of 7.00 g of C_3H_8 with 98.0 g of O_2?

A) 404 g B) 42.0 g C) 21.0 g D) 0.477 g

Worked Solution

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	First, we write out the balanced combustion reaction equation
$n_{C_3H_8} = \frac{7.00\text{ g}}{44.11\text{ g/mol}} = 0.159\text{ mol}$ $n_{O_2} = \frac{98.0\text{ g}}{32.00\text{ g/mol}} = 3.06\text{ mol}$	Next, we find the number of moles of each reactant by dividing by their corresponding molar mass
$\text{quotient}_{C_3H_8} = \frac{0.159\text{ mol}}{1} = 0.159$ $\text{quotient}_{O_2} = \frac{3.06\text{ mol}}{5} = 0.612$	To find the limiting reagent, we divide each reactant's molar value by its corresponding stoichiometric coefficient. C_3H_8 has the lowest resulting quotient, so it is the limiting reagent
$n_{CO_2} = n_{C_3H_8} \times \frac{3}{1} = 0.159\text{ mol} \times \frac{3}{1} = 0.477\text{ mol}$	Use molar ratios to determine the amount of CO_2 produced when all 0.159 moles of the limiting reagent is consumed
$m_{CO_2} = 0.477\text{ mol} \times 44.01\text{ g/mol} = 21.0\text{ g}$	Finally, find the mass of CO_2 produced by multiplying the number of moles by molar mass

CHAPTER 7 | **KINETICS**

- ***Chemical kinetics*** is the study of a reaction's rate or speed
- Kinetics can tell us how fast a reaction proceeds, but not whether it is energetically favourable (occurs spontaneously). The field of ***thermochemistry*** studies reaction spontaneity

REACTION MECHANISMS

- A ***reaction mechanism*** consists of individual ***elementary steps*** that together make up the overall reaction
- The sum of all elementary steps should equal the overall reaction
- Consider the following example reaction:

$$A_2 + 2B \rightarrow 2AB$$

- A potential reaction mechanism for this would be:

$$\begin{array}{lll} & \text{Step 1:} & A_2 + B \rightarrow A_2B \quad \text{(Slow)} \\ + & \text{Step 2:} & A_2B + B \rightarrow 2AB \quad \text{(Fast)} \\ \hline \text{Overall Reaction:} & & A_2 + 2B \rightarrow 2AB \end{array}$$

- In this example mechanism, A_2B is called an ***intermediate***, because it is neither a reactant nor product. When the elementary steps are added together, all intermediates cancel out
- Step 1 is called the ***rate-determining step (RDS)***, because it is the slowest and holds up the overall reaction. The rate of the overall reaction is determined by the rate of the RDS

RATE LAW ☆ HIGH-YIELD

- A reaction's ***rate*** describes how fast the reaction occurs, and can be expressed in terms of the change in concentration of reactants or products over time:

$$r = \frac{\Delta[\text{products}]}{t} = \frac{-\Delta[\text{reactants}]}{t}$$

- Note that if the reactant/product has a coefficient, the rate expression must be divided by that coefficient
- A reaction's ***rate law*** allows us to calculate instantaneous reaction rate from the concentration of reactants
- As expected, rate will decrease as the concentration of reactants decreases over the reaction's progress
- Usually, the concentration of reactants given is from the very beginning of the reaction. Therefore, the rate law calculates the ***initial rate***, or the instantaneous rate of reaction at the very beginning of the reaction
- The rate law is defined by the RDS of a reaction mechanism. The reactant coefficients of the RDS become the exponents of the rate law. These exponents are called ***reaction orders***. For example, given this reaction:

$$\begin{array}{rl} \text{STEP 1}: & 2NO_2 \rightarrow NO_3 + NO \quad \text{(Slow)} \\ \text{STEP 2}: & NO_3 + CO \rightarrow NO_2 + CO_2 \quad \text{(Fast)} \end{array}$$

- The rate law would be:

$$r = k[NO_2]^2$$

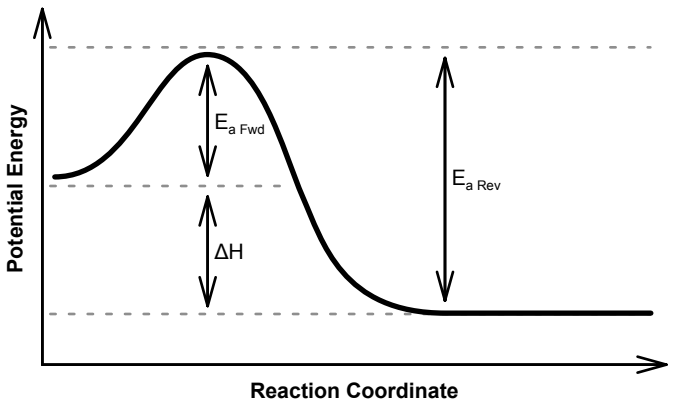
- The ***rate constant (k)*** is a proportionality coefficient, with units that change depending on the overall reaction order (the sum of individual reaction orders)
- Note that if we only had the overall reaction and not the RDS, then we would not be able to determine the rate law. In this case, the rate law would have to be determined experimentally

EXPERIMENTAL DETERMINATION OF RATE LAW ☆ HIGH-YIELD

- Rate law can be experimentally determined by running a series of reactions in which the concentration of reactants is systematically doubled one reactant at a time
- The rate of reaction is then measured, and a table is formed:
- Factors Affecting Rate Law
- The ***molecularity*** of a reaction is the number of reactants that participate in the RDS
  - For example, the molecularity of step 1 of our example reaction is two (bimolecular), since two reactants are involved (A_2 and B)
  - The molecularity of an overall reaction is equal to the molecularity of the RDS. It is *not* the sum of the molecularities of each step

REACTION COORDINATE DIAGRAMS

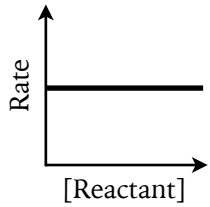
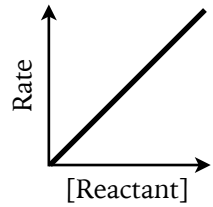
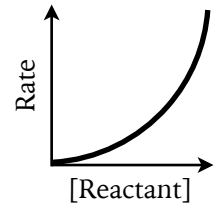
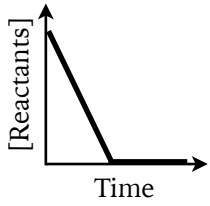
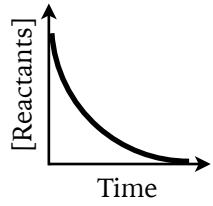
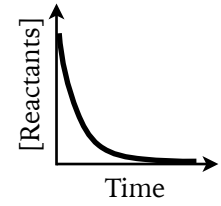
- A ***reaction coordinate diagram***, also known as a ***potential energy diagram,*** is a visual representation of the potential energy of the reactants, intermediates, and products of a reaction over the reaction coordinate (a reaction's progress over time):



- E_a represents the ***activation energy***, which is defined as the minimum amount of energy needed in order for the reaction to occur
  - Even a highly spontaneous reaction will not occur if the activation energy is not overcome. This is why gasoline can be safely transported in pipelines and tanks, as long as it does not come into contact with an energy source (i.e. an electrical spark, lit cigarette, etc.)
  - Once an exothermal (heat-producing) reaction is started, the activation energy is supplied by the heat generated from other reactions, resulting in a chain reaction
- ***ΔH*** represents the change in ***enthalpy***, which is defined as the heat given off or absorbed by a system. This will be discussed in more detail in chapter nine – thermodynamics
- A ***catalyst*** is a substance that lowers a reaction's activation energy (thus increasing rate) and is not consumed by the reaction. Catalysts are always regenerated at the end of a reaction and can be reused in the next one
  - On a reaction coordinate diagram, the presence of a catalyst is represented as an alternate reaction pathway, with an activation energy "bump" that is less steep
  - Catalysts can be chemical (i.e. platinum in a car's catalytic converter) or biological (i.e. the amylase enzyme in our digestive system)

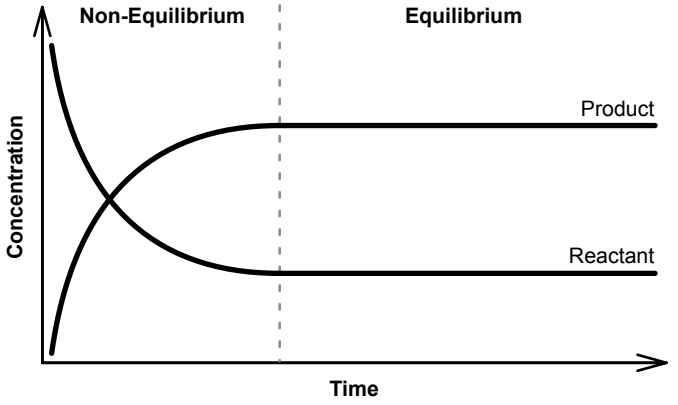
REACTION ORDERS

- ***Reaction order*** describes the relationship between a reactant concentration and the reaction rate
- The ***overall reaction order*** is equal to the sum of individual reaction orders
- For the DAT, you must understand three reaction orders:

Reaction Order	Zero-Order	First-Order	Second-Order
Rate Law	$r = k$	$r = k[\mathrm{A}]$	$r = k[\mathrm{A}]^2$ or $r = k[\mathrm{A}][\mathrm{B}]$
Rate vs [Reactant]* *(Initial Reactant Concentration)			
[Reactants]* vs Time *(Instantaneous Reactant Concentrations)			
Description	Rate is constant and independent of reactant concentration. Examples include the conversion of diamond to graphite	Rate is proportional to the concentration of the reactant. Examples include radioactive decay	Rate is proportional to the concentration of the reactant squared, or to the product of two reactant concentrations

CHAPTER 8 | **EQUILIBRIUM**

- In ***reversible reactions***, the reactants form products which can react with each other to form the reactants again
- Eventually, a reversible reaction will reach a state of ***equilibrium*** in which the forward and reverse reactions result in zero net change in the quantity of reactants and products
- Note that at equilibrium, the forward and reverse reactions are still occurring, there is simply no *net* change in concentration. This is often why a state of equilibrium is described as ***dynamic***
- ***Homogenous equilibrium*** occurs when the reactants and products are in the same phase
- ***Heterogenous equilibrium*** occurs when the reactants and products are in different phases
- Reactions must satisfy three conditions in order to be at equilibrium:
  - The reaction must be reversible (indicated by double arrows: $\rightleftharpoons$)
  - The rate of the reverse reaction must be equal to the rate of the forward reaction
  - The reaction takes place in a closed system and at constant temperature



THE EQUILIBRIUM CONSTANT ☆ HIGH-YIELD

- For a generic reversible reaction:

$$aA + bB \rightleftharpoons cC + dD$$

- The equilibrium constant (K) is defined as the forward reaction rate constant ($k_{forward}$) divided by the reverse reaction rate constant ($k_{reverse}$) at equilibrium:

$$K = \frac{k_{forward}}{k_{reverse}} = \frac{[C]^c[D]^d}{[A]^a[B]^b} \text{ (at equilibrium)}$$

- The magnitude of K can tell us about the relative product to reactant ratio at equilibrium:

K	Result
>1	Equilibrium favours products
$=1$	Equilibrium is balanced
<1	Equilibrium favours reactants

• When chemical reactions are changed, the new K value can be determined via the following rules:

If two or more reactions are added together, the new K is equal to the product of all the individual K values before the addition	If a reaction is multiplied by a constant, the new K is equal to the old K value raised to the power of that same constant	If a reaction is reversed, the new K is equal to the reciprocal of the old K value
$aA + bB \rightleftharpoons cC + dD \quad K_1$ $+ \quad cC + dD \rightleftharpoons eE + fF \quad K_2$ $aA + bB \rightleftharpoons eE + fF \quad K_{New}$	$aA + bB \rightleftharpoons cC + dD \quad K_{Old}$ Multiply by C: $C(aA + bB \rightleftharpoons cC + dD) \quad K_{New}$	$aA + bB \rightleftharpoons cC + dD \quad K_{Old}$ Reverse: $cC + dD \rightleftharpoons aA + bB \quad K_{New}$
$K_{New} = (K_1)(K_2)$	$K_{New} = (K_{Old})^C$	$K_{New} = \frac{1}{K_{Old}}$

THE REACTION QUOTIENT

• The definition for the ***reaction quotient (Q)*** is identical to that of the equilibrium constant (K), except it is used when the reaction is *not* at equilibrium

$$Q = \frac{[C]^c[D]^d}{[A]^a[B]^b} \text{ (NOT at equilibrium)}$$

• The magnitude of Q relative to K allows us to determine if the reaction will shift to the reactants or products:

Q	Result
< K	Reaction will shift to the product side, since the ratio of products to reactants is lower than it should be at equilibrium
= K	Reaction will not shift because it is at equilibrium
> K	Reaction will shift to the reactant side, since the ratio of products to reactants is higher than it should be at equilibrium

LE CHÂTELIER'S PRINCIPLE ☆ HIGH-YIELD

- ***Le châtelier's principle*** states that when an equilibrium is disturbed by a change in concentration, temperature, volume, or pressure, it will always shift in a direction that reduces the change:

Type of Change	Result
Concentration	If reactant concentrations increase, the equilibrium will shift to make more products. If product concentrations increase, the equilibrium will shift to make more reactants
Temperature	If temperature increases, the equilibrium will shift to the side of the reaction that consumes heat. If temperature decreases, the equilibrium will shift to the side of the reaction that produces heat
Volume or Pressure	If pressure increases or volume decrease, the equilibrium will shift to the side of the reaction that has fewer moles of gas. If pressure deceases or volume increases, the equilibrium will shift to the side of the reaction that has more moles of gas

SOLVING EQUILIBRIUM PROBLEMS ☆ HIGH-YIELD

- The ***ICE table*** strategy allows us to easily identify the known and missing variables of an equilibrium problem
- ICE stands for:
  - ***Initial*** – Concentration of reactants/products before reaching equilibrium
  - ***Change*** – Change in the concentration of reactant/products needed to reach equilibrium
  - ***Equilibrium*** – Concentration of the reactant/products at equilibrium
- Concentration is often represented by a pair of square brackets. For instance, [HCl] represents the concentration of hydrochloric acid
- Note that concentration can only be used in the ice table if the volume is the same throughout the reaction. If the volume changes, you must use moles instead of concentration in the ICE table. If the question asks specifically for concentrations, a separate calculation is needed afterwards to convert moles to concentrations

Example 1

0.3 mol of HA (a weak acid) is dissolved in 2 L of water. According to the following dissociation equation, what are the concentrations of reactants and products at equilibrium?

$$HA_{(aq)} + H_2O_{(l)} \rightleftharpoons A^-_{(aq)} + H_3O_{(aq)} \qquad K_a = 1.6 \times 10^{-2}$$

A) [HA] = 0.12 M, [A⁻] & [H_3O] = 0.047 M
B) [HA] = 0.090 M, [A⁻] & [H_3O] = 0.050 M
C) [HA] = 0.049 M, [A⁻] & [H_3O] = 0.049 M
D) [HA] = 0.10 M, [A⁻] & [H_3O] = 0.049 M

Worked Solution

	$HA + H_2O \rightleftharpoons A^- + H_3O$		
I	0.15 M	0 M	0 M
C			
E			

Set up an ICE table and fill in the known initial concentrations. Since 0.3 mol of HA is dissolved in 2 L of water, the initial [HA] is 0.15 M. Note that we ignore all solids or liquids (like H_2O), since they don't have a concentration

	$HA + H_2O \rightleftharpoons A^- + H_3O$		
I	0.15 M	0 M	0 M
C	$-x$	$+x$	$+x$
E			

Since the concentrations of products is initially 0 M, the equilibrium will shift to the right. Therefore, x amount of moles is subtracted from the products and added to the reactants

	$HA + H_2O \rightleftharpoons A^- + H_3O$		
I	0.15 M	0 M	0 M
C	$-x$	$+x$	$+x$
E	$0.15 - x$	x	x

To find the concentrations at equilibrium, simply add or subtract x from the initial concentrations

$$K_a = \frac{[A^-][H_3O]}{[HA]} = 1.6 \times 10^{-2}$$

$$\frac{(x)(x)}{0.15 - x} = 1.6 \times 10^{-2}$$

$$\frac{x^2}{0.15 - x} = 1.6 \times 10^{-2}$$

$$\frac{x^2}{0.15} \approx 1.6 \times 10^{-2}$$

$$x^2 \approx 2.4 \times 10^{-3}$$

$$x \approx 0.049 \text{ M}$$

Substitute each concentration into the equilibrium constant equation and solve for x

Note that the subtraction of x from the initial concentration can be ignored if the initial concentration is large enough for x to be negligible. This avoids the need to use the quadratic formula to solve for x

The DAT will almost always allow you to ignore x because they are testing your chemistry knowledge, not your ability to solve the quadratic formula

	$HA + H_2O \rightleftharpoons A^- + H_3O$		
I	0.15 M	0 M	0 M
C	$-x$	$+x$	$+x$
E	0.10 M	0.049 M	0.049 M

Now we can use x to find all the concentrations at equilibrium

Example 2

A reaction mixture contains 1 M of CO and 2 M of O_2. At equilibrium, the concentration of CO_2 is 0.5 M. What are the concentrations of CO and O_2 at equilibrium?

A) $[CO] = 0.5$ M, $[O_2] = 2.25$ M
B) $[CO] = 0.5$ M, $[O_2] = 0.5$ M
C) $[CO] = 0.75$ M, $[O_2] = 2.25$ M
D) $[CO] = 2.25$ M, $[O_2] = 0.5$ M

Worked Solution

$2CO + O_2 \rightleftharpoons 2CO_2$	Write out the balanced equilibrium equation
$2CO + O_2 \rightleftharpoons 2CO_2$ **I** 2 M 1 M **C** **E**	Set up an ICE table and fill in the known initial concentrations
$2CO + O_2 \rightleftharpoons 2CO_2$ **I** 2 M 1 M **C** $+2x$ $+x$ $-2x$ **E**	Since the concentration of CO is initially 0 M, the equilibrium will shift to the reactant side. $[O_2]$ will increase by x, while [CO] will increase by $2x$ due to molar ratios. Likewise, $[CO_2]$ will decrease by $2x$
$2CO + O_2 \rightleftharpoons 2CO_2$ **I** 2 M 1 M **C** $+2x$ $+x$ $-2x$ **E** $2x$ $2+x$ $1-2x$	To find the concentrations at equilibrium, simply add or subtract x from the initial concentrations
$2x = 0.5$ $x = \frac{0.5}{2}$ $x = 0.25$	The question told us that the concentration of CO_2 at equilibrium is 0.5 M, so we can find x
$2CO + O_2 \rightleftharpoons 2CO_2$ **I** 2 M 1 M **C** $+2x$ $+x$ $-2x$ **E** 0.5 M 2.25 M 0.5 M	Now we can use x to find all the concentrations at equilibrium

CHAPTER 9 | **THERMODYNAMICS**

- ***Thermodynamics*** studies the energy changes that occur in ***physical processes*** (heating/cooling, phase changes)
- ***Thermochemistry*** is a branch of thermodynamics that studies the energy changes that occur in chemical reactions (rearrangement of atoms and electrons)
  - Thermochemistry can predict how spontaneous a reaction is, but cannot predict how fast it will occur
  - This is in contrast to the study of chemical kinetics, which cannot predict how spontaneous a reaction is, but can predict how fast it will occur
  - The spontaneity of a reaction (thermodynamics) does not affect how fast it occurs (kinetics). For example, the conversion of diamond to graphite is a spontaneous reaction. However, its reaction rate is so slow that the amount of diamond converted to graphite (in a diamond ring, for example) is negligible

INTENSIVE VS EXTENSIVE PROPERTIES

- An ***intensive/intrinsic property*** is a physical property that does not depend on the amount of material (Ex: density, colour, melting point, boiling point, temperature, reduction potential
- An ***extensive/extrinsic property*** is a physical property that depends on the amount of material (Ex: mass, volume, enthalpy, entropy, Gibbs free energy, internal energy
- Temperature is the average kinetic energy of the particles in a system. Therefore it does not depend on the number of particles and is thus an intensive property
- Internal energy is the total kinetic and potential energy of the particles in a system. Therefore it does depend on the number of particles and is thus an extensive property
- For instance, a cup of coffee and a large hot tub may have the same temperature but would have different amounts of internal energy and thermal energy

STATE FUNCTIONS

- A ***state function*** is a property whose value depends on the system's current state, and not the path taken in order to reach that state
- For example, if you are currently in London your geographic position would be a state function since it does not matter whether you travelled from Hamilton or New York. However, the amount of gas consumed would *not* be a state function since it obviously would take more gas to travel from New York
  - Additional examples of state functions include: mass, pressure, volume, temperature, enthalpy, entropy, Gibbs free energy, and internal energy
- Heat is *not* a state function since it is defined as an amount of energy transferred between two masses, which would depend on the path taken ($q = mc\Delta T$)
- Work is also *not* a state function since the amount of work performed would depend on the path taken ($W = Fd = -P\Delta V$)

TEMPERATURE AND THE KELVIN SCALE

- ***Thermal energy*** is the kinetic energy of a system's particles
- ***Internal energy*** is the sum of a system's potential energy and kinetic energy
- ***Temperature*** is the average thermal energy of a system
- The ***Kelvin scale*** is another way to measure temperature, similar to the familiar Celsius scale
- Zero Kelvin (0 K) represents ***absolute zero***, the lowest possible temperature in which kinetic energy equals zero and there are no atomic vibrations (this is equivalent to $-273°C$)
- Each increment on the Kelvin scale is equal to an increment on the Celsius scale. This means that a temperature in Kelvin can be converted to degrees Celsius by using this formula:

$$°C = K + 273$$

SYSTEMS AND SURROUNDINGS ☆ HIGH-YIELD

- A thermodynamic ***system*** is the particular part of the universe being studied, while the rest of the universe outside the system is considered the ***surroundings/environment***
  - For example, if we are interested in a combustion reaction occurring inside a beaker, the system consists of the reactants and products, while the surroundings/environment consists of any material making thermal contact with the system (i.e. the beaker, atmosphere, lab building, the Earth, and the rest of the universe)
- There are three types of systems:
  - ***Open System*** – Can freely exchange both energy and matter with the surroundings (ex: a cup of coffee)
  - ***Closed System*** – Can exchange energy but not matter with the surroundings (ex: a sealed flask)
  - ***Isolated System*** – Can exchange neither energy nor matter with the surroundings (ex: an insulated calorimeter)
- There are four types of physical processes that a system can undergo:
  - ***Adiabatic Process*** – No heat exchange between system and surroundings ($\Delta q = 0$)
  - ***Isothermal Process*** – System does not change temperature ($\Delta T = 0$)
  - ***Isobaric Process*** – System does not change pressure ($\Delta P = 0$). No work is done ($W = -P\Delta V$)
  - ***Isochoric/Isovolumetric Process*** – System does not change volume ($\Delta V = 0$). No work is done

LAWS OF THERMODYNAMICS

- ***First Law of Thermodynamics*** – Energy can neither be created nor destroyed. The total energy of the universe is conserved/constant
- ***Second Law of Thermodynamics*** – Every spontaneous physical and chemical process increases the entropy of the universe. We will discuss the concept of entropy later in this chapter

HEAT TRANSFER ☆ HIGH-YIELD

- When there is a difference in temperature (ΔT), there is always a transfer of energy in the form of ***heat (q)*** from the warmer mass to the colder mass, until ***thermal equilibrium*** is reached
- ***Specific heat capacity (c)*** is a physical property that represents the amount of heat required to increase the temperature of one g or kg of a particular material by one degree Celsius. In other words, it describes how easily heat transfer occurs for a particular mass of a particular material
- The heat transfer (q) that occurs between two materials can be calculated using the equation:

$$q = mc\Delta T$$

$$\text{Where } \Delta T = T_{final} - T_{initial}$$

MNEMONIC Use "q = MCAT" to remember this equation

- Note that T_f and T_i must be in the same units. Once the difference is taken, a ΔT in Kelvin is equal to a ΔT in degrees Celsius, since the two scales have equivalent increments
- Assuming an isolated system with two objects, the heat lost from one object must equal the heat gained by the other object. Therefore we can use the following equation to represent heat transfer (q) between two objects:

$$q_1 = -q_2$$
$$m_1 c_1 \Delta T_1 = -m_2 c_2 \Delta T_2$$

- The minus sign can be factored into the ΔT term of the heat transfer equation:

$$m_1 c_1 (T_{final} - T_{initial\,1}) = m_2 c_2 (T_{initial\,2} - T_{final})$$

- Finally, if the two objects are made of the same material, then they must have the same specific heat capacity (c). Therefore, we can cancel out c on both sides to arrive at this simplified equation:

$$m_1 (T_{final} - T_{initial\,1}) = m_2 (T_{initial\,2} - T_{final})$$

DAT TIP It is important to memorize the above equation for the Canadian DAT. Even better, know how to derive it from the original heat transfer equation ($q = mc\Delta T$)

Example 1

How much energy does it take to raise the temperature of 5 grams of water from 20 to 50 °C? The specific heat capacity of liquid water is 4.18 J/g°C

A) 1,045 J B) 150 J C) 627 J D) 418 J

Worked Solution

$q = mc\Delta T$	Write out the heat transfer equation
$q = (5\text{ g})(4.18\text{ J/g°C})(50\text{ °C} - 20\text{ °C})$ $q = (5)(4.18)(30)$ $q = 627\text{ J}$	Substitute known values and solve

Example 2

A 100 gram sample of copper is heated to 100 °C and quenched in 200 grams of water, which had an initial temperature of 20 °C. After equilibrium is reached, the final temperature of the copper-water mixture is 23.5 °C. What is the specific heat capacity of copper? The specific heat capacity of liquid water is 4.18 J/g°C

A) 0.191 J/g°C B) 182 J/g°C C) 91.4 J/g°C D) 0.382 J/g°C

Worked Solution

$m_1c_1(T_{final} - T_{initial\,1}) = m_2c_2(T_{initial\,2} - T_{final})$	Write out the heat transfer equation for two objects made of different materials in an isolated system
$(200\text{ g})(4.18\text{ J/g°C})(23.5\text{°C} - 20\text{°C}) = (100)c_2(100\text{°C} - 23.5\text{°C})$ $(200)(4.18)(3.5) = (100)c_2(76.5)$ $c_2 = \dfrac{(200)(4.18)(3.5)}{(100)(76.5)}$ $c_2 = 0.382\text{ J/g°C}$	Substitute known values and solve for c_2

Example 3

5 grams of propane is combusted in a bomb calorimeter, causing an increase of temperature from 20 °C to 40 °C. Assuming the specific heat capacity of the calorimeter is 4 J/g°C, what is the heat of combustion per gram of propane?

A) 80 J/g B) −400 J/g C) −80 J/g D) 400 J/g

Worked Solution

$q_{calorimeter} = mc\Delta T$	Write out the heat transfer equation
$q_{calorimeter} = (5\text{ g})(4\text{ J/g°C})(40\text{ °C} - 20\text{ °C})$ $q_{calorimeter} = (5)(4)(20)$ $q_{calorimeter} = 400\text{ J}$	Substitute known values and solve
$q_{combustion} = -400\text{ J}$	Since $q_1 = -q_2$, we can reverse the sign to get the amount of heat given off by the combustion of propane
$q_{combustion/gram} = \dfrac{-400\text{ J}}{5\text{ g}} = -80\text{ J/g}$	Finally, divide by the number of grams of propane that reacted to get the heat of combustion per gram

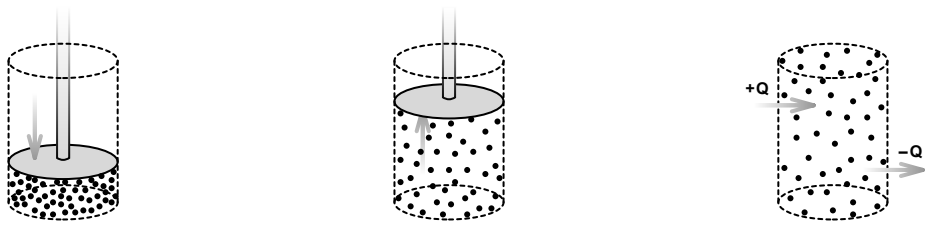
WORK

- A system composed of gases can perform ***work (W)***. Work is defined in physics as force times distance, but it can also be expressed as pressure times the difference in volume (ΔV):

$$W = F \times d \quad \text{or} \quad W = -P\Delta V$$

W represents work in units of joules (J) or litres (L) times kilopascals (kPa)
P represents pressure in kilopascals (kPa)
ΔV represents change in volume in litres (L)
F represents force in newtons (N)

- This can be represented with a model of gas piston:



+W (Work Done On Gas) –W (Work Done By Gas) Q (Heat Transfer)

- If ΔV is negative (the piston is compressed), then work is done on the gas (*W* is positive)

MNEMONIC Think of this as "something is pushing the gas, so the gas is the one *receiving* the work (*positive* value)"

- If ΔV is positive (the piston is expanded), then the gas is doing work (*W* is negative)

MNEMONIC Think of this as "the gas is pushing something, so the gas is the one *giving* the work (*negative* value)"

- ***Internal energy (U)*** describes the total energy of a system. For our purposes, it consists of heat (*Q*) and work (*W*). The change in internal energy (ΔU) is equal to:

$$\Delta U = Q + W_{on\ gas}$$

Where *W* represents the work done on the gas

- Note that work done on the gas is always positive and work done by the gas is always negative. If a DAT question presents work done by the gas as a positive number, we would have to change it to a negative number, thus subtracting it from *Q*:

$$\Delta U = Q - W_{by\ gas}$$

LATENT HEAT OF TRANSFORMATION ☆ HIGH-YIELD

- ***Latent heat of transformation (ΔH)*** describes the amount of heat required to change the phase of one g or kg of a particular material. Different latent heat values are used for different phase changes:
  - The ***latent heat of fusion (ΔH_f)*** is used for liquid to solid or vice versa
  - The ***latent heat of vaporization (ΔH_v)*** is used for liquid to gas or vice versa
  - The ***latent heat of sublimation (ΔH_s)*** is used for solid to gas or vice versa
- Note that the latent heat of sublimation is simply the sum of the latent heats of fusion and vaporization ($\Delta H_s = \Delta H_f + \Delta H_v$)
- The latent heat of vaporization is always larger than the latent heat of fusion, since more intermolecular interactions need to be broken
- Note that there is *no change* in temperature during a phase change, since all the added energy is going into breaking intermolecular interactions
- To calculate the amount of heat transfer involved in a particular phase change, use the equation:

$$q = m\Delta H$$

DAT TIP Note that specific heat capacity (c) is usually presented in J/g°C, while latent heat is usually presented in kJ/mol. Do not forget to convert into the proper units

Example

How much energy does it take to melt 10 grams of ice? The latent heat of fusion for water is 6.02 kJ/mol.

A) 3300 J B) 180 J C) 3.3 J D) 0.18 J

Worked Solution

$q = m\Delta H_f$	Write out the heat transfer equation for a fusion (solid-liquid) phase change
$n_{H_2O} = \dfrac{10\text{ g}}{18.02\text{ g/mol}} = 0.55\text{ mol}$	Find the number of moles of water
$q = (0.55\text{ mol})(6.02\text{ kJ/mol})$ $q = 3.3\text{ kJ}$	Substitute known values and solve
$q = 3300\text{ J}$	Convert to joules

ENTHALPY ☆ HIGH-YIELD

- ***Enthalpy (ΔH)*** is defined as the heat released/absorbed by a system undergoing a physical or chemical change
- Note that *absolute* enthalpies cannot be determined, since enthalpy is by definition a *difference* in heat
- For any chemical reaction occurring under standard conditions (25°C), the standard enthalpy change is:

$$\Delta H^\circ_{rxn} = \sum H^\circ_{products} - \sum H^\circ_{reactants}$$

The degree sign (°) means "standard state conditions"

- A positive standard enthalpy change (ΔH°) means the reaction releases heat (***exothermic***), while a negative ΔH° means the reaction absorbs heat (***endothermic***)
- At constant pressure, ΔH° is equal to heat transfer (q), and must be experimentally determined using calorimetry or standard enthalpies of formation
- The ***standard enthalpy of formation (ΔH°_f)*** of a compound is the enthalpy change that occurs when one mole of a substance is formed directly from its elements in their standard state. This reaction is called a ***formation reaction***. For example:

$$H_{2\,(g)} + \frac{1}{2}O_{2\,(g)} \rightarrow H_2O_{\,(g)} \qquad \Delta H^\circ_f = -241.8\ \text{kJ/mol}$$

- The ΔH°_f of an element in its standard state is zero by definition
- We can calculate ΔH° for any reaction given the ΔH°_f of all products and reactants involved:

$$\Delta H^\circ_{rxn} = \sum \Delta H^\circ_{f\,(products)} - \sum \Delta H^\circ_{f\,(reactants)}$$

Example

Using the reaction equation and standard heat of formations listed below, determine the standard enthalpy of combustion for solid glucose.

$$C_6H_{12}O_{6(s)} + 6O_{2(g)} \rightarrow 6CO_{2(g)} + 6H_2O_{(l)}$$

$\Delta H^\circ_f(CO_2) = -393.5\ \text{kJ/mol}$ $\Delta H^\circ_f(H_2O) = -285.8\ \text{kJ/mol}$ $\Delta H^\circ_f(C_6H_{12}O_6) = -1273.3\ \text{kJ/mol}$

A) 3075.3 kJ B) 2802.5 kJ C) −5349.1 kJ D) −2802.5 kJ

Worked Solution

$\Delta H^\circ = \sum \Delta H^\circ_{f\,(products)} - \sum \Delta H^\circ_{f\,(reactants)}$ — Write out the standard enthalpy change equation for heat of formations

$\Delta H^\circ = \Big(6(-393.5) + 6(-285.8)\Big) - \Big(-1273.3 + 0\Big)$
$\Delta H^\circ = -4075.8 + 1273.3$
$\Delta H^\circ = -2802.5\ \text{kJ}$

Substitute known values and solve. Note that oxygen is in its diatomic elemental state, so its heat of formation is zero

- ***Hess' Law*** states that the ΔH° of any reaction is equal to the sum of the enthalpy changes for each elementary step of the reaction. This means we can calculate the ΔH° of a reaction by adding together the ΔH° of its elementary reactions:

$$\begin{array}{lll} & \text{reactants} \rightarrow \text{elements}_{(\text{std state})} & -\Delta H^\circ_{f\,(reactants)} \\ + & \text{elements}_{(\text{std state})} \rightarrow \text{products} & \Delta H^\circ_{f\,(products)} \\ \hline & \text{reactants} \rightarrow \text{products} & \Delta H^\circ_{rxn} \end{array}$$

- When using Hess' Law, it may be necessary to modify some of the given elementary reactions such that they sum to the correct net reaction. The following rules apply:
  - Reversing the direction of a reaction requires the sign of ΔH° to be reversed as well, since enthalpy is an extrinsic property (unlike reduction potential in electrochemistry, which is an intrinsic property)
  - Multiplying the coefficients of a reaction by a common constant requires ΔH° to be multiplied by the same constant as well

Example

The following list contains the equation and standard enthalpy change of several reactions. Using this information, what is the standard enthalpy change for reaction ③?

$$\begin{array}{ll} \text{① } C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)} & \Delta H^\circ = -393.5 \text{ kJ} \\ \text{② } 2CO_{(g)} + O_{2(g)} \rightarrow 2CO_{2(g)} & \Delta H^\circ = -566.0 \text{ kJ} \\ \text{③ } 2C_{(s)} + O_{2(g)} \rightarrow 2CO_{2(g)} & \Delta H^\circ = ? \end{array}$$

A) 172.5 kJ B) 221.0 kJ C) −221.0 kJ D) −959.5 kJ

Worked Solution

$\mathbf{2} \times$ ①	$\mathbf{2}C_{(s)} + \mathbf{2}O_{2(g)} \rightarrow \mathbf{2}CO_{2(g)}$	$\Delta H^\circ = \mathbf{2}(-393.5 \text{ kJ})$	Note that every Hess' Law problem will have a different solution. There is no algorithm for solving these types of questions. Instead, we rely on insight and trial-and-error First, we look at the reactants of equation ③. Notice how the amount of C is exactly double that of equation ①. Thus, we add 2×(equation ①) to our summation
$2 \times$ ①	$2C_{(s)} + 2O_{2(g)} \rightarrow 2CO_{2(g)}$	$\Delta H^\circ = 2(-393.5 \text{ kJ})$	Next, we need to cancel out an oxygen in the reactants. Thus, we add the reverse of equation ② to our summation
$\mathbf{-1} \times$ ②	$2CO_{2(g)} \rightarrow 2CO_{(g)} + O_{2(g)}$	$\Delta H^\circ = \mathbf{-1}(-566.0 \text{ kJ})$	
$2 \times$ ①	$2C_{(s)} + 2O_{2(g)} \rightarrow 2CO_{2(g)}$	$\Delta H^\circ = -787.0 \text{ kJ}$	Finally, we can combine the equations and add up the ΔH° values
$-1 \times$ ②	$2CO_{2(g)} \rightarrow 2CO_{(g)} + O_{2(g)}$	$\Delta H^\circ = +566.0 \text{ kJ}$	
③	$2C_{(s)} + O_{2(g)} \rightarrow 2CO_{2(g)}$	$\Delta H^\circ = -221.0 \text{ kJ}$	

- ***Bond enthalpy*** is the amount of energy needed to break said bond in the gaseous phase. We can calculate the ΔH° of a reaction using bond enthalpies via the following equation:

$$\Delta H^\circ = \sum \Delta H^\circ_{bonds\ broken} - \sum \Delta H^\circ_{bonds\ formed}$$

Example

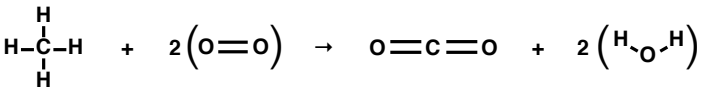
What is the standard enthalpy change for the combustion of methane gas? The reaction equation and standard bond enthalpies are provided below

$$CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$$

$\Delta H^\circ_{C-H} = 413$ kJ/mol $\quad \Delta H^\circ_{O-O} = 495$ kJ/mol $\quad \Delta H^\circ_{C=O} = 799$ kJ/mol $\quad \Delta H^\circ_{O-H} = 463$ kJ/mol

A) -808 kJ B) 1044 kJ C) 808 kJ D) -1044 kJ

Worked Solution



Draw out the lewis structures for the reaction equation, so we can see which bonds are being broken and formed

$$\Delta H^\circ = \sum \Delta H^\circ_{bonds\ broken} - \sum \Delta H^\circ_{bonds\ formed}$$

Write out the standard enthalpy change equation for bond enthalpies

$$\Delta H^\circ = \Big(4(\Delta H_{C-H}) + 2(\Delta H_{O-O})\Big) - \Big(2(\Delta H_{C=O}) + 4(\Delta H_{O-H})\Big)$$

$$\Delta H^\circ = \Big(4(413) + 2(495)\Big) - \Big(2(799) + 4(463)\Big)$$

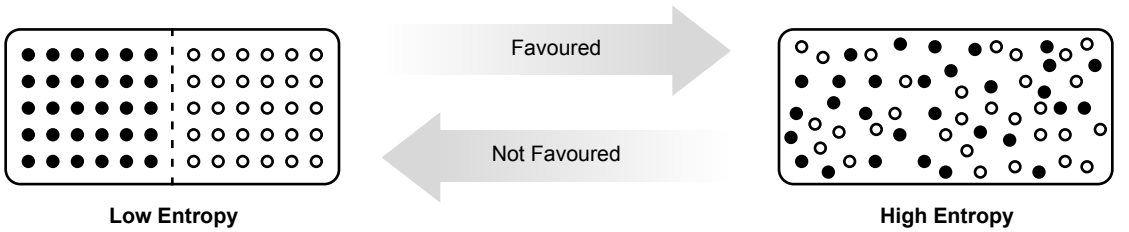
$$\Delta H^\circ = 2642 - 3450$$

$$\Delta H^\circ = -808 \text{ kJ}$$

Substitute known values and solve

ENTROPY ☆ HIGH-YIELD

- ***Entropy (S)*** is a measure of disorder within a system. The higher the number of possible configurations of a system, the greater the entropy
- According to the ***second law of thermodynamics***, every spontaneous physical and chemical process will increase the total entropy of the universe



- We measure changes in entropy as ΔS. If the amount of disorder in a system decreases, $\Delta S < 0$. If disorder in a system increases, $\Delta S > 0$
- Like enthalpy, entropy is also a state function. ΔS depends only on the entropies of the final and initial states, not the particular reaction path taken

- The addition of heat to a system generally increases entropy. According to the ***third law of thermodynamics***, the entropy of a perfectly ordered crystalline solid at a temperature of 0 K is defined to be zero
- We can rank the states of matter in order of increasing entropy as follows: solid < liquid < aqueous ions < gas

Example

Describe the change in entropy (ΔS) for the three reactions presented below, respectively:

$NaCl_{(s)} \rightarrow NaCl_{(aq)}$ $C_3H_{8(g)} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(g)}$ $2NO_{2(g)} \rightarrow N_2O_{4(g)}$

A) Positive, Positive, Negative
B) Negative, Positive, Positive
C) Positive, Zero, Negative
D) Negative, Negative, Positive

Worked Solution

$NaCl_{(s)} \rightarrow NaCl_{(aq)}$	Let's consider the first equation. The phase of NaCl changes from solid to aqueous. From our rank of the states of matter (solid < liquid < aqueous ions < gas), we know that entropy is increasing in this reaction
$C_3H_{8(g)} + 5O_{2(g)} \rightarrow 3CO_{2(g)} + 4H_2O_{(g)}$	Let's consider the second equation. This is a combustion reaction, so heat is being produced. Therefore entropy increases Another method involves noticing that the number of moles of gas increases. There is a total of six moles on the left and seven moles on the right. Therefore entropy increases
$2NO_{2(g)} \rightarrow N_2O_{4(g)}$	Let's consider the third reaction. The number of moles of gas decreases. There is a total of two moles on the left and one mole on the right. Therefore entropy decreases

- Unlike enthalpy, the absolute entropy of a system can be determined. Therefore, not only are changes in entropy (ΔS) measurable, but ***standard molar entropies ($S°$)*** are also defined
- Standard molar entropies represent the absolute entropy of 1 M of an element or compound in J/mol·K under standard conditions (25°C)
- Since entropy is only zero at 0 K, standard molar entropies are always positive
- We can calculate $\Delta S°$ for any reaction given the $S°$ of all products and reactants involved:

$$\Delta S° = \sum S°_{products} - \sum S°_{reactants}$$

Example

Given the following standard molar entropies, what is the change in standard entropy for the reaction between CS_2 and H_2?

$$CS_{2(g)} + 4H_{2(g)} \rightarrow CH_{4(g)} + 2H_2S_{(g)}$$

$$S^\circ_{CS_2} = 151\ \text{J/mol} \cdot \text{K} \qquad S^\circ_{H_2} = -130\ \text{J/mol} \cdot \text{K} \qquad S^\circ_{CH_4} = 186\ \text{J/mol} \cdot \text{K} \qquad S^\circ_{H_2S} = 205\ \text{J/mol} \cdot \text{K}$$

A) -1267 J/K B) 75 J/K C) 1267 J/K D) -75 J/K

Worked Solution

$\Delta S^\circ = \sum S^\circ_{products} - \sum S^\circ_{reactants}$ — Write out the standard entropy change equation for standard molar entropies

$\Delta S^\circ = \Big((186) + 2(205)\Big) - \Big((151) + 4(130)\Big)$

$\Delta S^\circ = 596 - 671$

$\Delta S^\circ = -75$ J/K

Substitute known values and solve. We can double-check that our answer should be negative by noticing that the number of moles of gas decreases from five to three. Therefore the change in entropy should be negative

GIBBS FREE ENERGY ☆ HIGH-YIELD

- ***Gibbs free energy (G)*** is defined as the amount of energy available to drive the spontaneity of a reaction. The free energy change of a reaction can be calculated via the following equation:

$$\Delta G = \Delta H - T\Delta S$$

T represents temperature in Kelvin

DAT TIP Note that ΔH is usually presented in kJ, while ΔS is presented in J. Do not forget to convert into the same units when calculating ΔG

- Like enthalpy and entropy, Gibbs free energy is a state function. Thus we can also calculate ΔG as:

$$\Delta G_{rxn} = \sum G_{products} - \sum G_{reactants}$$

- The sign of ΔG indicates a reaction's spontaneity:
  - ***Negative ΔG*** – Reaction occurs spontaneously (without energy input). Products are favoured when the reaction reaches its equilibrium state
  - ***Positive ΔG*** – Reaction does not occur spontaneously (requires energy input to proceed). Reactants are favoured when the reaction reaches its equilibrium state

- Due to the nature of the free energy equation, temperature is a factor that can determine if ΔG is negative or positive, and thus if the reaction is spontaneous or not:

ΔH	ΔS	Result	Example
−	+	Spontaneous at all temperatures	Wood burning
−	−	Spontaneous at low temperatures	Water freezing
+	+	Spontaneous at high temperatures	Sweat evaporating
+	−	Non-spontaneous at all temperatures	Photosynthesis

- Reactions in which ΔH and ΔS are both positive are ***entropically driven***, since only the effect of entropy is favourable for spontaneity
- Reactions in which ΔH and ΔS are both negative are ***enthalpically driven***, since only the effect of enthalpy is favourable for spontaneity

Example

The change in enthalpy for the following reaction is −92.22 kJ, and the change in entropy is −198 J/K. If carried out at 25°C, what is the change in free energy? Will the reaction be spontaneous?

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$

A) −33,216 J; Non-spontaneous
B) −87,270 J; Spontaneous
C) +33,216 J; Non-spontaneous
D) −33,216 J; Spontaneous

Worked Solution

$T = 25°C + 273 = 298\ K$	First, convert the temperature to Kelvin
$\Delta G = \Delta H - T\Delta S$ $\Delta G = -92{,}220\ J - (298\ K)(-198\ J/K)$ $\Delta G = -92{,}220 + 59{,}004$ $\Delta G = -33{,}216\ J$	Write out the Gibbs free energy equation. Substitute known values and solve. Don't forget to convert and into the same units (choose either J or kJ) Since $\Delta G < 0$, the reaction is spontaneous at this temperature

- Remember that ΔG only predicts a reaction's *spontaneity* and not its *speed*
- Gibbs free energy can be calculated from the equilibrium constant (K) through the following equation:

$$\Delta G = -RT \ln K$$

T represents temperature in Kelvin

- The following table summarizes the relationship between ΔG, K and spontaneity

ΔG	K	Result
<0	>1	Spontaneous; reaction favours products
=0	=1	Reaction favours neither side
>0	<1	Non-spontaneous; reaction favours reactants

CHAPTER 10 | **GASSES**

INTRODUCTION

- The properties of gasses are defined by four variables: ***volume (V)***, ***pressure (P)***, ***temperature (T)***, and ***number of moles (n)***. Pressure is the perpendicular force applied by a gas to the surface of an object, per unit area. On the DAT, it may be represented as any of the following interconvertible units:

$$1 \text{ atm} = 101 \text{ kPa} = 760 \text{ mmHg} = 760 \text{ Torr}$$

DAT TIP It is important to memorize these conversion factors for the Canadian DAT. Wrong answer choices will often present the correct value in an incorrect unit

- Volume is represented in the following interconvertible units:

$$1 \text{ L} = 1000 \text{ mL} = 1000 \text{ cm}^3$$

IDEAL GAS LAW HIGH-YIELD

- An ***ideal gas*** is a hypothetical gas whose molecules experience no intermolecular forces and occupy no volume
- Under low pressure and high temperature, many gasses behave in an ideal fashion
- The ***ideal gas law*** is a combination of three separate laws:
  - ***Boyle's Law*** – Pressure and volume are inversely proportional under isothermal conditions (in which temperature does not change):

$$PV = k \quad \text{or} \quad P_1V_1 = P_2V_2$$

  - ***Gay-Lussac's Law*** – Pressure and temperature are proportional under isochoric conditions (in which volume does not change):

$$\frac{P}{T} = k \quad \text{or} \quad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

  - ***Charle's Law*** – Volume and temperature are proportional under isobaric conditions (in which pressure does not change):

$$\frac{V}{T} = k \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

  - ***Avogadro's Law*** – Number of moles is proportional to volume under isothermal and isobaric conditions:

$$\frac{V}{n} = k \quad \text{or} \quad \frac{V_1}{n_1} = \frac{V_2}{n_2}$$

- Combining Boyle's, Gay-Lussac's, Charle's, and Avogadro's Law gives us the ***ideal gas law***:

$$PV = nRT \quad \text{or} \quad \frac{P_1V_1}{n_1T_1} = \frac{P_2V_2}{n_2T_2}$$

R represents the ideal gas constant (0.0821 L·atm/K·mol or 8.314 L·kPa/K·mol)
T represents the temperature in Kelvin

- Note that the ideal gas constant (R) changes depending on which units of pressure we use. R equals approximately 0.082 when using atm, and 8.3 when using kPa
- All calculations made using the ideal gas laws must use Kelvin instead of degrees Celsius
- ***Standard temperature and pressure (STP)*** is defined as 273 K (0°C) and 1 atm. One mole of any gas at STP always has a volume equal to 22.4 L

Example

2 mol of methane gas is stored in a 1 L compressed cylinder under 300 atm of pressure. What is the temperature of the gas?

A) 459°C B) 90°C C) 183°C D) −90°C

Worked Solution

$PV = nRT$ $T = \frac{PV}{nR}$	Write the ideal gas law and solve for T
$T = \frac{(300\ \text{atm})(1\ \text{L})}{(2\ \text{mol})(0.0821\ \text{L} \bullet \text{atm/K} \bullet \text{mol})}$ $T = \frac{300}{0.164}$ $T = 183\ \text{K}$	Substitute known values and solve. Since pressure is given in atm, we need to use 0.0821 as the ideal gas constant (R)
$T = 183\ \text{K} - 273 = -90°\text{C}$	Convert Kelvins to degrees Celsius

Example

48 grams of an unknown gas has a volume of 33 Litres under STP. What is the identity of this gas?

A) He B) O_2 C) N_2 D) Cl_2

Worked Solution

$n = \frac{33\ \text{L}}{22.4\ \text{L/mol}}$ $n = 1.5\ \text{mol}$	Since one mole of any gas under STP has the volume of 22.4 L, we can calculate how many moles of our gas we have
$MM = \frac{48\ \text{g}}{1.5\ \text{mol}}$ $MM = 32\ \text{g/mol}$	We can calculate the molar mass of our unknown gas
$MM = 32\ \text{g/mol} \rightarrow O_2$	Since oxygen is the only gas that matches our molar mass, it must be the identity of the unknown gas. Remember that oxygen is a diatomic gas, so it's molar mass is 2×16 g/mol

DALTON'S LAW OF PARTIAL PRESSURES ☆ HIGH-YIELD

- ***Dalton's law*** states that when multiple gasses share the same container without chemical interaction, each gas will behave independently of each other
- The pressure exerted by each individual gas is called the ***partial pressure***
- The total pressure of the gas mixture is equal to the sum of all partial pressures:

$$P_{total} = \sum P_{partial}$$

- The partial pressure of an individual gas can be calculated from total pressure by simply multiplying total pressure with the mole fraction of that particular gas:

$$P_{partial} = P_{total} X_{gas}$$

Example

A compressed cylinder with a pressure of 505 kPa contains of 56 grams nitrogen, 32 grams oxygen, and 60 grams neon. What is the pressure of only oxygen gas in this mixture?

A) 168 kPa B) 253 kPa C) 84.2 kPa D) 3030 kPa

Worked Solution

$$n_{N_2} = \frac{56\text{ g}}{28\text{ g/mol}} = 2\text{ mol}$$

$$n_{O_2} = \frac{32\text{ g}}{32\text{ g/mol}} = 1\text{ mol}$$

$$n_{O_2} = \frac{60\text{ g}}{20\text{ g/mol}} = 3\text{ mol}$$

First, we convert masses to moles. Remember that nitrogen and oxygen are diatomic gasses

$$X_{O_2} = \frac{n_{O_2}}{n_{N_2} + n_{O_2} + n_{Ne}}$$

$$X_{O_2} = \frac{1}{2+1+3} = \frac{1}{6}$$

Next, we find the mole fraction of oxygen in the mixture

$$P_{O_2} = P_{total} X_{O_2}$$

$$P_{O_2} = (505\text{ kPa})(\frac{1}{6})$$

$$P_{O_2} = 84.2\text{ kPa}$$

Finally, we multiply the mole fraction of oxygen with the total pressure

HENRY'S LAW

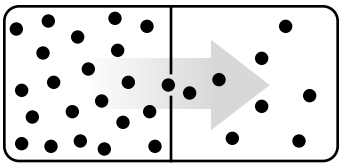
- ***Henry's law*** states that the amount of dissolved gas in a liquid is directly proportional to its partial pressure on the surface of that liquid:

$$[\text{Gas Dissolved}] = \frac{P_{partial}}{K_H}$$

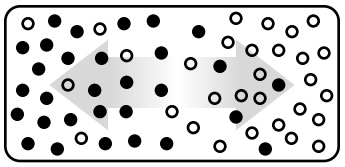
K_H is the Henry's law constant

GRAHAM'S LAW OF EFFUSION/DIFFUSION

- ***Effusion*** is the flow of gas particles from one compartment to another via a pinhole or small opening
- ***Diffusion*** is the tendency of gas particles to mix due to random kinetic motion



Effusion



Diffusion

- ***Graham's law*** states that under isothermal and isobaric conditions, the rate of effusion or diffusion for two gases is inversely proportional to the square root of their molar masses:

$$\frac{r_1}{r_2} = \sqrt{\frac{MM_2}{MM_1}}$$

r_1 is the rate of effusion/diffusion for gas 1
r_2 is the rate of effusion/diffusion for gas 2

Example

An aircraft tire is filled with nitrogen and argon. A microscopic puncture is later discovered. Which gas would be the first to completely leave the tire, and how many times faster compared to the other gas?

A) Nitrogen, 1.84x B) Argon, 1.2x C) Nitrogen, 1.2x D) Argon, 1.84x

Worked Solution

$$\frac{r_{N_2}}{r_{Ar}} = \sqrt{\frac{MM_{Ar}}{MM_{N_2}}}$$

Write out Graham's Law of effusion

$$\frac{r_{N_2}}{r_{Ar}} = \sqrt{\frac{40\ g/mol}{28\ g/mol}}$$

$$\frac{r_{N_2}}{r_{Ar}} = 1.2$$

Substitute known values and solve for the ratio. Remember that nitrogen is a diatomic gas

Since the ratio is greater than 1, nitrogen has the larger rate of effusion. Therefore it will be the first to completely leave the tire

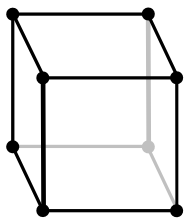
DAT TIP You will not be expected to calculate complex square roots on the Canadian DAT. However, basic radicals such as $\sqrt{4}, \sqrt{9}, \sqrt{16}$, etc. may show up on the exam

CHAPTER 11 | **LIQUIDS AND SOLIDS**

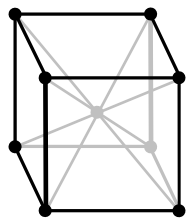
- Matter can exist in three different physical forms, called ***phases***
- The phase that any particular material adopts depends on a balance between the attractive forces of its particles and the kinetic forces that separate them. Gases tend to have higher average kinetic energy, while solids tend to have higher average intermolecular forces
- In this section, we will review the important properties of liquids and solids

SOLIDS

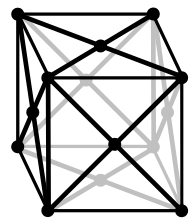
- Solids have well-defined shapes and volumes that remain constant and are not dependent on a container (unlike liquids and gasses). Because their volume cannot be easily changed, solids are incompressible
- The low kinetic energy of solids exist predominantly as ***vibrational energy***, contained within ***covalent***, ***ionic***, or ***metallic bonds***. These bond types were discussed in detail in Chapter 5 (molecular structure)
- Solids can be classified into two categories based on molecular pattern:
  - ***Amorphous Solid*** – Consists of a disordered array of molecules with no apparent organization. Examples include glass, rubber, and plastic
  - ***Crystalline Solid*** – Consists of an ordered array of highly-organized molecules arranged in three-dimensional geometric units that repeat. Examples include diamond, salt, and sugar crystals. Crystalline solids can be further classified based on their repeating geometric pattern, called a ***unit cell***:



Simple Cubic



Body-Centred Cubic



Face-Centred Cubic

- Solids can also be classified into ***metals*** and ***non-metals***, each of which have distinctive physical and chemical properties:

	Metals	**Non-Metals**
Physical Properties	Lustrous, Hard, Dense, Conductive, Malleable, Ductile	Dull, Soft, Less Dense, Non-Conductive, Brittle
Chemical Properties	Metals tend to lose electrons to form cations. Metal oxides form basic solutions in water.	Non-metals tend to gain electrons to form anions. Non-metal oxides form acidic solutions in water.

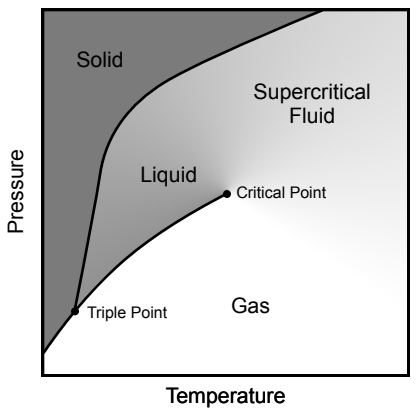
LIQUIDS

- Liquids are fluids with a constant volume and variable shape, depending on their container. Like solids, they are considered incompressible
- The particles that make up liquids have a higher average kinetic energy than solids, however they are still held together by the various intermolecular forces discussed in Chapter 5 (molecular structure)
- If a liquid is physically combined with another liquid, solid, or gas, it forms a mixture. ***Heterogenous mixtures*** are inconsistent in concentration or appearance, while ***homogenous mixtures*** are consistent throughout
- A ***solution*** is a homogeneous mixture that consists of a substance called the ***solute*** being dissolved in another substance called the ***solvent***. We will discuss solutions and their properties in the next chapter
- ***Miscibility*** is the ability of two substances to fully dissolve in each other at any concentration, forming a solution. ***Immiscible*** substances do not mix (i.e. oil in water)
- If two immiscible substances are forcefully combined via mechanical agitation or vigorous shaking, an ***emulsion*** will be formed. Emulsions appear macroscopically to be homogenous mixtures, but are actually heterogenous mixtures made of small suspended droplets called ***micelles***

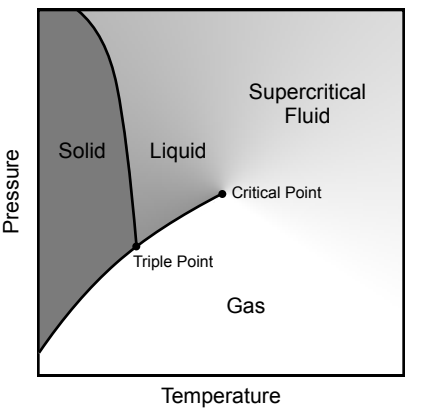
PHASE DIAGRAMS

- ***Phase diagrams*** depict the four phases of matter and their transition points over changes in pressure (on the y-axis) and temperature (on the x-axis)
  - ***Gasses*** exist and low pressure and high temperature
  - ***Solids*** exist at high pressure and low temperature
  - ***Liquids*** exist at medium pressure and temperature
  - ***Supercritical fluids*** exist at high pressure and temperature
- The ***triple point*** represents when the solid, liquid, and gas phases exist in equilibrium
- The ***critical point*** represents when the liquid and gas phases merge to become one phase – a supercritical fluid
  - Supercritical fluids have the high density of liquids but also the low viscosity of gasses, and are therefore excellent solvents for use in industrial extraction (ex: decaffeination)
  - A gas must be cooled below its critical temperature in order for condensation to be possible via a pressure increase. Otherwise, the gas will become a supercritical fluid instead of a liquid
- Most substances have a positively-sloped solid-liquid boundary, since solids are usually more dense than liquids. Increasing pressure while holding temperature constant would thus transform liquids to solids. However, since water is more dense than ice, it has a negatively-sloped solid-liquid boundary:

Phase Diagram for Most Substances



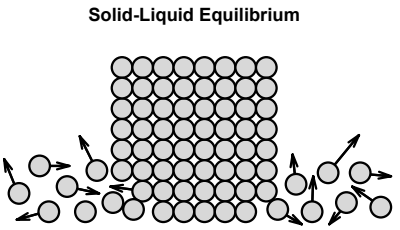
Phase Diagram for Water

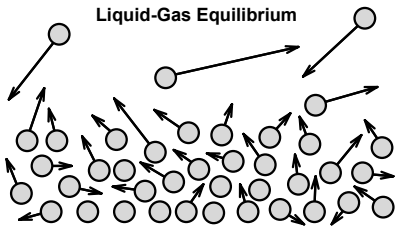


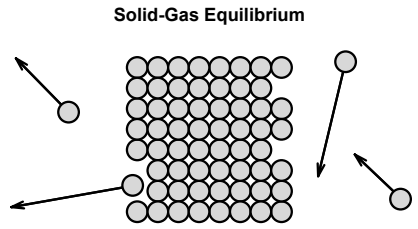
DAT TIP This is an important exception to know for the Canadian DAT

PHASE EQUILIBRIUM

- The transition between two phases is called a ***phase boundary***
- At every phase boundary, there is balance between the conversion of one phase to another. For instance, at the surface of an ice cube, there will be a certain number of molecules that gain enough kinetic energy to escape the solid crystal lattice and join the liquid phase
- There will also be a certain number of molecules that lose enough kinetic energy to join the solid phase. At the freezing point of water (0°C) the rate of these two changes are equal. Therefore a ***dynamic equilibrium*** exists







- There are six types of phase changes:
  - ***Melting/Fusion*** – Solid to liquid
  - ***Freezing/Solidification*** – Liquid to solid
  - ***Evaporation/Vaporization*** – Liquid to gas
  - ***Condensation*** – Gas to liquid
  - ***Deposition*** – Gas to solid without a liquid intermediate
  - ***Sublimation*** – Solid to gas without a liquid intermediate

CHAPTER 12 | **SOLUTIONS**

- A ***solution*** is a homogeneous mixture that consists of a substance called the ***solute*** being dissolved in another substance called the ***solvent***
- ***Dissolution/dissociation*** is the process in which a solid substance is converted to its dissolved form. A solid substance dissolved in water is said to be in ***aqueous*** form:

$$NaCl_{(s)} \rightarrow Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

- ***Precipitation*** is the opposite of dissolution:

$$Na^{+}_{(aq)} + Cl^{-}_{(aq)} \rightarrow NaCl_{(s)}$$

- There are several factors that affect the rate of dissolution:
  - ***Surface Area*** – Substances with larger surface areas will dissolve faster, since more molecules of solute are exposed to the kinetic energy of the solvent. This is why granulated sugar dissolves faster than rock sugar
  - ***Temperature*** – Higher temperatures increase the rate of dissolution, since greater kinetic energy allows the solvent to "bump" into solute molecules and break its intermolecular bonds
  - ***Agitation*** – Greater agitation (i.e. stirring, shaking, etc.) increases the rate of dissolution for the same reason as higher temperatures
- ***Total ionic equations*** show chemical reactions between iconic compounds:

$$H^{+}_{(aq)} + Cl^{-}_{(aq)} + Na^{+}_{(aq)} + OH^{-}_{(aq)} \rightarrow H_2O_{(l)} + Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

- Ions that are not directly involved in the reaction are called ***spectator ions***
- ***Net ionic equations*** are similar to total ionic equations, except they do not include spectator ions:

$$H^{+}_{(aq)} + OH^{-}_{(aq)} \rightarrow H_2O_{(l)}$$

CONCENTRATION AND DENSITY ☆ HIGH-YIELD

- ***Concentration (C)*** describes an amount of moles divided by a unit volume (most commonly moles per litre, or grams per millilitre):

$$C = \frac{n}{V} \quad \text{or} \quad C = \frac{m}{V}$$

- The concentration of chemical "*X*" in solution is denoted by square brackets (ex: [*X*])
- ***Density (ρ)*** describes mass divided by a unit volume (most commonly grams per millilitre):

$$\rho = \frac{m}{V}$$

DAT TIP On the Canadian DAT, you may need to convert the mass of water into volume or vice versa. Water has a density of 1 g/mL, so 1 kg of water is 1 L. Note that although 1 cm^3 of volume equals 1 mL, 1 m^3 equals 1000 L due to the cubic exponential. You should commit these conversion factors to memory

PARTS PER MILLION/BILLION

- Parts per million and parts per billion are both measures of concentration that are often used for very dilute solutions (ex: the amount of mercury in tap water)
- ***Parts per million (ppm)*** is defined as the mass of solute divided by the mass of solution (expressed in the same units), multiplied by one million:

$$\text{ppm} = \frac{m_{solute}}{m_{solution}} \times 10^6$$

- ***Parts per billion (ppb)*** is identical to parts per million, except multiplied by one billion:

$$\text{ppb} = \frac{m_{solute}}{m_{solution}} \times 10^9$$

Example

Fluorinated tap water is produced by diluting 1.5 g of fluoride in 1000 L of water. What is the concentration of fluoride ions in ppm?

A) 1.2 B) 1.5 C) 1.5×10^6 D) 1.5×10^9

Worked Solution

$m_{F^-} = \dfrac{1.5\text{ g}}{1000\text{ g/kg}} = 0.0015\text{ kg}$

$m_{H_2O} = (1000\text{ L})(1\text{ kg/L}) = 1000\text{ kg}$

First, convert all quantities into the same unit of mass (let's choose kilograms in this case)

$$\text{ppm} = \frac{m_{solute}}{m_{solution}} \times 10^6$$

$$\text{ppm} = \frac{0.0015\text{ kg}}{1000\text{ kg}} \times 10^6$$

$$\text{ppm} = 1.5$$

Then, write out the formula for ppm and solve. Since ppm is based on a mass ratio, the end result has no units

PERCENTAGE COMPOSITION

- ***Percentage composition*** describes the mass of the solute divided by the mass of the solution:

$$\%\text{ Composition} = \frac{m_{solute}}{m_{solution}} \times 100\,\%$$

MOLE FRACTION

- ***Mole fraction*** describes the number of moles of the solute divided by the number of moles of the solution:

$$X = \frac{n_{solute}}{n_{solution}}$$

MOLARITY VS MOLALITY ☆ HIGH-YIELD

- Molarity and molality are both measures of concentration, but they have a few subtle differences:
- ***Molarity (M)*** is the moles of a solute divided by the *volume* of the *solution* in litres. Since volume may fluctuate with temperature and pressure, molarity is also dependent on those two variables

$$M = \frac{n_{solute}}{V_{solution}}$$

- ***Molality (m)*** is the moles of a solute divided by the *mass* of the *solvent* in kilograms. Unlike molarity, molality does not change with temperature and pressure because mass is independent of those two variables

$$m = \frac{n_{solute}}{m_{solvent}}$$

Example

A saline solution is made by dissolving 4 cm^3 of NaCl in 500 mL of water. What is the molarity and molality of the resulting product, respectively? The density of NaCl is 2 g/cm^3

A) $M = \frac{0.14\ mol}{0.500\ L}, m = \frac{0.14\ mol}{0.500\ kg}$ B) $M = \frac{0.14\ mol}{0.504\ L}, m = \frac{0.14\ mol}{0.500\ kg}$

C) $M = \frac{8\ mol}{0.504\ L}, m = \frac{8\ mol}{0.500\ kg}$ D) $M = \frac{0.14\ mol}{0.500\ L}, m = \frac{0.14\ mol}{0.504\ kg}$

Worked Solution

$m_{NaCl} = (4\ cm^3)(2\ g/cm^3) = 8\ g$

$n_{NaCl} = \frac{8\ g}{58\ g/mol} \approx 0.14\ mol$

Let's calculate molarity first. We need to convert the volume of NaCl into mass, and then the mass to moles

$V_{NaCl} = (4\ cm^3)(1\ mL/cm^3) = 4\ mL$

$V_{solution} = 4\ mL + 500\ mL = 504\ mL$

$V_{solution} = \frac{504\ mL}{1000\ mL/L} = 0.504\ L$

We also need to convert the volume of the solution from millilitres into litres. Keep in mind that the volume of the solute (NaCl) must be included in the volume of the solution

$M = \frac{n_{solute}}{V_{solution}}$

$M = \frac{0.14\ mol}{0.504\ L}$

Finally, we substitute into our molarity equation and solve

$m_{H_2O} = (500\ mL)(1\ g/mL) = 500\ g$

$m_{H_2O} = \frac{500\ g}{1000\ g/kg} = 0.500\ kg$

Now let's calculate molality. We need to use the density of water (1 g/mL) to convert volume into mass. We also need to convert the mass of the solution from grams to kilograms

$m = \frac{n_{solute}}{m_{solvent}}$

$m = \frac{0.14\ mol}{0.500\ kg}$

Then we substitute into our molality equation and solve

DILUTIONS ☆ HIGH-YIELD

- The process of ***dilution*** does not change the amount of solute in a solution. Rather, it changes the amount of solvent, which is directly proportional to volume and inversely proportional to concentration
- The new concentration of a solution after dilution can be calculated with the following formula:

$$C_{initial}V_{initial} = C_{final}V_{final}$$

- The ratio between the solution's initial and final volume is called the ***dilution factor***. For instance, mixing 1 mL of solute with 9 mL of solvent results in a dilution factor of 1/10 or 0.1
- A ***serial dilution*** is when a volume of diluted solution is diluted again in solvent. This process repeats, until the final dilution has an extremely low solute concentration
- The concentration of a solution after *n* number of dilutions can be calculated with the following equation:

$$C_{final} = (C_{initial})(DF)^n$$

DF represents the dilution factor

Example

A serial dilution is performed by transferring 0.2 mL of a 5 M solution into a test tube filled with 3.8 mL of water. What is the final concentration after three rounds of dilution?

A) $\frac{1}{800}$ M B) 1600 M C) $\frac{1}{4}$ M D) $\frac{1}{1600}$ M

Worked Solution

$$DF = \frac{V_{initial}}{V_{final}}$$

$$DF = \frac{0.2\text{ mL}}{0.2\text{ mL} + 3.8\text{ mL}}$$

$$DF = \frac{0.2}{4} = \frac{1}{20}$$

Calculate the dilution factor by dividing the solution's initial volume by its final volume

$$C_{final} = (C_{initial})(DF)^n$$

$$C_{final} = (5\text{ M})\left(\frac{1}{20}\right)^3$$

$$C_{final} = \frac{5}{8000} = \frac{1}{1600}\text{ M}$$

Write out the serial dilution equation and substitute known values

SOLUBILITY ☆ HIGH-YIELD

- ***Solubility*** describes the maximum amount of a substance (in grams or moles) that can fully dissolve per litre of solution. When the concentration of a solution is equal to its solubility, it is ***saturated***
- The ***solubility product constant (K_{sp})*** is the equilibrium constant of a substance's dissociation equation
- For example, for this example reaction:

$$NaCl_{(s)} + H_2O_{(l)} \rightarrow Na^+_{(aq)} + Cl^-_{(aq)}$$

- The solubility constant would be:

$$K_{sp} = [Na^+][Cl^-]$$

- Note that substances in non-aqueous phases (such as solids and liquids) are ignored in the *Ksp* equation, since they do not have meaningful concentrations
- As with all equilibria, temperature changes the solubility constant. The solubility constant usually increases as temperature increases
- The ***solubility product quotient (Q_{sp})*** describes the state of the dissociation equation when not a equilibrium
- The relative magnitude of *Ksp* and *Qsp* can tell us whether a dissociation or precipitation will occur:
  - $Q_{sp} > K_{sp}$ – Precipitation will occur because the dissociation equation's product to reactant ratio is higher than it should be at equilibrium. The solution is ***supersaturated***
  - $Q_{sp} = K_{sp}$ – Neither precipitation nor dissociation occurs. The solution is ***saturated***
  - $Q_{sp} < K_{sp}$ – Dissociation will occur because the product to reactant ratio is lower than it should be at equilibrium. The solution is ***undersaturated***
- ***Molar solubility*** is defined as the molarity of the solute dissolved in a saturated solution of a particular solvent
- The ***common ion effect*** describes the decrease in solubility that occurs when a ***common ion*** (one that is already contained in solution) is added to an ionic solution

Example

If 1 L of 6 M $CaCl_2$ is added to 1 L of an aqueous solution containing 10 M NaCl, what is the Q_{sp} of NaCl? Will a precipitate form? The solubility product of NaCl in water is 30.

A) 33, precipitate B) 55, precipitate C) 18, no precipitate D) 33, no precipitate

Worked Solution

$$[Ca^{2+}] = \frac{(C_1)(V_1)}{V_2} = \frac{(6\ M)(1\ L)}{2\ L} = 3\ M$$

$$[Na^+] = \frac{(C_1)(V_1)}{V_2} = \frac{(10\ M)(1\ L)}{2\ L} = 5\ M$$

$$[Cl^-] = \frac{(6\ M)(1\ L)(2) + (10\ M)(1\ L)}{2\ L} = \frac{22}{2} = 11\ M$$

First, find the molar concentrations of all ions in the final solution. A dilution calculation is needed because the solution's total volume is doubled after $CaCl_2$ is added

Since Cl is a common ion, its final concentration must be obtained by adding up the number of moles and dividing by the solution's final volume

$$Q_{sp} = [Na^+][Cl^-]$$
$$Q_{sp} = (5\ M)(11\ M)$$
$$Q_{sp} = 55$$

Next, write out the solubility product quotient (Q_{sp}) equation for the dissolution of NaCl

$$55 > 30$$

Since $Q_{sp} > K_{sp}$, a precipitate will form

- Some compounds are ***insoluble*** in water, meaning they don't dissolve. Compounds can identified as soluble or insoluble depending on if they contain the following ions:

Soluble	**Insoluble**
Nitrates (NO_3^-)	Metal Oxides (Metal + Oxygen) ① ③
Acetates ($C_2H_3O_2^-$)	Hydroxides (OH^-) ① ③
Sulfates (SO_4^{2-}) ① ②	Carbonates (CO_3^{2-}) ③ ④
Ammonium (NH_4^+)	Phosphates (PO_4^{3-}) ③ ④
Group 1 Elements (Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+)	Sulfides (S^{2-}) ③ ④
Group 17 Elements (F^-, Cl^-, Br^-, I^-, At^-) ②	Sulfites (SO_3^{2-}) ③ ④

- Exceptions:
  - ① – Compounds that also contain Ca^{2+}, Sr^{2+}, or Ba^{2+}
  - ② – Compounds that also contain Pb^{2+}, Hg^{2+}, or Ag^+
  - ③ – Compounds that contain group 1 elements (Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+)
  - ④ – Compounds that contain NH_4^+

COLLIGATIVE PROPERTIES ☆ HIGH-YIELD

- ***Colligative properties*** are dependent on the ratio of solute to solvent particles, but not the type of particle
- For example, a liquid's osmolarity is a colligative property because it increases in proportion to the number of dissolved particles. The exact particle does not matter, so a 1 M solution of Na^+ has the same osmolarity as a 1 M solution of $C_6H_{12}O_6$ (glucose)
- Important examples of colligative properties include boiling point elevation, freezing point depression, vapour pressure depression, and osmotic pressure, which will all be explored in their own sections below

BOILING POINT ELEVATION ☆ HIGH-YIELD

- ***Boiling point elevation*** is a colligative property that describes the increase in a liquid's boiling point after a solute is added (ie: adding salt before boiling pasta can slightly increase the water's boiling point)
- This phenomenon is due to solute particles forming attractive interactions with solvent particles at the liquid's surface, thus increasing the amount of energy required to free a solvent molecule from the rest of the solution and into the gaseous state
- We can calculate the increase in boiling point with the formula:

$$\Delta T_b = k_b i m$$

k_b represents the solvent's boiling point elevation constant
i represents the solute's van't Hoff factor
m represents the solution's concentration in molality

MNEMONIC Remember this equation as "T = Kim"

- The ***van't Hoff factor*** of a solute is equal to the number of particles formed after the dissociation of one solute particle. For instance, $C_6H_{12}O_6$ (glucose) has a van't Hoff factor of 1 while NaCl has a van't Hoff factor of 2
- For non-electrolytes (non-ionic compounds), the van't Hoff factor is usually equal to 1

FREEZING POINT DEPRESSION ☆ HIGH-YIELD

- ***Freezing point depression*** is a colligative property that describes the decrease in a liquid's freezing point after a solute is added (ie: sidewalk salt used during the winter lowers the freezing point of water and prevents ice)
- This phenomenon is due to solute particles interfering with the physical packing of solvent molecules into an ordered crystal lattice, thus decreasing the temperature needed to induce freezing
- We can calculate the decrease in freezing point with the formula:

$$\Delta T_f = -k_f i m$$

k_f represents the solvent's freezing point depression constant
i represents the solute's van't Hoff factor
m represents the solution's concentration in molality

VAPOR PRESSURE DEPRESSION ☆ HIGH-YIELD

- ***Vapour pressure*** is the pressure exerted by gasses that are in thermodynamic equilibrium with its liquid phase
- Vapour pressure is directly correlated to a liquid's volatility and inversely related to the strength of a liquid's intermolecular interactions
- ***Boiling point*** is defined as the temperature at which the liquid's vapour pressure is equal to atmospheric pressure of the environment. This is why water boils at lower temperatures in regions of high altitude
- ***Vapour pressure depression*** is a colligative property that describes the decrease in a liquid's vapour pressure after a solute is added
- This phenomenon occurs due to boiling point elevation, another colligative property that makes it harder for the liquid to evaporate. Solute particles form attractive interactions with solvent particles, thus producing less evaporated liquid and resulting in a lower vapour pressure
- The following equation is called ***Raoult's law***, and is used to calculate vapour pressure depression after the addition of a non-volatile solute:

$$P^{\circ}_{solution} = P^{\circ}_{solvent} \times X_{solvent}$$

$P^{\circ}_{solution}$ represents the vapour pressure of the solution
$P^{\circ}_{solvent}$ represents the vapour pressure of the solvent
$X_{solvent}$ represents the mole fraction of the solvent

OSMOTIC PRESSURE ☆ HIGH-YIELD

- ***Osmosis*** is a colligative property that describes the net movement of water across a semipermeable membrane in order to equalize a concentration gradient. Water flows from low solute concentration to high solute concentration
- ***Osmotic pressure*** is the hydrostatic pressure needed to stop osmosis and achieve ***osmotic equilibrium***, when there is no net movement of water across the membrane
- The following equation is used to calculate osmotic pressure:

$$\Pi = TRiM$$

Π represents osmotic pressure in atm
T represents the temperature in Kelvin
R represents the ideal gas constant
i represents the solute's van't Hoff factor
M represents the solution's concentration in molarity

MNEMONIC Remember this equation as "Pie = Trim"

CHAPTER 13 | **ACIDS AND BASES**

ACID AND BASE PROPERTIES

Acids
- Turns litmus paper red
- Tastes sour
- Reacts with metals to produce hydrogen gas
- Reacts with bases to form water and a salt
- Aqueous solutions conduct electricity

Bases
- Turns litmus paper blue
- Tastes bitter
- Feels soapy or slippery
- Reacts with acids to form water and a salt
- Aqueous solutions conduct electricity

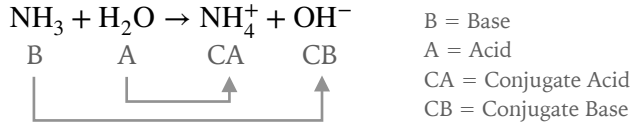
- Note that ***metal oxides*** produce basic solutions in water, while ***non-metal oxides*** produce acidic solutions:
  - Metal Oxide: $Na_2O + H_2O \rightarrow 2NaOH$
  - Non-Metal Oxide: $CO_2 + H_2O \rightarrow H_2CO_3$

ARRHENIUS DEFINTION ☆ HIGH-YIELD

- ***Svante Arrhenius*** was the first scientist to define acids and bases
- According to the ***Arrhenius definition***:
  1. All acids release protons (H^+) upon dissociation in water
  2. All bases release hydroxide (OH^-) upon dissociation in water
- The most common examples of Arrhenius acids and bases are HCl and NaOH, respectively
- The Arrhenius definition needed to be revised because it failed to explain the acid/base properties of non-aqueous solutions and compounds that did not contain OH^-, such as NH_3

BRØNSTED-LOWRY DEFINITION ☆ HIGH-YIELD

- ***Johannes Brønsted*** and ***Thomas Lowry*** proposed a more general definition of acids and bases
- According to the ***Brønsted-Lowry definition***:
  1. All acids donate H^+
  2. All bases accept H^+
  3. All acids and bases exist in ***conjugate acid-base pairs***
  4. Conjugate pairs always differ from each other by the gain or loss of a single H^+



- Acids can be ***monoprotic*** (possess one donor hydrogen), or ***polyprotic*** (possess multiple donor hydrogens)
- Polyprotic acids have multiple ***dissociation constants (K_a)***, one for each donor hydrogen's dissociation equilibrium. This will be further discussed later in the chapter
- The Brønsted-Lowry definition also needed to be revised because it failed to explain the acid/base properties of compounds that did not contain hydrogen, such as CO_2

LEWIS DEFINITION ☆ HIGH-YIELD

- ***Gilbert Lewis*** proposed the most inclusive and comprehensive definition for acids and bases
- According to the ***Lewis definition***:
  1. All acids donate an electron pair
  2. All bases accept an electron pair
- Just like the Brønsted-Lowry definition, Lewis acids and bases also exist in conjugate pairs. Sometimes the conjugate acid and base will be the same compound, called an ***acid-base adduct***:

$$\underset{\text{B}}{CO_2} + \underset{\text{A}}{H_2O} \rightarrow \underset{\text{Adduct}}{H_2CO_3} \qquad \begin{matrix}\text{B = Base}\\ \text{A = Acid}\end{matrix}$$

NOMENCLATURE OF ARRHENIUS ACIDS

- Arrhenius acids are named after their anion component. The ***"–ide"*** ending of the anion is replaced with the suffix ***"–ic"*** and the prefix ***"hydro–"***. Consider the following examples:
  - Cl^- (chloride) → HCl (hydrochloric acid)
  - F^- (fluoride) → HCl (hydrofluoric acid)
  - Br^- (bromide) → HCl (hydrobromic acid)
- Acids that contain oxygen are called ***oxyacids***, and are named after their oxyanion component.
  - If the oxyanion ends with ***"–ite"***, the acid has the suffix ***"–ous acid"***. Consider the following examples:
    - NO_2^- (nitrite) → HNO_2 (nitrous acid)
    - ClO_2^- (chlorite) → $HClO_2$ (chlorous acid)
    - ClO^- (hypochlorite) → HClO (hypochlorous acid)
  - If the oxyanion ends with ***"–ate"***, the acid has the suffix ***"–ic acid"***. Consider the following examples:
    - NO_3^- (nitrate) → HNO_3 (nitric acid)
    - ClO_3^- (chlorate) → $HClO_3$ (chloric acid)

ACID AND BASE STRENGTH ☆ HIGH-YIELD

- ***Weak acids*** and ***weak bases*** partially dissociate in solution, forming an equilibrium:

$$HA + H_2O \rightleftharpoons A^- + H_3O^+ \qquad \text{or} \qquad B + H_2O \rightleftharpoons HB^+ + OH^-$$

- Note that in reality, free protons (H^+) instantly react with water to form a ***hydronium ion (H_3O^+)***. However, chemists often simplify the dissociation equation by writing H^+ instead of H_3O^+:

$$HA \rightleftharpoons A^- + H^+$$

- ***Strong acids*** and ***strong bases*** completely dissociate in solution:

$$HA + H_2O \rightarrow A^- + H_3O^+ \qquad \text{or} \qquad B + H_2O \rightarrow HB^+ + OH^-$$

- The stronger the acid/base, the weaker its conjugate. This is because it is more likely for an acid/base to donate/accept a proton if the product (conjugate) is stable (thus itself being a weak base/acid)
  - Group 1 and 2 metals are conjugates of strong bases, therefore they are weak acids
  - I^-, Cl^-, Br^-, NO_3^-, ClO_3^-, ClO_4^-, and HSO_4^- are conjugates of strong acids, therefore they are weak bases. However, since H_2SO_4 is diprotic (possesses two hydrogens), HSO_4^- can also act as a weak acid. Compounds that can act as both an acid or base are called ***amphoteric***

• For the Canadian DAT, it is important that you are familiar with the common strong acids and bases:

Strong Acids	Mnemonic
HI	I
HCl	Clorox
HBr	Brass,
HNO_3	Not
$HClO_3$	Closets,
$HClO_4$	Clothes, or
H_2SO_4	Socks

Strong Bases	Mnumonic
LiOH	Like
NaOH	Nathan
KOH	Knows,
$Ca(OH)_2$	California
$Sr(OH)_2$	Surely is
$Ba(OH)_2$	Basic

pH AND pOH ☆ HIGH-YIELD

• ***pH*** is defined as the negative log of a solution's proton (H^+) concentration:

$$pH = -\log[H^+]$$

• ***pOH*** is the negative log of a solution's hydroxide (OH^-) concentration:

$$pOH = -\log[OH^-]$$

• Note that if the H^+ or OH^- concentration is expressed in base ten notation (ten to the power of x), then the pH is simply the negative of x (whatever number is in the exponent)

Example

What is the pH of a 1 L solution containing 1.0×10^{-4} moles of aqueous HCl?

A) 8 B) -2 C) 4 D) -4

Worked Solution

$pH = -\log[H^+]$	Write out the pH formula
$[H^+] = \frac{1.0 \times 10^{-4}\ \text{mol}}{1\ \text{L}}$	Since HCl is a strong acid, it dissociates completely in water. Therefore we can calculate the concentration of protons by dividing moles by volume
$pH = -\log(1.0 \times 10^{-4})$ $pH = 4$	Substitute into the pH formula and solve

K_a, K_b, AND K_w ☆ HIGH-YIELD

- The ***dissociation constant (K)*** is the equilibrium constant for the dissociation reaction of a weak acid (K_a), or base (K_b). For example, given the generic acid and base reactions:

$$HA + H_2O \rightleftharpoons A^- + H_3O^+ \qquad \text{or} \qquad B + H_2O \rightleftharpoons HB^+ + OH^-$$

- The respective K_a and K_b values would be:

$$K_a = \frac{[A^-][H_3O^+]}{[HA]} \qquad\qquad K_b = \frac{[HB^+][OH^-]}{[B]}$$

- The pK_a and pK_b values are just the negative log of K_a and K_b:

$$pK_a = -\log\left(\frac{[A^-][H_3O^+]}{[HA]}\right) \qquad pK_b = -\log\left(\frac{[HB^+][OH^-]}{[B]}\right)$$

- Strong acids/bases have very large K_a and K_b values, while weak acids/bases have smaller K_a and K_b values. This trend is reversed for pK_a and pK_b
- Water dissociates spontaneously in a process called ***autoionization***. K_w is the equilibrium constant for this reaction, which equals 10^{-14} for pure water at 25°C:

$$H_2O \rightleftharpoons H^+ + OH^-$$

$$K_w = [H^+][OH^-] = 10^{-14} \qquad \text{and} \qquad pK_w = pH + pOH = 14$$

- K_w is related to K_a and K_b through the equations:

$$K_w = K_a \times K_b \qquad \text{and} \qquad pK_w = pK_a + pK_b$$

Example

Ammonia is a weak base that partially dissociates according to the following equation:

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

If dissolving 2 moles of ammonia in 8 litres of water results in a hydroxide concentration of 10^{-2} M, what is the pH, K_b, and pK_a of the solution?

A) 14, 2×10^{-4}, $7 - \log\left(2 \times 10^{-4}\right)$
B) 12, 4×10^{-4}, $14 - \log\left(4 \times 10^{-4}\right)$
C) 12, 8×10^{-4}, $14 - \log\left(8 \times 10^{-4}\right)$
D) 12, 4×10^{-4}, $7 - \log\left(4 \times 10^{-4}\right)$

Worked Solution

$pOH = -\log[OH^-]$
$pOH = -\log[10^{-2}] = 2$
$pH = 14 - 2 = 12$

Let's calculate pH first. Since we know the concentration of $[OH^-]$, we can find pOH and convert to pH

$$K_b = \frac{[NH_3^+][OH^-]}{[NH_4^+]}$$

$$K_b = \frac{(10^{-2}\ \text{M})(10^{-2}\ \text{M})}{0.25\ \text{M}}$$

$$K_b = \frac{10^{-4}}{0.25}$$

$$K_b = 4 \times 10^{-4}$$

Next let's calculate K_b. Since the molar ratio of NH_4^+ and OH^- is 1:1, they have the same concentration. We can calculate the concentration of NH_3 by dividing moles by volume

$$pK_b = -\log\left(4 \times 10^{-4}\right)$$

$$pK_a = 14 - \log\left(4 \times 10^{-4}\right)$$

We can calculate pK_a from pK_b

PREDICTING ACID STRENGTH

- The following criteria can be used to predict the relative strength of two acids:
  - ***Dissociation Constant (K)*** – The stronger the weak acid/base, the more products are favoured in the equilibrium and the larger the dissociation constant. Strong acids/bases completely dissociate in solution, so their dissociation constant will always be very large
  - ***Electronegativity*** – For two acids with conjugates in the same period (i.e. H_2S and HCl), the acid with the more electronegative conjugate will be more acidic (i.e. HCl is more acidic than H_2S). This is because the more electronegative conjugate is more stable with a negative charge
  - ***Atomic Radius*** – For two acids with conjugates in the same column (i.e. HCl and HI), the acid with the larger conjugate will be more acidic (i.e. HI is more acidic than HCl). This is because the conjugate with the larger atomic radius can better delocalize (spread out) a negative charge and thus is more stable

ACID/BASE PROPERTIES OF SALTS ☆ HIGH-YIELD

- ***Salts*** are created from neutralization reactions between an acid and base
- When dissolved in water, a salt may form a neutral, acidic, or basic solution
- We can determine the general *pH* of the salt's solution by determining how the aqueous ions behave as conjugate acids/bases. For example:
  - NaCl is a neutral salt because Na^+ is a weak acid (conjugate of strong base) and Cl^- is a weak base (conjugate of strong acid)
  - $NaCH_3COO$ is a basic salt because Na^+ is a weak acid (conjugate of strong base) and CH_3COO^- is a strong base (conjugate of weak acid)
  - NH_4Cl is an acidic salt because NH_4^+ is a strong acid (conjugate of weak base) and Cl^- is a weak base (conjugate of strong acid)
- In general, the following neutralization reactions generate these respective salts:
  - Strong Acid + Strong Base = Neutral Salt
  - Strong Acid + Weak Base = Acidic Salt
  - Weak Acid + Strong Base = Basic Salt

BUFFERS ☆ HIGH-YIELD

- A buffer consists of a weak acid or base in equilibrium with its conjugate
- The dissociation equation for a generic buffer is the same as the equation for a generic weak acid or base:

$$HA \rightleftharpoons A^- + H^+ \qquad \text{or} \qquad B + H_2O \rightleftharpoons HB^+ + OH^-$$

- For example, the following is a buffer made from the bicarbonate ion:

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

- A buffer will prevent a dramatic change in *pH* following the addition of strong acids or bases. This occurs because the added strong acid/base will cause a shift in equilibrium (Le Châtelier's principle), resulting in the strong/acid base being replaced with a weak acid/base
- For example, if we add HCl to our bicarbonate buffer, the H^+ ions will react with HCO_3^- to produce more H_2CO_3, the weak acid:

$$H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

- The ideal buffer will have equal molar amounts of acid/base and its conjugate, to maximize its ability to react with strong acids/bases. However, as long as the ratio of HA and H^- are within a factor of ten, buffering capacity remains efficient
- The *pH* of a buffer can be estimated using the ***Henderson-Hasselbalch equation***:

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

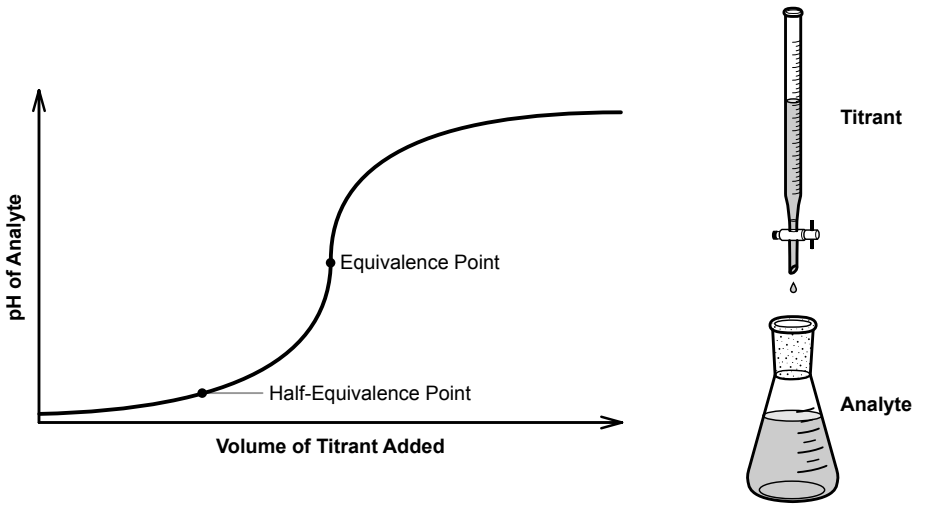
- Since the *pH* depends on the ratio of A^- to HA, adding water to a buffer solution will not affect *pH*
- Note that according to the Henderson-Hasselbalch equation, $pH = pK_a$ when the concentrations of the acid and conjugate base are equal, since $\log(1) = 0$. In a titration this occurs at the ***half-equivalence point***

TITRATIONS ☆ HIGH-YIELD

- A ***titration*** is a lab procedure used to determine the molarity of a solution by slowly adding a solution of known molarity until neutralization (***equivalence point***)
- The known solution is called the ***titrant*** and the unknown solution is called the ***analyte***. The analyte is said to be titrated "against" or "with" the titrant
- The volume and molarity of the titrant can then be used alongside the neutralization equation's molar ratios to calculate the number of moles of the analyte, and thus its molarity

DAT TIP Equivalence points and half-equivalence points are often confused. The equivalence point is when the number of moles of acid and base are equal (in other words, when the analyte is fully neutralized). The half-equivalence point is when the moles of acid/base and it's conjugate base are equal ($[HA] = A^-$ or $B = HB^+$)

- Titration protocols usually involve an Erlenmeyer flask and burette, with the analyte in the Erlenmeyer flask and the titrant in the burette
- A colour-changing ***pH indicator*** is used to monitor when the titration approaches the equivalence point. The indicator consists of a weak acid that has a conjugate base with a different colour
- It is best to use an indicator with a pK_a that is close to the *pH* at equivalence point
- The titration ***end point*** occurs when the indicator changes colour. Note that this does not necessarily have to be equal to the equivalence point, since an indicator's colour change can occur before or after true equivalency



Example

A 100 mL sample of sulphuric acid is titrated with 0.5 M barium hydroxide. It takes 50 mL of the titrant to reach the equivalence point. What is the initial concentration of the analyte?

A) 1 M B) 0.5 M
C) 2 M D) 0.25 M

Worked Solution

$Ba(OH)_2 + H_2SO_4 \rightarrow 2H_2O + BaSO_4$

First, write the balanced reaction equation for the neutralization of sulphuric acid (the analyte) with barium hydroxide (the titrant)

$n_{Ba(OH)_2} = \left(C_{Ba(OH)_2}\right)\left(V_{Ba(OH)_2}\right)$

$n_{Ba(OH)_2} = (0.5\text{ M})(0.050\text{ L})$

$n_{Ba(OH)_2} = 0.025\text{ mols}$

$n_{H_2SO_4} = (1)\left(n_{Ba(OH)_2}\right) = 0.025\text{ mols}$

Next we calculate the number of moles of the titrant used. Note that the stoichiometric ratio between H^+ and OH^- is 1:1, since there are two moles of H^+ per H_2SO_4 and two moles of OH^- per $Ba(OH)_2$. This means that the number of moles of titrant consumed is equal to the number of moles of analyte neutralized

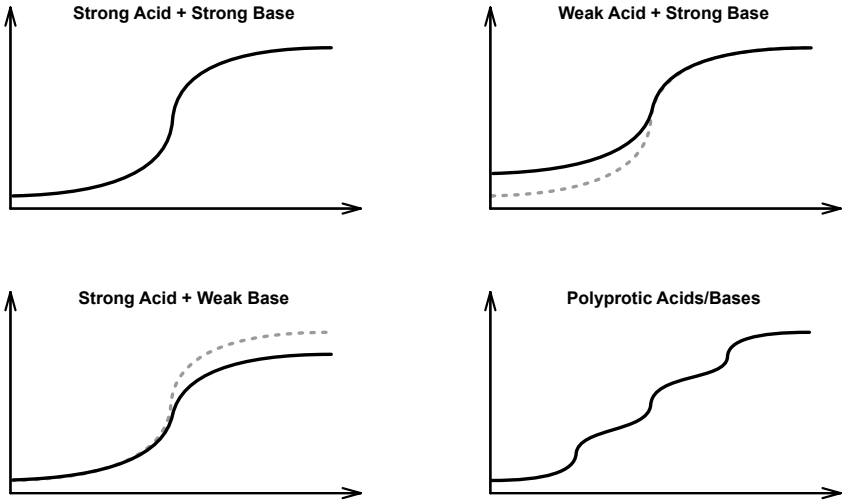
$$M = \frac{n_{H_2SO_4}}{V_{H_2SO_4}}$$

$$M = \frac{0.025\text{ mols}}{0.100\text{ L}}$$

$M = 0.25\text{ mol/L}$

Now we can calculate the initial molarity of the analyte

- A ***titration curve*** is a graphical representation of the analyte's *pH* throughout the titration
  - The titration curve of a strong acid + strong base is ***sigmoidal***, with the most vertical region representing the equivalence point and end point
  - The titration curve of a weak acid + strong base or strong acid + weak base will have flat ***buffer zones***, in addition to the usual sigmoidal region
  - Polyprotic acids have multiple equivalence points and thus multiple vertical regions in the titration curve



- Titrations can be conducted between any combination of weak and strong acids/bases. In general, the following rules apply:
  - Strong Acid + Strong Base = Neutral *pH* at Equivalence Point
  - Weak Acid + Strong Base = Basic *pH* at Equivalence Point
  - Strong Acid + Weak Base = Acidic *pH* at Equivalence Point

TECHNIQUE Calculating *pH* for Strong + Strong Titration

- To calculate the *pH* or *pOH* of a titration between a strong acid and strong base, we simply need to determine the concentration of H^+ or OH^- ions
- Since the neutralization reaction between a strong acid and base proceeds to completion, we can simply take the difference between the initial number of moles of H^+ or OH^-, and then divide this number by the new volume. This will result in the concentration of residual or excess H^+ or OH^- ions
- The calculation method remains the same regardless of which phase of the titration we are considering (before, during, or after the equivalence point)

DAT TIP Remember that a titration consists of both a neutralization and a dilution reaction. The volumes of the titrant and analyte dilute each other. Therefore, do not forget to add up the initial volumes to calculate the final volume of the titrant + analyte mixture

Example

A 20 mL sample of 0.5 M hydrochloric acid (a strong acid) is titrated with 0.5 M sodium hydroxide (a strong base). What is the *pH* after the addition of 10 mL of hydrochloric acid?

A) $-\log(0.17)$ B) $-\log(0.005)$
C) $-\log(6)$ D) $-\log(0.03)$

Worked Solution

$HCl + NaOH \rightarrow H_2O + NaCl$	First, write the balanced reaction equation for the neutralization of hydrochloric acid (the analyte) with sodium hydroxide (the titrant)
$n_{HCl} = (0.020\ L)(0.5\ M) = 0.01$ mols $n_{NaOH} = (0.010\ L)(0.5\ M) = 0.005$ mols	Next we must find the number of moles of the analyte and the titrant
Excess $HCl = 0.01 - 0.005 = 0.005$ mols	We started with 0.01 mol of HCl, and we added 0.005 mol of NaOH. Since the reaction between a strong acid and base proceeds to completion, all 0.005 mol of NaOH react, and 0.005 mol of HCl are left over
$V = 20\ mL + 10\ mL = 30\ mL$ $V = \frac{30\ mL}{1000\ mL/L} = 0.03\ L$	Next we find our new volume after the titrant has been added. Do not forget to convert millilitres into litres
$M = \frac{0.005\ mols}{0.03\ L} = 0.17\ mol/L$	We can now calculate the molarity of excess H^+ ions
$pH = -\log(0.17)$	Finally, we calculate pH using the appropriate formula

TECHNIQUE Calculating *pH* for Weak + Strong Titration Before Equivalence Point

- The amount of strong acid/base added will react fully with the weak base/acid. Thus, the excess concentration of weak base/acid can be determined by subtraction
- Use an ICE table to determine $[H^+]$ after the weak acid/base equilibrium has been re-established. If the concentration of the weak base/acid is equal with that of its conjugate, we can use the simplified Henderson-Hasselbalch equation ($pH = pK_a$ or $pOH = pK_b$)

Example

50 mL of 0.2 M acetic acid (a weak acid) is titrated with 0.05 M sodium hydroxide (a strong base). What is the *pH* after addition of 100 mL of sodium hydroxide? The pK_a of acetic acid is 4.8

A) 2 B) 4.8 C) 9.6 D) 9.2

Worked Solution

$CH_3COOH + OH^- \rightleftharpoons H_2O + CH_3COO^-$	First, write the balanced reaction equation
$n_{CH_3COOH} = (0.050\ L)(0.2\ M) = 0.01$ mols $n_{NaOH} = (0.100\ L)(0.05\ M) = 0.005$ mols	Next, find the number of moles of the analyte and titrant
$n_{CH_3COO^-} = 0.01 - 0.005 = 0.005$ mols	Since the strong base reacts fully with the weak acid (acetic acid), 0.005 mol of its conjugate base will form (the acetate ion)
$V = 50\ mL + 100\ mL = 150\ mL$ $V = \frac{150\ mL}{1000\ mL/L} = 0.150\ L$	Next we find our new volume after the titrant has been added. Do not forget to convert millilitres into litres
$M_{CH_3COOH} = \frac{0.005\ mols}{0.150\ L} = 0.03\ mol/L$ $M_{CH_3COO^-} = \frac{0.005\ mols}{0.150\ L} = 0.03\ mol/L$	We can now calculate the molarity of acetic acid and the acetate ion. Notice how both concentrations are the same. This means the titration is at half-equivalence point
$pH = pK_a + \log\frac{[A^-]}{[HA]}$ $pH = pK_a + \log(1)$ $pH = pK_a$ $pH = 4.8$	Since we are at the half-equivalence point, we can use the simplified Henderson-Hasselbalch equation to calculate *pH*

TECHNIQUE Calculating *pH* for Weak + Strong Titration at Equivalence Point

- Use an ICE table to determine $[H^+]$ after the weak acid/base equilibrium has been re-established

Example

50 mL of 0.2 M acetic acid (a weak acid) is titrated with 0.05 M sodium hydroxide (a strong base). At the equivalence point, 200 mL of sodium hydroxide has been added. What is the *pH* of the solution? The K_b of the acetate ion is 5.6×10^{-10}

A) 0.7 B) 7 C) 13.3 D) 8.7

Worked Solution

$CH_3COOH + OH^- \rightleftharpoons H_2O + CH_3COO^-$	First, write the balanced reaction equation
$n_{CH_3COOH} = (0.050\ \text{L})(0.2\ \text{M}) = 0.01\ \text{mols}$ $n_{NaOH} = (0.200\ \text{L})(0.05\ \text{M}) = 0.01\ \text{mols}$	Next, find the number of moles of the analyte and titrant. Note that they are equal, as expected for the equivalence point of a titration
$n_{CH_3COO^-} = 0.01\ \text{mols}$	Since the strong base reacts fully with the weak acid (acetic acid), 0.01 mol of its conjugate base will form (the acetate ion)
$V = 50\ \text{mL} + 200\ \text{mL} = 250\ \text{mL}$ $V = \dfrac{250\ \text{mL}}{1000\ \text{mL/L}} = 0.250\ \text{L}$	Next we find our new volume after the titrant has been added. Do not forget to convert millilitres into litres
$M_{CH_3COO^-} = \dfrac{0.01\ \text{mols}}{0.250\ \text{L}} = 0.04\ \text{mol/L}$	We can now calculate the molarity of the acetate ion
$CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$ **I** 0.04 M — 0 M — 0 M **C** $-x$ — $+x$ — $+x$ **E** $0.04 - x$ — x — x	Use an ICE table to calculate the concentration of OH^- after the weak acid/base equilibrium
$K_b = \dfrac{[CH_3COO^-][OH^-]}{[CH_3COOH]}$ $5.6 \times 10^{-10} = \dfrac{(x)(x)}{0.04 - x}$ $5.6 \times 10^{-10} \approx \dfrac{x^2}{0.04}$ $x \approx \sqrt{(5.6 \times 10^{-10})(0.04)}$	We can ignore the "$-x$" term by assuming that it is very small compared to 0.04
$pOH = -\log\left(\sqrt{(5.6 \times 10^{-10})\,(0.04)}\right)$ $pOH = 5.3$ $pH = 14 - 5.3 = 8.7$	Finally, we can calculate pOH and convert to pH. Note that the pH is slightly basic at the equivalence point because the titration is a weak acid + strong base

TECHNIQUE Calculating pH for Weak + Strong Titration After Equivalence Point

- The effect of the strong acid/base on *pH* is far greater than the effect of the weak base/acid equilibrium
- Therefore, ignore the equilibrium and estimate *pH* using the excess concentration of the strong acid/base

Example

50 mL of 0.2 M acetic acid (a weak acid) is titrated with 0.05 M sodium hydroxide (a strong base). What is the *pH* after addition of 300 mL of sodium hydroxide?

A) 12.1 B) 7 C) 13.3 D) 9.3

Worked Solution

$CH_3COOH + OH^- \rightleftharpoons H_2O + CH_3COO^-$	First, write the balanced reaction equation
$n_{CH_3COOH} = (0.050\ L)(0.2\ M) = 0.01$ mols $n_{NaOH} = (0.300\ L)(0.05\ M) = 0.015$ mols	Next, find the number of moles of the analyte and titrant
$n_{NaOH} = 0.015 - 0.01 = 0.005$ mols	Since there is an excess of strong base, we subtract to find the amount of NaOH left over
$V = 50\ mL + 300\ mL = 350\ mL$ $V = \frac{350\ mL}{1000\ mL/L} = 0.350\ L$	Next we find our new volume after the titrant has been added. Do not forget to convert millilitres into litres
$M_{NaOH} = \frac{0.005\ mols}{0.350\ L} = 0.014\ mol/L$	We can now calculate the molarity of excess NaOH
$M_{OH^-} = M_{NaOH} = 0.014\ mol/L$	Since there is 1 mol of OH^- per 1 mol of NaOH, the molarity of OH^- is also 0.014
$pOH = -\log(0.014)$ $pOH = 1.9$ $pH = 14 - 1.9 = 12.1$	Calculate *pOH* and convert to *pH*

CHAPTER 14 | **REDOX REACTIONS**

- ***Redox reactions*** involve the transfer of electrons between chemical species
- The term "redox" is a combination of the words "reduction" and "oxidation"
- ***Reduction*** is the gain of electrons while ***oxidation*** is the loss of electrons

MNEMONIC "OIL RIG" → "Oxidation Is Losing, Reduction Is Gaining"

OXIDATION STATES HIGH-YIELD

- ***Oxidation states (OS)*** (also called oxidation numbers) are denoted with the sign placed in front of the number (ex: +1) rather than behind the number as in actual charges (ex: 1+)
- OS are used to track the loss/gain of electrons in a redox reaction. OS are assigned to each atom according to the following rules:

1. **The OS of fluorine is always −1**
2. **The OS of atoms in their elemental state is always 0**
   - Ex: Cl_2, O_2, and Al all have an OS of 0
3. **The OS of a monoatomic ion is always equal to it's charge**
   - Ex: Na^+ has an OS of +1; Ca^{2+} has an OS of +2
4. **The OS of group 1 and 2 elements is always +1 and +2 respectively**
   - Ex: K^+ and Ca^{2+} have an OS of +1 and +2 respectively
5. **The OS of oxygen is usually −2**
   - Ex: In NaOH, oxygen has an OS of −2
   - **Exception:** When combined with fluorine, oxygen's OS is positive
     - Ex: In OF_2, oxygen has an OS of +2
   - **Exception:** When in peroxides (compounds with the structure R−O−O−R), oxygen's OS is −1
     - Ex: In BaO_2, oxygen has an OS of −1
6. **The OS of hydrogen is usually +1**
   - Ex: In HCl, hydrogen has an OS of +1
   - **Exception:** When combined with less electronegative elements, hydrogen's OS is negative
     - Ex: In NaH, hydrogen has an OS of −1
7. **The OS of group 7 elements is usually −1**
   - Ex: In HCl, chlorine has an oxidation state of −1
   - **Exception:** When combined with more electronegative elements, OS is positive
     - Ex: In HOCl, chlorine has an oxidation state of +1, due to the presence of oxygen
8. **The sum of individual OS is equal to the overall charge of the molecule or polyatomic ion**
   - Ex: In $MgCl_2$, the overall charge of the molecule is 0. Therefore, if each of the two chlorines have an OS of −1, than the magnesium must have an OS of +2, since $2(-1) + 2 = 0$

- Oxidation states must be integers (whole numbers). It is possible to get a decimal oxidation state using the method above. For example, the oxidation state of S in $S_4O_6^{2-}$ appears to be +2.5, however this decimal represents the average oxidation state of all sulphurs. The actual oxidation state of each sulphur is an integer

Example

What is the change in oxidation state for bromine in the following redox reaction?

$$I_2 + 2Br^- \rightarrow 2I^- + Br_2$$

A) 0 B) -1 C) $+1$ D) $+2$

Worked Solution

$I_2 + 2Br^- \rightarrow 2I^- + Br_2$	First, let's assign oxidation states for each element in the reaction
$\overset{0}{I_2} + 2Br^- \rightarrow 2I^- + Br_2$	Iodine is a neutral element, so its oxidation state is 0 by definition
$\overset{0}{I_2} + 2\overset{-1}{Br}^- \rightarrow 2I^- + Br_2$	Br^- has a charge of -1, to it's oxidation state is also -1
$\overset{0}{I_2} + 2\overset{-1}{Br}^- \rightarrow 2\overset{-1}{I}^- + Br_2$	I^- has a charge of -1, to it's oxidation state is also -1
$\overset{0}{I_2} + 2\overset{-1}{Br}^- \rightarrow 2\overset{-1}{I}^- + \overset{0}{Br_2}$	Bromine is a neutral element, so its oxidation state is 0 by definition
Oxidation $I_2 + 2Br^- \rightarrow 2I^- + Br_2$ Reduction	We can see that bromine's oxidation states changes from -1 to 0 (net change is $+1$). It loses one electron and is therefore oxidized. Iodine's oxidation state changes from 0 to -1 (net change is -1). It gains one electron and therefore is reduced

Example

What is the oxidation state of carbon in H_2CO?

A) 0 B) -1 C) $+1$ D) $+2$

Worked Solution

$H_2\overset{-2}{C}O$	The oxidation state of oxygen is usually -2
$\overset{+1}{H_2}\overset{-2}{C}O$	The oxidation state of hydrogen is usually $+1$
$2(+1) + x + (-2) = 0$ $x = 0$	The sum of oxidation states (excluding that of carbon) is currently 0. Since H_2CO is a neutral molecule, the oxidation state of carbon must also be 0

HALF-REACTIONS ☆ HIGH-YIELD

- A redox reaction equation can be split into two components or ***half-reactions***
- For example, given the following redox reaction:

$$I_{2\,(s)} + 2Br^-_{(aq)} \rightarrow 2I^-_{(aq)} + Br_{2\,(s)}$$

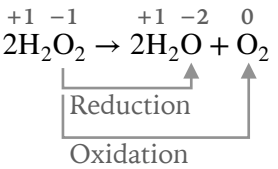
- The ***reduction half-reaction*** is:

$$I_{2\,(s)} + 2e^- \rightarrow 2I^-_{(aq)}$$

- And the ***oxidation half-reaction*** is:

$$2Br^-_{(aq)} \rightarrow Br_{2\,(aq)} + 2e^-$$

- The number of electrons involved in each half-reaction must be equal
- When the same molecule undergoes both oxidation and reduction, it is called a ***disproportionation reaction***:



BALANCING REDOX REACTIONS ☆ HIGH-YIELD

- The ***law of conservation of mass*** states that matter cannot be created nor destroyed. Therefore the total mass of reactants must equal the total mass of products
- The ***law of conservation of charge*** states that an electrical charge cannot be created nor destroyed. Therefore the total sum of positive and negative charges on the reactants side must equal the sum on the products side
- Due to the two laws mentioned above, both the atoms and charges in a redox reaction must be balanced

TECHNIQUE The following steps describe how to balance a redox reaction:

1. Separate the reaction into oxidation and reduction half-reactions
2. For each half-reaction, balance the atoms on each side:
    2.1. Balance all non-oxygen and non-hydrogen atoms first
    2.2. Balance oxygens by adding H_2O
    2.3. For redox reactions occurring in acidic or neutral solutions, balance hydrogens by adding H^+
    2.4. For redox reaction occurring in basic solutions, add OH^- to both sides until all H^+ is neutralized to produce H_2O
3. For each half reaction, balance charges by adding electrons
4. Make sure both half-reactions have the same number of electrons
5. Combine the two half-reactions via addition, canceling out terms that appear on both sides of the equation and simplifying coefficients to the lowest common ratio
6. Double-check that the number of elements and charges on both sides are equal

DAT TIP The DAT often asks how many electrons are involved in a particular redox reaction. In this case, you do not have to fully balance the reaction, just follow the instructions until step 4

Example

What is the balanced equation for the following reaction, occurring under acidic conditions?

$$Cr_2O_7^{2-} + HNO_2 \rightarrow Cr^{3+} + NO_3^-$$

A) $3HNO_2 + 5H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 3NO_3^- + 4H_2O$
B) $3HNO_2 + 14H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 3NO_3^- + 4H_2O$
C) $3HNO_2 + 5H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 3NO_3^- + 10H_2O$
D) $HNO_2 + 5H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 3NO_3^- + 4H_2O$

Worked Solution

$Cr_2O_7^{2-} \rightarrow Cr^{3+}$ $HNO_2 \rightarrow NO_3^-$	Separate into half-reactions
$Cr_2O_7^{2-} \rightarrow \mathbf{2}Cr^{3+}$ $HNO_2 \rightarrow NO_3^-$	Balance non-oxygen and non-hydrogen elements
$Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + \mathbf{7H_2O}$ $HNO_2 + \mathbf{H_2O} \rightarrow NO_3^-$	Balance oxygens by adding water
$\mathbf{14H^+} + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 7H_2O$ $HNO_2 + H_2O \rightarrow NO_3^- + \mathbf{3H^+}$	We are dealing with acidic conditions, so balance hydrogens by adding protons
$\mathbf{6e^-} + 14H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 7H_2O$ $HNO_2 + H_2O \rightarrow NO_3^- + 3H^+ + \mathbf{2e^-}$	Balance charges by adding electrons
$6e^- + 14H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 7H_2O$ $\mathbf{3}HNO_2 + \mathbf{3}H_2O \rightarrow \mathbf{3}NO_3^- + \mathbf{9}H^+ + \mathbf{6}e^-$	Make sure both half-reactions have the same number of electrons. We need to multiply the second equation by 3
$\cancel{6e^-} + \cancel{14}H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + \cancel{7}H_2O$ $3HNO_2 + \cancel{3H_2O} \rightarrow 3NO_3^- + \cancel{9}H^+ + \cancel{6e^-}$ $3HNO_2 + 5H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 3NO_3^- + 4H_2O$	Add the reactions and cancel out common terms

	Left Side	Right Side
Hydrogen:	3 + 5 = 8	4(2) = 8
Nitrogen:	3	3
Oxygen:	3(2) + 7 = 13	3(3) + 4 = 13
Chromium:	2	2
Net Charge:	5(+1) − 2 = +3	2(+3) − 3 = +3

Double-check that the number of elements and charges are the same on each side

Example

What is the balanced equation for the following reaction, occurring under basic conditions?

$$ClO_3^- + N_2H_4 \rightarrow NO + Cl^-$$

A) $3HNO_2 + 5H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 3NO_3^- + 4H_2O$
B) $3HNO_2 + 14H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 3NO_3^- + 4H_2O$
C) $3HNO_2 + 5H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 3NO_3^- + 10H_2O$
D) $HNO_2 + 5H^+ + Cr_2O_7^{2-} \rightarrow 2Cr^{3+} + 3NO_3^- + 4H_2O$

Worked Solution

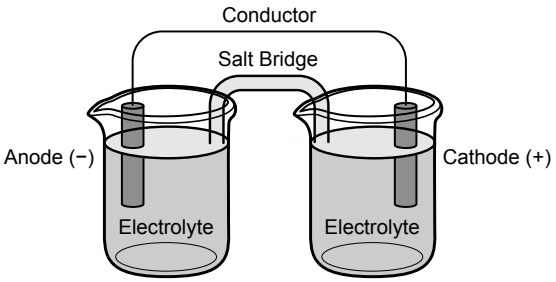
$ClO_3^- \rightarrow Cl^-$ $N_2H_4 \rightarrow NO$	Separate into half-reactions
$ClO_3^- \rightarrow Cl^-$ $N_2H_4 \rightarrow \mathbf{2}NO$	Balance non-oxygen and non-hydrogen elements
$ClO_3^- \rightarrow Cl^- + \mathbf{3H_2O}$ $N_2H_4 + \mathbf{2H_2O} \rightarrow 2NO$	Balance oxygens by adding water
$ClO_3^- + \mathbf{6H^+} + \mathbf{6OH^-} \rightarrow Cl^- + 3H_2O$ $N_2H_4 + 2H_2O \rightarrow 2NO + \mathbf{8H^+} + \mathbf{8OH^-}$	We are dealing with basic conditions, so balance protons and add hydroxide to neutralize
$ClO_3^- + \mathbf{3H_2O} \rightarrow Cl^-$ $N_2H_4 \rightarrow 2NO + \mathbf{6H_2O}$	Upon neutralization, the protons and hydroxide react to form water. Simplify and combine the terms
$ClO_3^- + 3H_2O + \mathbf{6e^-} \rightarrow Cl^-$ $N_2H_4 \rightarrow 2NO + 6H_2O + \mathbf{8e^-}$	Balance charges by adding electrons
$\mathbf{4}ClO_3^- + \mathbf{12}H_2O + \mathbf{24}e^- \rightarrow \mathbf{4}Cl^-$ $\mathbf{3}N_2H_4 \rightarrow \mathbf{6}NO + \mathbf{18}H_2O + \mathbf{24}e^-$	Make sure both half-reactions have the same number of electrons. We need to multiply the first equation by 4 and the second equation by 3
$4ClO_3^- + \cancel{12}H_2O + \cancel{24e^-} \rightarrow 4Cl^-$ $3N_2H_4 \rightarrow 6NO + \cancel{18}H_2O + \cancel{24e^-}$ $4ClO_3^- + 3N_2H_4 \rightarrow 6NO + 6H_2O + 4Cl^-$	Add the reactions and cancel out common terms

	Left Side	Right Side	
Chlorine:	4	4	Double-check that the number of elements and charges are the same on each side
Oxygen:	4(3) = 12	6 + 6 =12	
Nitrogen:	3(2) = 6	6	
Hydrogen:	3(4) = 12	6(2) = 12	
Net Charge:	4(−1) = −4	4(−1) = −4	

CHAPTER 15 | **ELECTROCHEMISTRY**

ELECTROCHEMICAL CELLS ☆ HIGH-YIELD

- ***Electrochemistry*** is the study of the conversion between electric and chemical energy
- There are two types of ***electrochemical cells*** (also known as batteries):
  - ***Galvanic/Voltaic Cell*** – Converts chemical energy to electrical energy via a spontaneous redox reaction ($\Delta G < 0$). For example, the lithium ion battery in your phone is a galvanic cell
  - ***Electrolytic Cell*** – Converts electrical energy to chemical energy via electrolysis, a non-spontaneous redox reaction ($\Delta G > 0$). For example, when you plug in your phone to recharge, it becomes an electrolytic cell
- All electrochemical cells are composed of the following basic components:
  - ***Anode*** – A conductive solid material that contacts the electrolyte. Oxidation occurs at the interface between the anode and the electrolyte
  - ***Cathode*** – A conductive solid material that contacts the electrolyte. Reduction occurs at the interface between the cathode and the electrolyte
  - ***Electrolyte*** – A conductive liquid that can be either an aqueous solution of ions (most common), or a molten salt (at extremely high temperatures)
  - ***Salt Bridge*** – A conductive liquid used to connect the electrolyte solutions of the anode and cathode, allowing a free flow of ions between the oxidation and reduction reactions. This prevents a buildup of charge on either side of the cell
  - ***Conductor*** – A material (usually a wire) that conducts electrons from the anode to the cathode



- In the conductor, electrons always flow from the anode to the cathode because oxidation (loss of electrons) always occurs at the anode and reduction (gain of electrons) always occurs at the cathode
- In the salt bridge, anions of the electrolyte always migrate to the anode while cations migrate to the cathode
- The charge of the anode and cathode depend on the type of electrochemical cell:
  - In a galvanic cell, the anode is negative and cathode is positive
  - In an electrolytic cell, the anode is positive and cathode is negative

MNEMONIC The properties of a galvanic cell can be memorized using the mnemonic "ANO CPR":

Mnemonic	Properties	Mnumonic	Properties
A	Anode	**C**	Cathode
N	Negative	**P**	Positive
O	Oxidation	**R**	Reduction

CELL DIAGRAMS

- A ***cell diagram*** is a short-hand notation that represents a galvanic cell. The following conventions are used when writing a cell diagram:
  - The anode is always written first, on the leftmost side
  - The cathode is written last, on the rightmost side
  - The electrolyte ions are written in the middle, in the order in which they occur from anode to cathode. They are separated from the anode and cathode on either side by a single vertical bar
  - The salt bridge is indicated by a double vertical bar
  - If two or more reactants are in the same phase, they are separated using a comma
  - Stoichiometric coefficients and species that are not directly involved in the reaction are not shown
- For example, given the following electrochemical reaction:

$$2Ag^{+}_{(aq)} + Cu_{(s)} \rightarrow 2Ag_{(s)} + Cu^{2+}_{(aq)}$$

- The cell diagram is:

$$Cu_{(s)} \mid Cu^{2+}_{(aq)} \parallel Ag^{+}_{(aq)} \mid Ag_{(s)}$$

ELECTROCHEMICAL STOICHIOMETRY

- Similar to general stoichiometry, we can used balanced electrochemical equations to predict the amount of electrical charge consumed/produced by a reaction
- Charge is measured in ***Coulombs (C)***. The amount of charge in one mole of a species is represented by ***Faraday's constant (F)***, which is equal to 96,500 Coulombs/mol
- The flow of charge (through a wire, for example) is measured in ***Amperes (A)***, with units of Coulomb/second
- The voltage or potential difference of a cell is measured in ***Volts (V)***, with units of Joules/Coulomb

Example

In an electrolytic cell, a 24 amp current is applied to a solution of Cu^{2+} for one hour. What is the mass of solid copper produced?

A) $\dfrac{(24)(3{,}600)(64)}{(96{,}500)(2)}$ B) $\dfrac{(24)(3{,}600)(64)(2)}{(96{,}500)}$ C) $\dfrac{(24)(64)}{(96{,}500)(2)}$ D) $\dfrac{(24)(3{,}600)}{(96{,}500)(2)}$

Worked Solution

$C = A \times t$ $C = (24\text{ amp})(3{,}600\text{ s})$	Find the number of Coulombs by multiplying amps by the number of seconds elapsed
$n(e^{-}) = \dfrac{(24\text{ amp})(3{,}600\text{ sec})}{96{,}500\text{ C/mol}}$	Find the number of moles of electrons by dividing the number of Coulombs by Faraday's constant
$Cu^{2+}_{(aq)} + 2e^{-} \rightarrow Cu_{(s)}$	Write out the reduction half-reaction. The ratio of $Cu_{(s)}$ to electrons is 1:2
$n(Cu_{(s)}) = \dfrac{(24\text{ amp})(3{,}600\text{ sec})}{(96{,}500\text{ C/mol})(2)}$	Obtain the number of moles of $Cu_{(s)}$ by multiplying the number of moles of electrons by ½
$m(Cu_{(s)}) = \dfrac{(24\text{ amp})(3{,}600\text{ sec})(64\text{ g/mol})}{(96{,}500\text{ C/mol})(2)}$	Convert moles to grams of $Cu_{(s)}$ by multiplying by the molar mass of copper
$m(Cu_{(s)}) = \dfrac{(24)(3{,}600)(64)}{(96{,}500)(2)}$	Our answer matches option A)

REDUCTION POTENTIALS ☆ HIGH-YIELD

- ***Standard reduction potentials ($E°_r$)*** describe the potential difference (V) between a given half-reaction and the half-reaction of the standard hydrogen electrode
- The reduction potential of the ***standard hydrogen electrode*** is 0 V by definition:

$$2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)}$$

Where $[H^+]$ equals 1 M and the reaction occurs under SATP (1 atm, 25°C)

- Reduction half-reactions will always have a positive $E°_r$. The more positive the value of $E°_r$, the easier it is for the reactant to be reduced, making it a stronger oxidizing agent
- Oxidation half-reactions will always have a negative $E°_r$. The more negative the value of $E°_r$, the easier it is for the reactant to be oxidized, making it a stronger reducing agent
- To convert a standard reduction potential to a ***standard oxidation potential ($E°_o$)***, multiply $E°_r$ by -1. However, unlike standard enthalpies of formation, standard reduction potentials are not multiplied by a constant if the half-reaction equation is multiplied by the same constant. This is because standard reduction potential is an intrinsic property (not dependent on quantity)
- The sum of the reduction and oxidation potentials of a cell's half-reactions equals the ***cell potential ($E°_{cell}$)***:

	Reduction Half-Rxn	$Cu^{2+}_{(aq)} + 2e^- \rightarrow Cu_{(s)}$	$E°_r = 0.34$
+	Oxidation Half-Rxn	$Zn_{(S)} \rightarrow Zn^{2+}_{(aq)} + 2e^-$	$E°_o = 0.76$
		$Cu^{2+}_{(aq)} + Zn_{(s)} \rightarrow Cu_{(s)} + Zn^{2+}_{(aq)}$	$E°_{cell} = 1.1$

- The cell potential ($E°_{cell}$) is related to Gibbs free energy (ΔG) through the equation:

$$\Delta G° = -nFE°_{cell}$$

n represents the moles of electrons transferred
F represents Faraday's constant

- Note that $E°_{cell}$ is and ΔG have opposite signs, therefore:

ΔG	E_{cell}	K	Result
<0	>0	>1	Reaction favours products
$=0$	$=0$	$=1$	Equilibrium
>0	<0	<1	Reaction favours reactants

Example

Given the following half-reactions and their reduction potentials, what is the standard cell potential of the resulting galvanic cell?

$$\mathrm{Sn_{(s)} \rightarrow Sn^{2+}_{(aq)} + 2e^-} \qquad E^\circ_r = +0.14\ \mathrm{V}$$
$$\mathrm{Ag_{(s)} \rightarrow Ag^{+}_{(aq)} + e^-} \qquad E^\circ_r = -0.80\ \mathrm{V}$$

A) +0.94 B) −0.94 C) +0.66 D) −0.66

Worked Solution

$\mathrm{Sn_{(s)} \rightarrow Sn^{2+}_{(aq)} + 2e^-} \quad E^\circ_r = +0.14\ \mathrm{V}$ $\mathrm{Ag^{+}_{(aq)} + e^- \rightarrow Ag_{(s)}} \quad E^\circ_o = +0.80\ \mathrm{V}$	Since we are working with a galvanic cell, the standard cell potential must be positive. Therefore, we assume that silver is oxidized. In this case, we reverse its half-reaction and convert its standard reduction potential (negative value) to a standard oxidation potential (positive value)
$\mathrm{Sn_{(s)} \rightarrow Sn^{2+}_{(aq)} + 2e^-} \quad E^\circ_r = +0.14\ \mathrm{V}$ $\mathbf{2}\mathrm{Ag_{(s)} + \mathbf{2}e^- \rightarrow \mathbf{2}Ag^{+}_{(aq)}} \quad E^\circ_o = +0.80\ \mathrm{V}$	We need to multiply the second equation by 2, such that the number of electrons in both half-reactions are equal Remember that the standard reduction/oxidation potentials are NOT multiplied by the coefficient
$\mathrm{Sn_{(s)} \rightarrow Sn^{2+}_{(aq)} + \cancel{2e^-}} \quad E^\circ_r = +0.14\ \mathrm{V}$ $\mathrm{2Ag_{(s)} + \cancel{2e^-} \rightarrow 2Ag^{+}_{(aq)}} \quad E^\circ_o = +0.80\ \mathrm{V}$ $\mathrm{Sn_{(s)} + 2Ag_{(s)} \rightarrow Sn^{2+}_{(aq)} + 2Ag^{+}_{(aq)}} \quad E^\circ_{cell} = +0.94\ \mathrm{V}$	Finally, add the two equations and standard potentials to calculate the standard cell potential

Example

What is the change in Gibb's free energy for the following galvanic cell?

$$\mathrm{Fe^{2+}_{(aq)} + 2e^- \rightarrow Fe_{(s)}} \qquad E^\circ_r = -0.44\ \mathrm{V}$$
$$\mathrm{Na^{+}_{(aq)} + e^- \rightarrow Na_{(s)}} \qquad E^\circ_r = -2.71\ \mathrm{V}$$

A) +(2)(96,500)(2.27) B) +(2)(96,500)(3.15) C) −(2)(96,500)(2.27) D) −(2)(96,500)(3.15)

Worked Solution

$E^\circ_{cell} = 2.71 - 0.44 = 2.27\ \mathrm{V}$	Since this is a galvanic cell, the standard cell potential must be positive. Therefore, sodium is oxidized. Remember that standard potentials are NOT multiplied by a coefficient
$\Delta G^\circ = -nFE^\circ_{cell}$ $\Delta G^\circ = -(2)(96{,}500\ \mathrm{C/mol})(2.27\ \mathrm{V})$	Substitute known values into the equation for Gibb's free energy and solve. $n = 2$ because two moles of electrons are transferred. The answer matches option C)

CHAPTER 16 | **NUCLEAR REACTIONS**

- Whereas ***chemical reactions*** are rearrangements of a molecule's atoms and electrons, ***nuclear reactions*** are rearrangements of an atom's ***nucleons***
- A ***nucleon*** refers to the particles that exist within the nucleus (protons and neutrons)

ATOMIC NOTATION ☆ HIGH-YIELD

Mass Number (A) ← ${}^{16}_{8}O$ → Elemental Symbol
Atomic Number (Z) ←

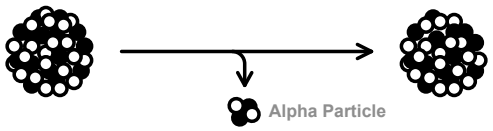
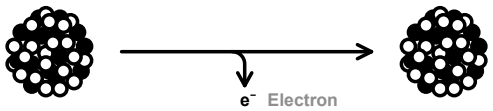
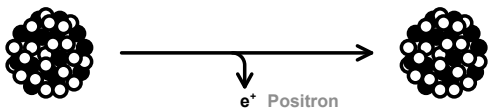
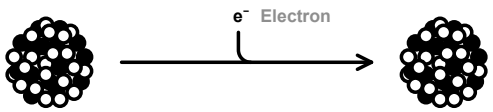
MNEMONIC A is always on top because it comes before Z in the alphabet

MNEMONIC Remember A stands for "mAss number"

- ***Atomic number (Z)*** is the number of protons in an element's nucleus
- ***Mass number (A)*** is the number of protons (Z) plus the number of neutrons in an element's nucleus
- Isotopes are elements that have the same electron configuration and number of protons, but have a different number of neutrons. Thus they have different mass numbers (A)

RADIOACTIVE DECAY ☆ HIGH-YIELD

- Radioactive decay is a type of spontaneous ***nuclear fission*** (splitting)
- There are four main types of radioactive decay, defined by the type of particle they emit:
  - ***Alpha Decay*** – ${}^{4}_{2}\mathrm{He}^{2+}$ particle is released (a helium nucleus)
    - The alpha particle is relatively massive and has low penetration
    - Mass decreases by 4, number of protons decreases by 2 ($A - 4$, $Z - 2$)
  - ***Beta Decay*** – Electron or positron is released (depending on β^- or β^+ decay). If the type of beta decay is not specified, assume β^- decay
    - ***β^- Decay*** – Neutron decays into a proton, releasing an electron and antineutrino
      - Mass remains the same, number of protons increases by 1 (A, $Z + 1$)
    - ***β^+ Decay*** – Proton decays into a neutron, releasing a positron and neutrino
      - Mass remains the same, number of protons decreases by 1 (A, $Z - 1$)
  - ***Gamma Decay*** – γ particle is released (a high energy photon)
    - The γ particle has no charge and very little mass, so it has dangerously high penetration and is hazardous to organisms
    - Mass and number of protons remain the same (A, Z)
    - This form of decay usually follows another form as a way to shed excess energy
  - ***Electron Capture*** – Proton and electron combine to form a neutron
    - Extremely rare, it is the only form of decay in which no particle is emitted
    - Mass remains the same, number of protons decreases by 1 (A, $Z - 1$)

Type of Radioactive Decay	Illustration	Change in Atomic Notation
Alpha Decay		$(A-4, Z-2)$
Beta (–) Decay		$(A, Z+1)$
Beta (+) Decay		$(A, Z-1)$
Gamma Decay		(A, Z)
Electron Capture		$(A, Z-1)$

Example

In the following nuclear reaction, what is the identity of element "X"?

$$^{152}_{63}\text{Eu} \rightarrow {}^{4}_{2}\text{He}^{2+} + \text{X}$$

A) $^{145}_{61}\text{Pm}$ B) $^{148}_{65}\text{Tb}$ C) $^{156}_{61}\text{Pm}$ D) $^{148}_{61}\text{Pm}$

Worked Solution

$A_{final} = 152 - 4 = 148$ $Z_{final} = 63 - 2 = 61$	Since a helium nucleus was released during the reaction, we know that this is alpha decay. The product of alpha decay has a mass number of $A - 4$ and an atomic number of $Z - 4$
$^{148}_{61}\text{Pm}$	The atomic number 61 corresponds to Pm on the periodic table

- ***Half-life ($t_{½}$)*** is the amount of time for a substance's mass to decrease by 50%
- The amount of mass remaining can be calculated with the following equation:

$$m = A(\frac{1}{2})^n ; n = \frac{t}{t_{1/2}}$$

A represents the initial mass
n represents the number of half-lives elapsed
t represents the time elapsed (in the same units as $t_{½}$)
$t_{½}$ represents the half-life (in the same units as *t*)

Example

The half-life of a highly radioactive compound is 10 days. If 100 grams of this compound is stored in a closed container for two months, how much of it remains?

A) $\frac{100\text{ g}}{128}$ B) $\frac{100\text{ g}}{64}$ C) $\frac{100\text{ g}}{32}$ D) $\frac{100\text{ g}}{16}$

Worked Solution

$t = (2\text{ months})(30\text{ days/month}) = 60\text{ days}$	Convert all measures of time into the same units
$n = \frac{t}{t_{1/2}}$ $n = \frac{60\text{ days}}{10\text{ days}}$ $n = 6$	Calculate the number of half-lives elapsed (*n*)
$m = A\left(\frac{1}{2}\right)^n$ $m = (100\text{ g})\left(\frac{1}{2}\right)^6$ $m = \frac{100\text{ g}}{64}$	Substitute into the equation for radioactive decay and calculate the amount of mass remaining (*m*)

BINDING ENERGY AND MASS DEFECT

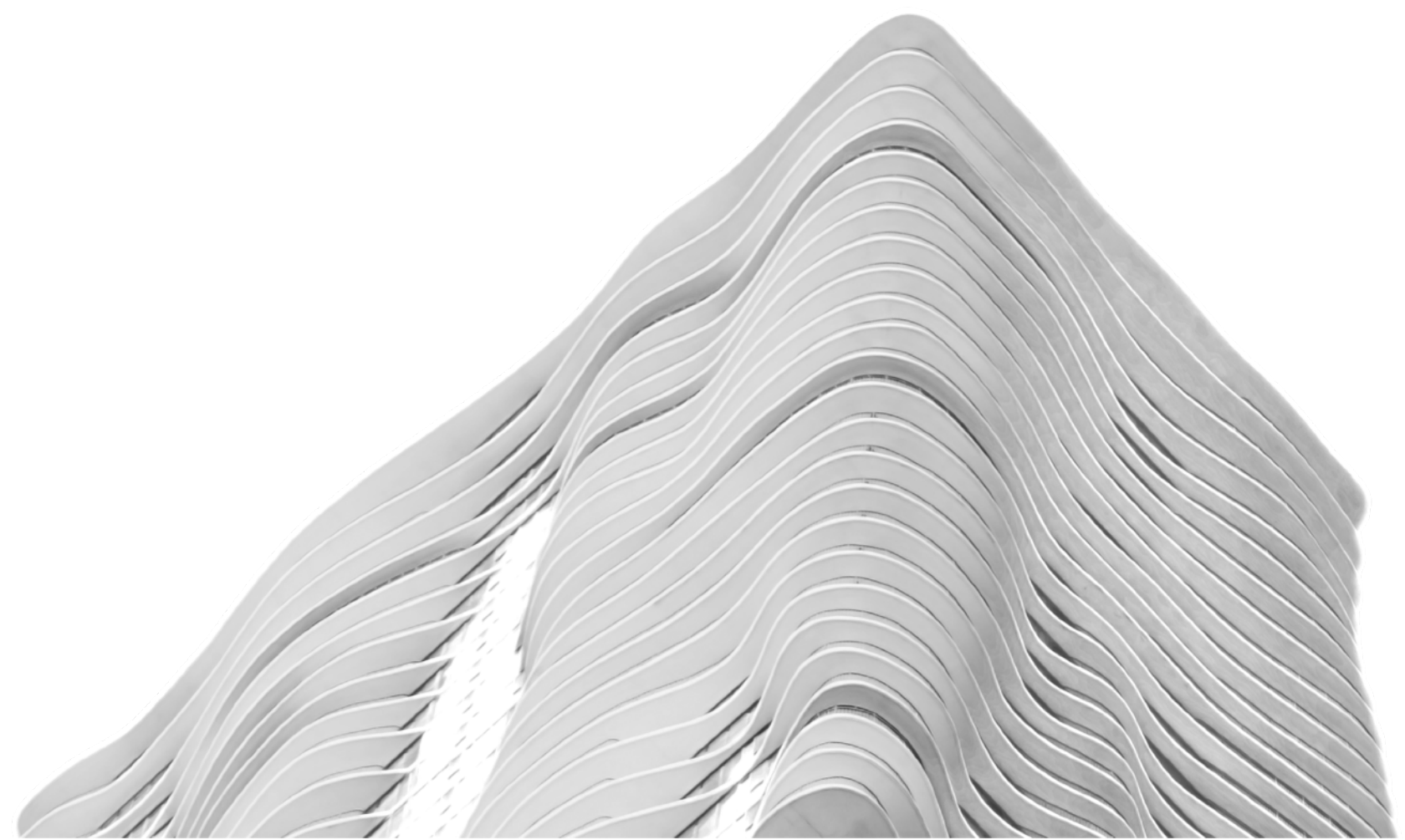
- ***Binding energy*** is the energy that holds protons and neutrons together in the nucleus
- The greater the binding energy, the more stable the nucleus and lower the probability of radioactive decay
- Binding energy is calculated via Einstein's mass-energy equivalence equation:

$$E = mc^2$$

E represents binding energy
m represents mass defect
c represents the speed of light (3×10^8 m/s)

- An atom's ***mass defect*** is the difference between its predicted mass (sum of proton and neutron masses) and its actual mass. This difference represents the mass that has been converted into the nuclear binding energy (*E*)

SECTION 4 PERCEPTUAL ABILITY



CHAPTER 1 | **PRINCIPLES OF PAT**

MINDSET

The purpose of the perceptual ability section in the Canadian DAT is to evaluate your ability to comprehend and manipulate three-dimensional objects. Top scorers on the PAT section rely heavily on algorithmic and elimination-based strategies, in addition to their mental ability to manipulate objects. The objects and shapes that appear in the PAT are very complex, and the average human brain is capable of retaining only seven independent pieces of information at once. Therefore, relying only on your brain's ability to keep track of all the shapes in order to mentally manipulate them is a very high-risk approach. As you study and practice this section, you will realize that very little mental manipulation is actually required to answer most questions. Time-saving algorithms paired with basic multiple choice elimination will produce the highest scores. In this section, we will discuss the six different categories of questions on the PAT, as well as the algorithms and techniques that have worked the best for the majority of high scorers.

TEST NAVIGATION

There are six sections in the PAT, presented in the following order: keyholes, top-front-end, angle ranking, hole punching, cube counting, pattern folding. Time management is absolutely critical for the successful completion of this section – there are 90 questions (15 per section) that need to be answered within 60 minutes. That equals 40 seconds per question on average. Most students will run out of time during the actual PAT, resulting in the guessing of multiple questions. This will significantly hurt your score, making it difficult to achieve above a 20. This usually occurs because students start the PAT with the keyholes section, which is very cognitively demanding. Since it takes time for us to mentally warm up and develop a rhythm, you should always start at the easiest section (in which you score the most points) and leave the most difficult sections for later (usually keyholes and top-front-end). To maximize your PAT score and minimize the amount of flipping back-and-forth between sections, begin at question 46 (hole punching) and work through each section in the following order:

Section	Time Budgeted	Time Elapsed	Time Remaining
Flip to Question 46 → **Hole Punching**	8 min	8 min	52 min
Cube Counting	8 min	16 min	44 min
Pattern Folding	10 min	26 min	34 min
Flip to Question 1 → **Keyholes**	15 min	41 min	19 min
Top-Front-End	15 min	56 min	4 min
Angle Ranking	4 min	60 min	0 min

Notice how we start at a relatively fast pace (32 seconds per question), and slow down to around 60 seconds per question for the more cognitively demanding sections, before speeding up again for angle ranking. This is the suggested method for the majority of test writers. However, it is recommended that you develop a strategy that is most suitable for your strengths and weaknesses. For instance, if you find angle ranking to be very easy, then you should complete that section first. If for some reason you find hole punching to be near impossible, you should complete that section last. For all other sections with intermediate difficulty, you should complete them in the middle of the PAT, allocating more time than the extremely easy or difficult sections.

Like the SNS and RCT, questions on the PAT will be presented in a booklet, and your answers must be "bubbled in" on a separate answer sheet. Many students prefer to circle their answer choices directly on the question booklet prior to transferring them onto the answer sheet. This allows them to complete multiple questions in a row before breaking their rhythm or train of thought. We recommend bubbling in your answers after every page, to maximize efficiency. Bubbling after every question would result in too much back-and-forth referencing, which wastes time and increases the risk of making a transposition error. On the other hand, bubbling in after every section is extremely risky, as all your non-transferred answers would be lost if you run out of time.

USING ELIMINATION PROPERLY

As you learn the PAT strategies in this section, you will notice that most of the recommended techniques involve the elimination of answer choices. This is because elimination is the most efficient method of arriving at an answer on an exam where time is the limiting factor. When practicing elimination, always ensure that you are eliminating answer choices that contain a discrepancy or mistake that *proves* the answer choice is incompatible with the question stem and thus incorrect. If you are unsure, leave the answer choice as a possible option and move on to the next answer choice. Often, the same mistake in one answer choice will be repeated in other answer choices. If you notice this, you can immediately eliminate the other answer choices which have the same mistake. When you have finished examining all the answer choices for those that can be easily eliminated, return to the ones you have left and re-evaluate.

Hole punching and cube counting are the only two sections in which using elimination is not recommended. In these sections, it is more efficient to work out the correct answer and simply select the corresponding answer choice. If you are confident that your answer is correct, refrain from examining the remaining options. It is an inefficient use of time to search for mistakes that prove all the remaining answers incorrect when you have already figured out the correct answer.

As you practice the techniques in this section of the textbook, your accuracy and speed should increase. The next few chapters will present strategies for each of the six PAT question categories (hole punching, cube counting, pattern folding, keyholes, top-front-end, angle ranking) in the order that we recommend completing them in.

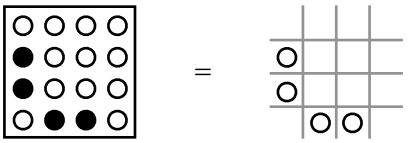
CHAPTER 2 | **HOLE PUNCHING**

INTRODUCTION

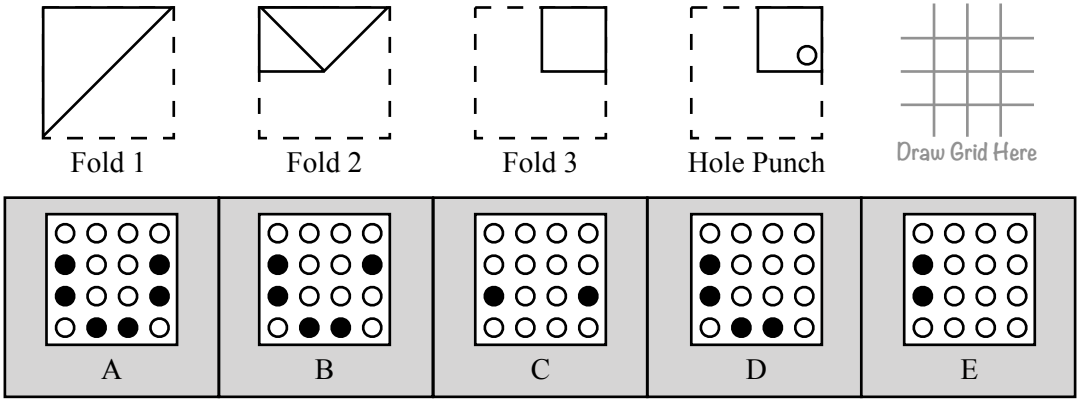
- ***Instructions:*** A square piece of paper is folded one or more times. Dotted lines indicate the original position of the paper, while solid lines indicate the position of the folded paper. 3-5 ***frames*** will be shown. Each frame represents a fold, with the last frame representing the hole punch. You must mentally unfold the paper and determine the pattern of holes in the original square.
- ***Rules:***
  - The paper is always folded in the direction travelling *out* of the page, not into the page (like the pattern folding section of the PAT). This means you will always be able to see the new edges created by the fold
  - The folded paper always remains within the lines of the original square
  - The paper is never turned or twisted
  - The holes are illustrated as "filled-in" with white. They are not transparent. Do not expect to see the edge of a fold through a hole
- ***Mindset:*** This is one of the least cognitively intensive sections, if you use the correct technique. As mentioned in the previous chapter, try to complete this section first and in under 8 minutes. Always aim for a perfect score (15/15) on this section

THE GRID SYSTEM

- The ***grid system*** is a tool that helps us visualize where hole punches are located and how they might move after a fold is made. A 4×4 grid is used to represent 16 possible locations:

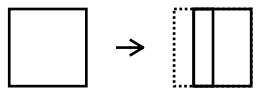
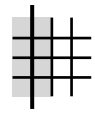
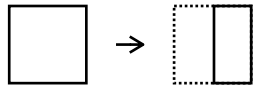
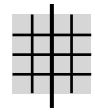
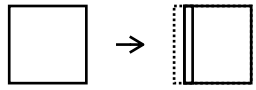
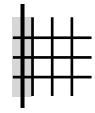
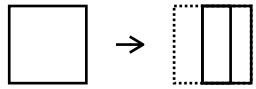
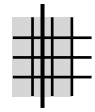
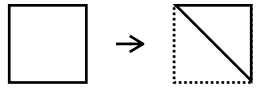
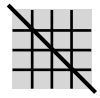
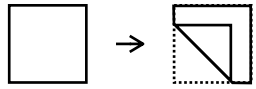
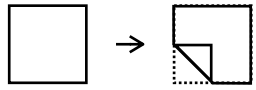


- On the exam, try to draw your 4×4 grid as straight and uniform as possible. Major distortions in your grid will make it more difficult for you to transpose the folds onto the grid system
- Also make sure to draw your grid relatively aligned with the frames. This will make it easier for you to find the corresponding the location of hole punches on the grid system:

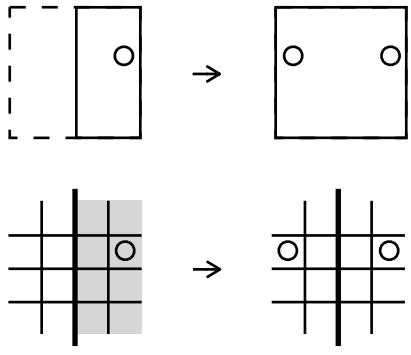


TYPES OF FOLDS

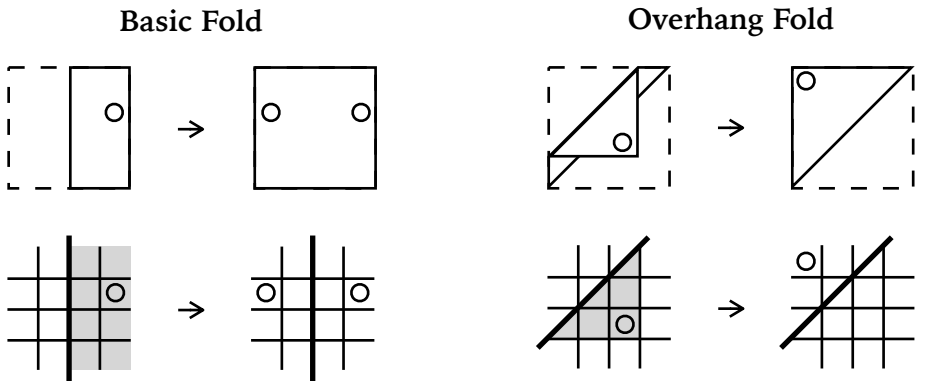
- It is critical to know the types of folds that can appear on the PAT and how they behave when hole punched
- Note that these folds can appear in any orientation, but only one is depicted in this summary table:

Type of Fold	Appearance	Representation on 4x4 Grid
1/4 Fold		
1/2 Fold		
1/8th Fold		
3/8th Fold		
4x4 Diagonal Fold		
3x3 Diagonal Fold		
2x2 Diagonal Fold		

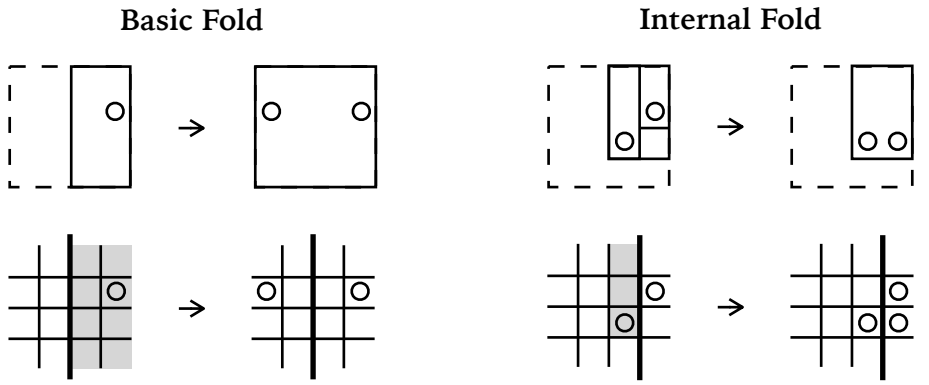
- Notice how it is impossible for the paper to be folded more than half its width, since it would go outside the lines of the original square
- The basic folds presented above will ***reflect and duplicate*** all hole punches within the fold region (illustrated below in grey) across its ***line of symmetry*** when unfolded:



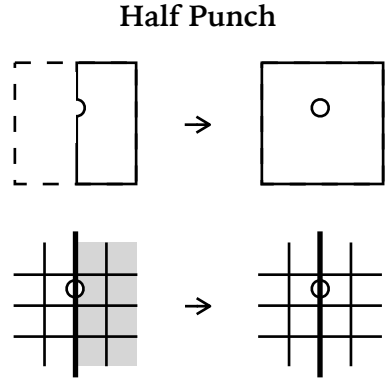
- In addition to the seven basic folds, you may encounter two special folds with unique properties:
  - ***Overhang Folds***
    - These folds occur when the final paper position extends beyond the initial paper's boundaries. The portion of paper that extends beyond is in a location where no paper previously existed. Because of this, hole punches made in this area will only be reflected (not duplicated) when the paper is unfolded:



  - ***Internal Folds***
    - These folds can easily cause confusion during the exam if you have not seen them before. Internal folds do not alter the size or shape of the paper's boundaries, but they do create additional internal lines that represent the new edges formed. Hole punches made within the fold region will be reflected and duplicated, while punches made outside the fold region will be obscured after the paper is unfolded:



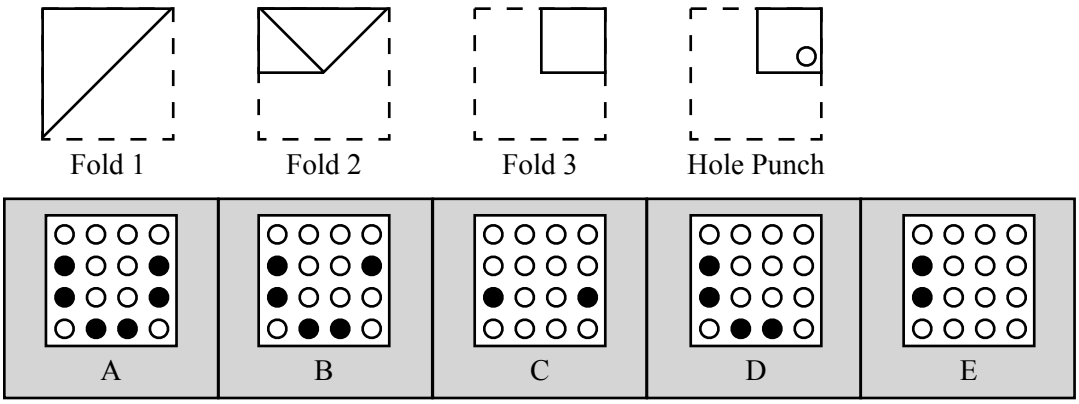
- Sometimes, a hole punch may be placed on the edge of a fold. These ***half punches*** will always unfold to become a full hole punch. Therefore, always draw them on your grid system as if they are normal hole punches:



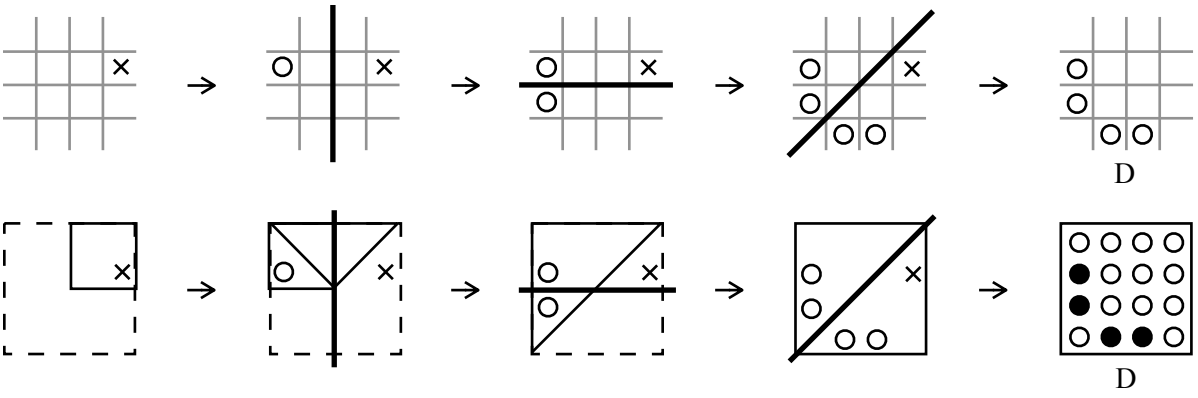
THE HOLE-PUNCHING ALGORITHM

1. Draw a 4×4 grid in the upper right corner of the question
2. Look at the last frame and compare it to the frame that comes before. Ignore all other frames and ask yourself: Is the fold a basic fold or an overhang fold?
   - For basic folds, draw an ○ in the corresponding location of the hole punch
   - For overhang folds, draw a × to represent hole punches on the overhanging portion of the fold
3. Reflect and duplicate all ○ and × that are within the fold region across its line of symmetry
   - × will become an ○ after reflecting
   - Half-punches will eventually become full punches, so treat them as a full ○
4. Repeat steps 2-3 for all remaining frames
5. Pick the answer choice that matches the ○ pattern on your 4×4 grid (ignore ×)

Example



Worked Solution



- In this example, we begin by drawing a 4×4 grid
- We compare fold 3 with fold 2 and see that it is an overhang fold. Therefore, we draw an × to represent the hole punch on the overhanging portion of the fold. Next we reflect the × across the fold's line of symmetry. It becomes an ○ after being reflected
- Now we compare fold 2 with fold 1 and see that it is a basic 1/2 fold. Therefore we reflect the ○ across the fold's line of symmetry
- Finally we unfold fold 1, reflecting and duplicating all ○ across the fold's line of symmetry
- Our pattern of ○ matches answer choice D)

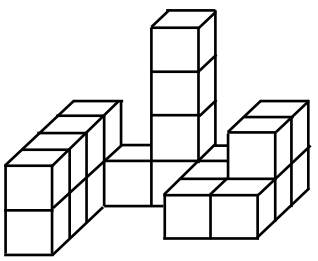
CHAPTER 3 | **CUBE COUNTING**

INTRODUCTION

- ***Instructions:*** A figure has been made by stacking and glueing solid cubes together. After glueing, all surfaces are painted except for the bottom surface which the figure is resting on. Your task is to determine how many cubes have one, two, three, four, or five sides painted
- ***Rules:***
  - The bottom surface on which the figure is resting is *never* painted
  - All cubes must be touching a face of another cube
  - There are *no* free-floating cubes
  - The *only* hidden cubes that exist are those that are required to support other visible cubes
- ***Mindset:*** Like hole punching, this is one of the least cognitively intensive sections, if you use the correct technique. As mentioned in the previous chapter, try to complete this section first and in under 8 minutes. Always aim for a perfect score (15/15) on this section

THE TALLY SYSTEM

- The most effective way to keep track of cubes as you count is with a two-column ***tally system***
- For example, the following figure results in the following number of tallies:

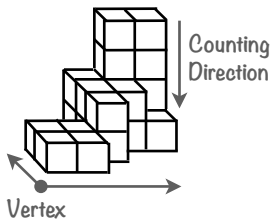


Sides Painted	# of Cubes
0	
1	𝍸
2	𝍸 ||
3	𝍸 |
4	𝍸 |
5	|

- On the actual exam, it will not be necessary to write the titles of the two columns. You should be familiar enough with the tally system such that all you need to draw is a single line down the centre of the page

THE CUBE-COUNTING ALGORITHM

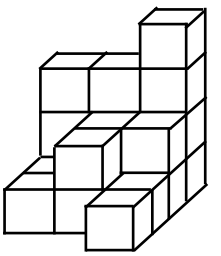
1. Draw the two-column tally system with "0, 1, 2, 3, 4, 5" down the left column
2. Scan the entire figure and identify the vertex that is closest to the forefront (closest to you, the observer). From this vertex, start examining each cube one-by-one and count the number of painted sides. Record this number in the form of a tally mark in your table under the correct row
   - It is easier to visualize obscured cubes if you first understand the cubes that surround them. Therefore, always start counting from the most visible cube (the vertex). Within the same cube column, always count from top to bottom, since cubes on top are more visible than cubes on the bottom



3. After counting all cubes, refer to your tally system for the answer to each question related to the figure

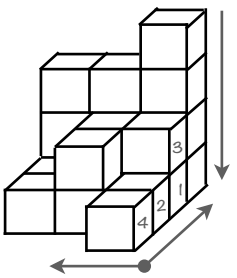
Example

In the following figure, how many cubes have three of their exposed sides painted?



A. 2 cubes
B. 3 cubes
C. 4 cubes
D. 5 cubes
E. 6 cubes

Worked Solution



Sides Painted	# of Cubes
0	I
1	IIII
2	𝍸 I
3	𝍸
4	III
5	I

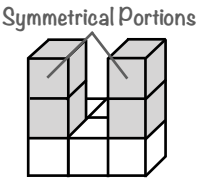
- In this example, the vertex is in the lower right. Therefore we start counting from here
- The vertex cube has four sides exposed, so we add a tally in the row labelled "4"
- The next cube has two sides exposed, so we add a tally in the row labelled "2"
- The next cube has three sides exposed, so we add a tally in the row labelled "3"
- The next cube has only one side exposed, so we add a tally in the row labelled "1"
- Continue counting until all cubes have been accounted for
- The question asks how many cubes have *three* sides painted, so we look at the row labeled "3" and see that D) is the answer. Five cubes have three of their sides painted

ADVANCED TECHNIQUES

- After you have mastered the basic algorithm, these techniques can help you save precious time

TECHNIQUE **Counting by Symmetry**

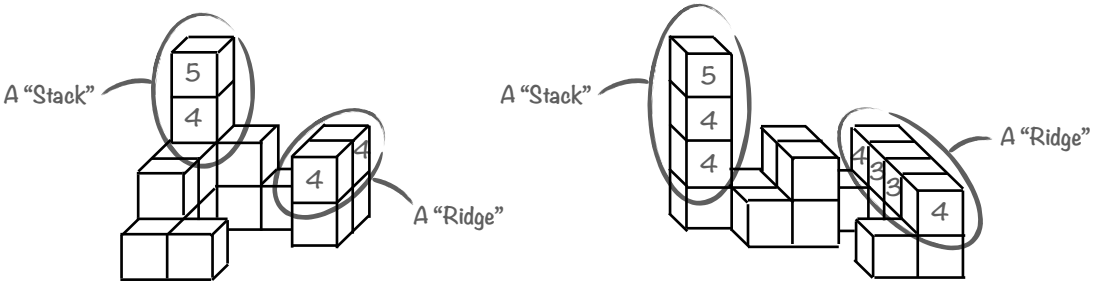
- If two stacks of columns are identical or mirror images of each other, you can count just one column and multiply your tally by two. This cuts the amount of time spent counting those cubes in half
- A downside to this technique is that you increase the risk of double-counting a cube. Make sure that you always keep track of which cubes have already been counted



Sides Painted	# of Cubes
4	1 x 2 for symmetry
5	1 x 2 for symmetry

TECHNIQUE **Search Images**

- Just like predators form "search images" to quickly identify their prey, you can use this technique to increase your counting speed. Instead of manually counting the painted sides of each cube, memorize what all cubes with a particular number of sides look like
- For example, realize that:
  - All free-standing cubes at the top of a "stack" have five painted sides
  - All free-standing cubes in the middle of a "stack" have four painted sides
  - All cubes at the end of a "ridge" have four painted sides
  - All cubes in the middle of a "ridge" have three painted sides



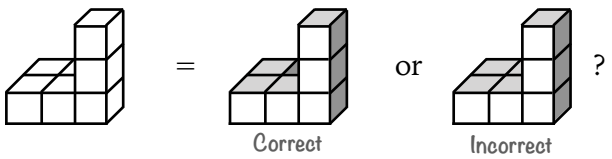
- This will become easier with practice. After many questions, you should be able to look at a cube and instantly know how many painted sides it has, from appearance alone

TECHNIQUE **Counting By Column**

- Instead of counting cube by cube, scan the entire column from top to bottom and remember the number of sides on each cube by repeating them in your head until you tally them down. This saves time from glancing back and forth between the figure and your tally system
- Alternatively, count however many cubes you can retain in your short term memory. Make sure to keep track of which cubes you have already counted by using your non-writing hand as a "landmark"

DEALING WITH AMBIGUITY

- You may encounter situations in which it is ambiguous as to whether a cube exists
- When this occurs, ask yourself if the ambiguous cube is needed to physically support another cube. If not, then it does not exist



CHAPTER 4 | **PATTERN FOLDING**

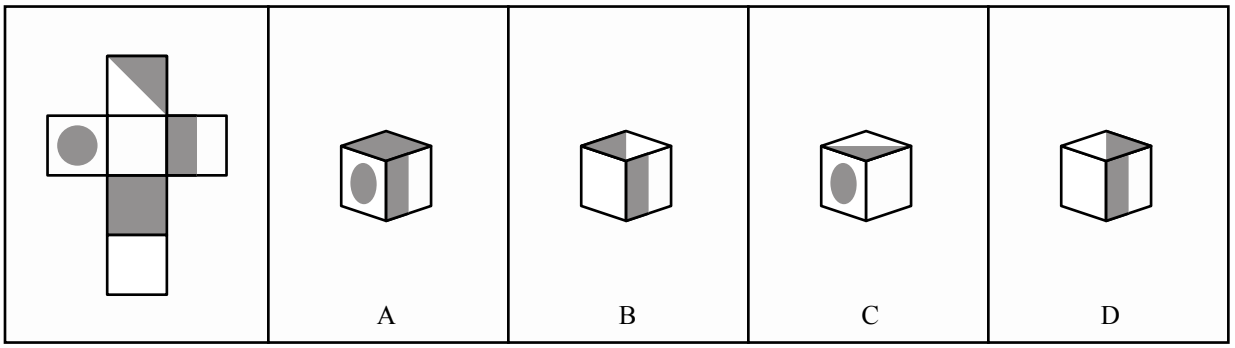
INTRODUCTION

- ***Instructions:*** A two-dimensional net with patterns on its faces will be presented. You must mentally fold the net into a three-dimensional object and choose the correct folded pattern from the answer choices
- ***Rules:***
  - The net is always folded in the direction that goes *into* the page, not out of the page (like the hole punching section of the PAT). This is a critical rule because in some questions, folding into or out of the page determines if you get the correct answer choice or its *mirror image*. Since all folds go *into* the page, any patterns on the net's faces will end up on the *outside* of the folded shape
  - All sides of a face will always end up touching another side when folded
- ***Mindset:*** After completing the hole punching and cube counting sections, you will already be functioning at the correct pace and intensity. Try to maintain the speed in which you complete questions, but rest assured that you have slightly more time (40 seconds per question). This section becomes very difficult if you attempt to mentally fold the entire structure at once. Instead, use the techniques in this chapter to help focus in on one detail at a time for fast elimination of answers

CUBE QUESTIONS

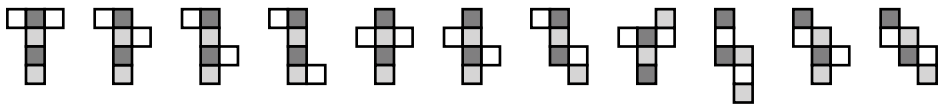
- These types of pattern folding questions present the net of a cube and requires you to select the correct pattern of faces from the answer choices

Example



TECHNIQUE **Identifying Opposite Faces**

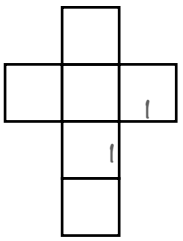
- ***Opposite faces*** will *never* touch sides when folded. Therefore, we can use this technique to eliminate answer choices that depict opposite faces as adjacent to each other
- To use this technique, you must memorize the ***opposite face pairs*** of every possible cube net:



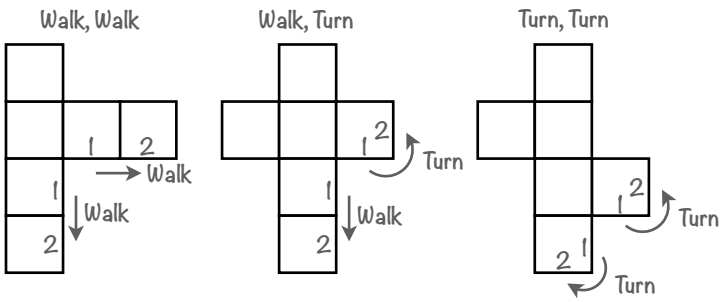
- Notice how in each row or column of the net, every other face is an opposite face pair
- Once you have identified the opposite face pairs in the rows and columns, the remaining opposite face pairs are in a "L" configuration, exactly like the path of a knight in a game of chess

TECHNIQUE Identifying Adjacent Faces

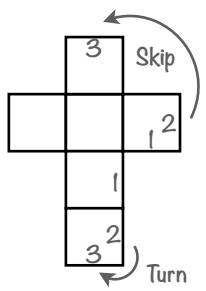
- ***Adjacent faces*** will *always* touch sides when folded. In order to predict the correct folded pattern, we need to identify which faces are adjacent
- To identify adjacent faces, we begin at a ***corner*** and start numbering sides, travelling in opposite directions. A pair of sides that share the same number is called an ***adjacent side pair***. A pair of faces that share the same adjacent side pair is an adjacent face



Corners
- Always start numbering from a corner
- The two sides of a corner will always be an adjacent side pair. We label these sides "1"
- Continue numbering sides by "walking" in opposite directions



Walking and Turning
- When we continue numbering outwards, there are three possible scenarios:
- ***Walk, Walk*** = Sides are adjacent side pairs
- ***Walk, Turn*** = Sides are adjacent side pairs
- ***Turn, Turn*** = Sides are *not* adjacent side pairs



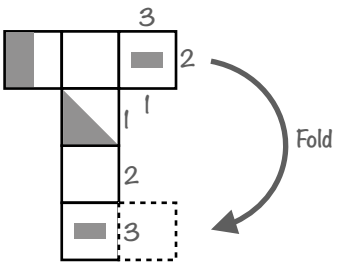
Skipping
- If you encounter another corner while walking, skip it (do not number the sides)

TECHNIQUE Rotating Faces

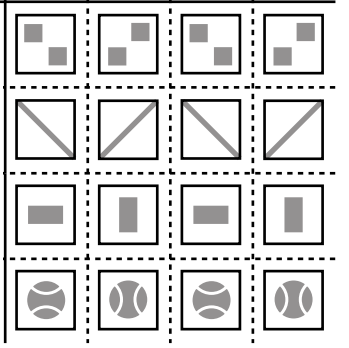
- After identifying adjacent faces, we can use this technique to determine the orientation in which they touch
- When you mentally fold a net such two adjacent faces touch, visualize one face staying stationary while the other rotates 90 degrees:



- This seems simple enough, but how do we determine the orientation of faces in more complex folds? For instance, how can we predict the orientation of the following face after being folded to meet the bottom?



- Notice how faces with a diagonal line of symmetry *or* both vertical and horizontal lines of symmetry will "flip-flop" between only *two* possible states, each differing by a 90 degree rotation:

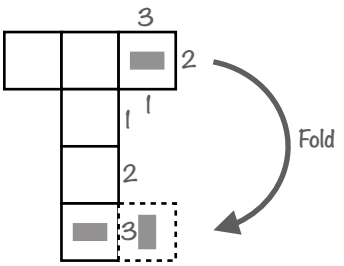
Degrees of Rotation:	**0°**	**90°**	**180°**	**270°**
Number of 90° Rotations:	**0**	**1**	**2**	**3**
				

- If the number of 90 degree rotations is even, the face appears identical to the unrotated state. If the number is odd, the face appears in the rotated state
- The number of 90 degree rotations necessary to properly orientate a face is equal to:

# of adjacent side pairs + # of skipped corners

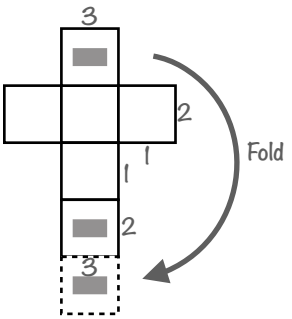
- Since each face can only have up to three adjacent sides, there is a maximum of *three* 90 degree rotations. If you have to rotate a face more than three times to touch another face, they are *not* adjacent faces

Example 1



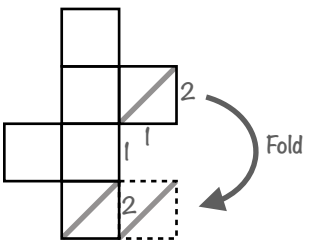
- In this example, we have already identified our two adjacent faces and numbered the sides using our "walking" technique. Now we want to determine the orientation of the rotating face
- We count three adjacent side pairs
- Therefore, the face will undergo three 90 degree rotations
- Three is an odd number, therefore the face will appear in its rotated state

Example 2



- We count three adjacent side pairs, and one corner that we skipped
- Therefore, the face will undergo three + one = four 90 degree rotations
- Four is an even number, therefore the face will appear in its unrotated state

Example 3



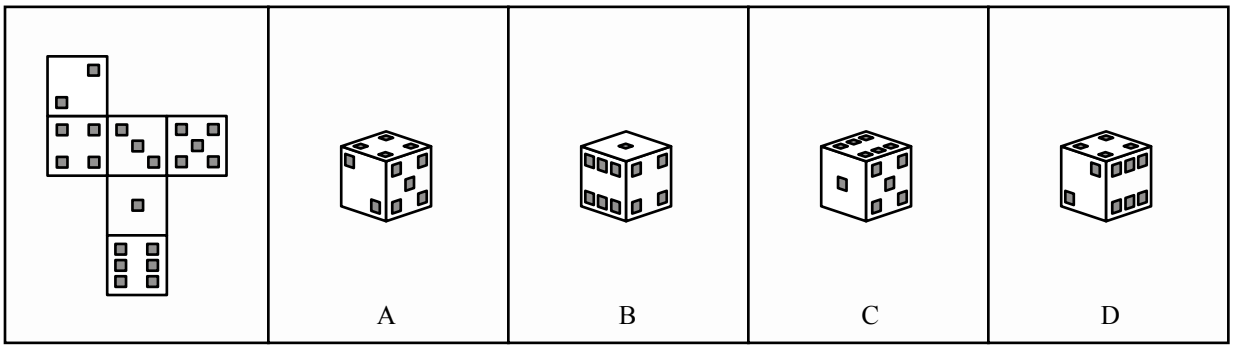
- We count two adjacent side pairs
- Therefore, the face will undergo two 90 degree rotations
- Two is an even number, therefore the face will appear in its unrotated state

- Note that in order to be an effective tool, this technique should be executed relatively fast. Practice until you can accurately predict the orientation of folded faces in under 20 seconds. If you have trouble visualizing or remembering the folded faces, sketch them out!

DICE QUESTIONS

- This type of question presents a cube with die faces on each side and requires you to choose the correct triad of faces from the answer choices. Dices questions are a specific type of the more generalized *cube questions*

Example



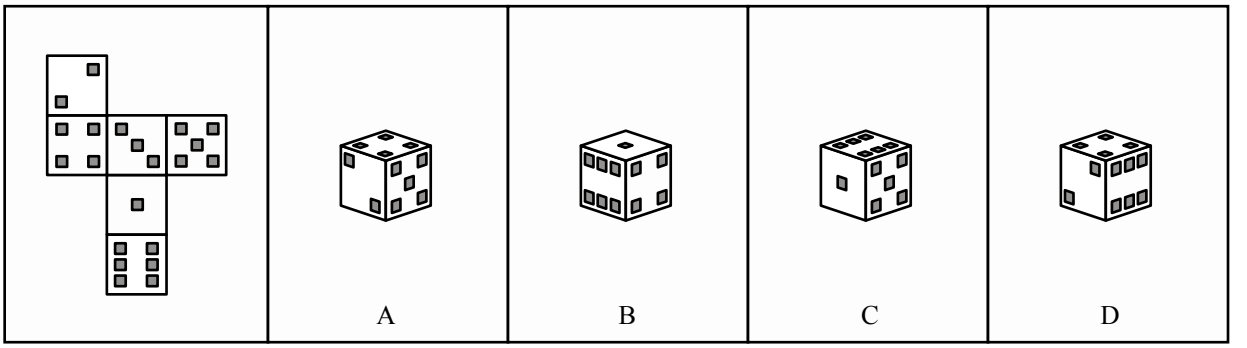
- Every answer choice is going to be a ***triad*** (a group of three adjacent faces). Our task to determine if the triad exists in the unfolded net. If it does not, the answer choice cannot be correct

TECHNIQUE **Landmarking**

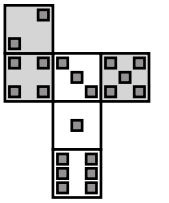
- ***Directional faces*** "point" in a particular direction
- The ⚀, ⚁, and ⚅ face are the only directional faces
- The ⚀, ⚃, and ⚄ face are rotationally symmetrical and thus ***nondirectional***
- The following instructions describe how to use landmarking to eliminate incorrect answer choices:

1. Look at the first answer choice and identify one or more directional faces
2. Using the directional faces as a landmark, look at the unfolded net and determine if the other faces in the triad exist adjacently, and in the correct orientation. Use the techniques for general cube questions mentioned earlier
3. If the triad does not exist in the unfolded net in the correct orientation, the answer choice is incorrect. Eliminate and repeat until the correct answer remains

Example

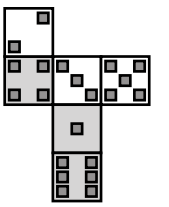


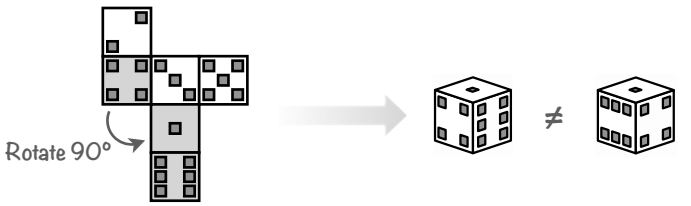
Worked Solution



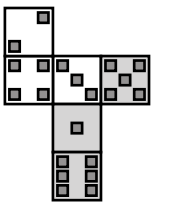
- First we consider answer choice A). ⚀ is a directional face, so we will use it as a landmark. In the unfolded net, we see the three faces of our triad as highlighted here
- Using the *identifying opposite faces* technique, we see that ⚃ and ⚄ are opposite and therefore should not ever meet when folded. Therefore answer choice A) is incorrect

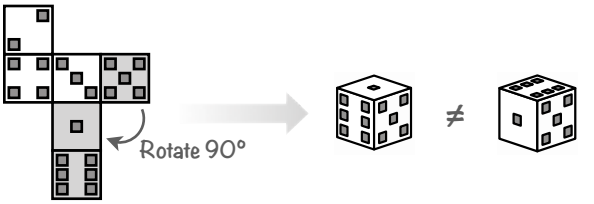
- Now let's consider answer choice B). ⚅ is a directional face. In the unfolded net, the ⚅ "points" towards the ⚀ face. However in the folded answer choice, the ⚅ "points" towards the ⚃ face. Therefore answer choice B) cannot be correct
- Furthermore, using the *rotating faces* technique, we see that the folded triad will result in a different pattern than the answer choice, regardless of how the cube is rotated after folding. Therefore, answer B) is incorrect



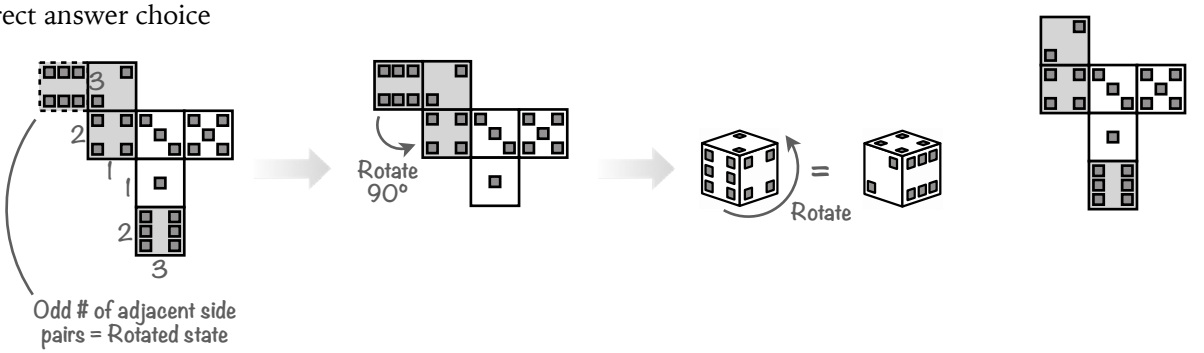


- Now let's consider answer choice C). ⚅ is our directional face. In the unfolded net, the ⚅ "points" towards the ⚀ face. In the folded answer choice, the ⚅ also "points" towards the ⚀ face. This answer looks promising at first
- However, using the *rotating faces* technique, we see that the folded triad will result in a different pattern than the answer choice, regardless of how the cube is rotated after folding. Therefore, answer C) is also incorrect





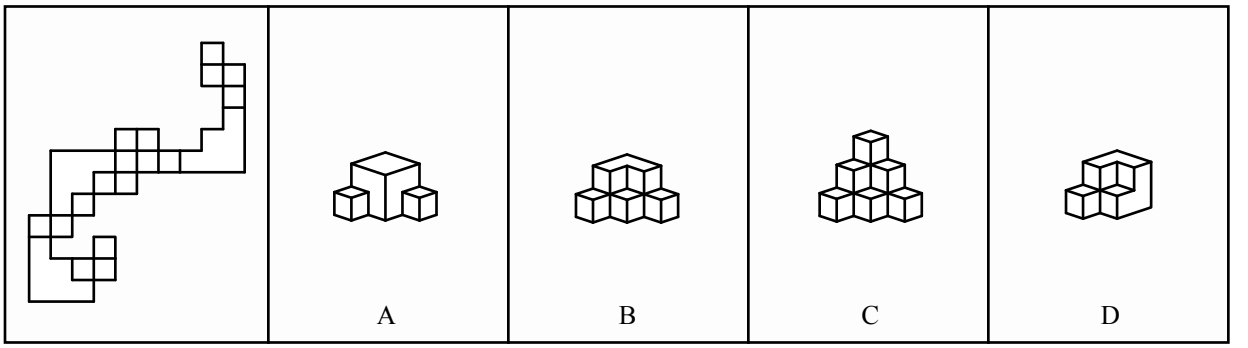
- Finally let's consider answer choice D). ⚅ and ⚁ are our directional faces
- Using the *identifying opposite faces* and *rotating faces* technique, we see that ⚅ actually touches ⚁ and ⚂ when folded, and in the correct orientation. Therefore, D) is the correct answer choice



POLYGON QUESTIONS

- This type of pattern folding question presents a very complex two-dimensional net and requires you to choose the correct folded three-dimensional object

Example



- The key to these questions is *not* attempting to mentally visualize the entire net folding, since doing so would be time-consuming and error-prone. Instead, we use the following techniques to make step-by-step comparisons between the net and folded objects, allowing us to use the process of elimination

TECHNIQUE **Accounting**

1. Look at the first folded answer choice and choose a face. Search for the shape in the unfolded net to make sure it is "accounted" for
2. Eliminate answer if the face does not exist in the unfolded net, or has the wrong dimensions
3. When only two answer choices are left, ignore the unfolded net and search for a difference between the two remaining answer choices
4. When the difference is found, compare to the unfolded net and eliminate the answer choice that is the most incorrect (deviates farthest from the unfolded net)

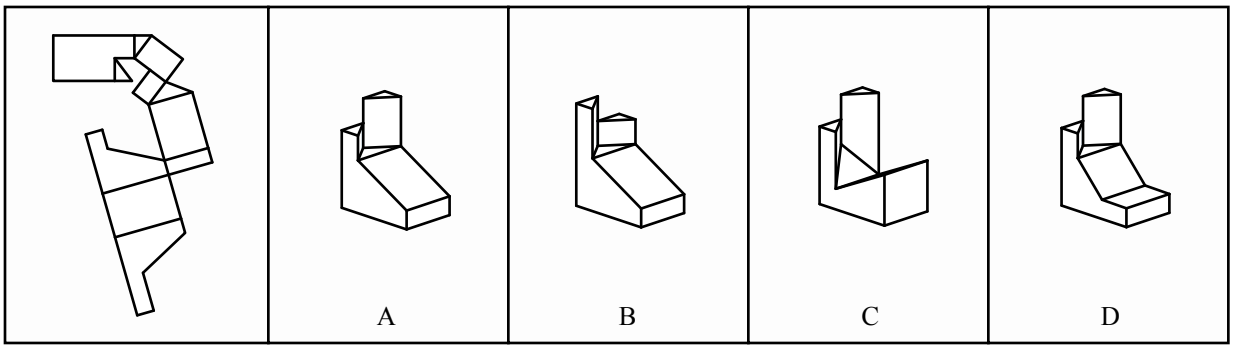
TECHNIQUE **Landmarking**

1. Pick a unique face in the folded answer choice and identify it in the unfolded net. This is your ***landmark***
2. Look at the faces adjacent to your landmark in the unfolded net. Do the adjacent faces in the answer choice have the same shape and patterns? Eliminate answer choices that are inconsistent with the net
3. Rinse and repeat. Note that if your landmark face is non-unique (more than one copy exists in the net), you must repeat the comparison process for every instance of that face in the figure

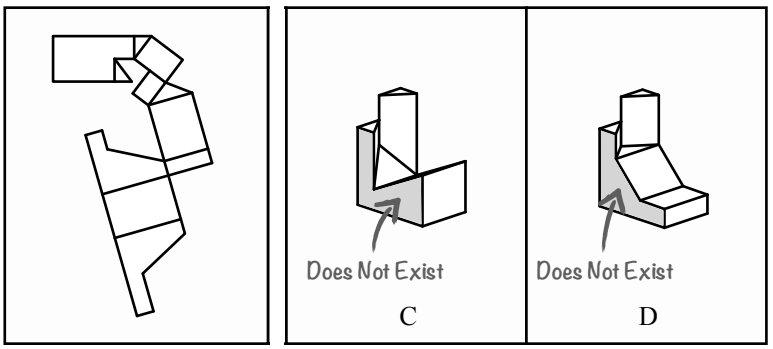
TECHNIQUE **Enantiomers**

- A ***chiral*** shape is non-superimposable on its mirror image
- When two answer choices are chiral and are mirror images of each other, they are ***enantiomers***
- When you recognize that two answer choices are enantiomers, the correct answer choice is always the one that is folded *into* the page. The incorrect answer will be a mirror image, obtained by folding the net *out* of the page

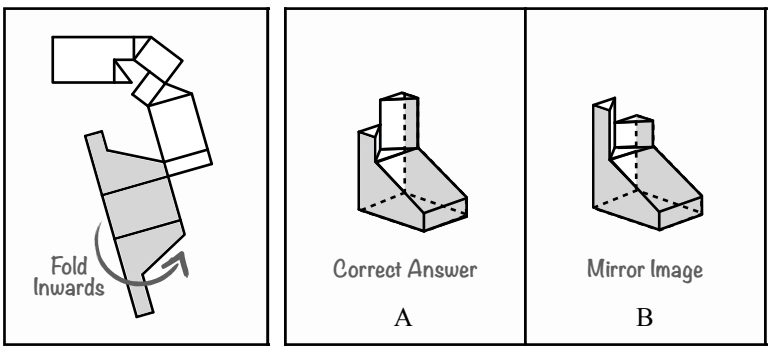
Example



- In the question above, answer choices D) and C) can be quickly eliminated using the *accounting* technique, because they contain shapes that do not exist within the net:



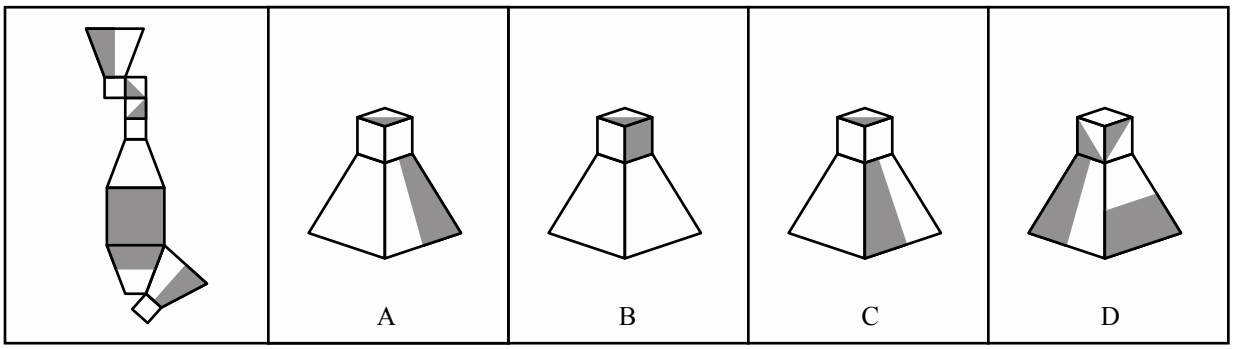
- Answer choices A) and B) are enantiomers. By visualizing a part of the net folding *into* the page, we can eliminate B), the mirror image. Therefore A) is the correct answer:



STACKED SHAPE QUESTIONS

• This type of pattern folding question involves a shape stacked on top of an other shape

Example



TECHNIQUE **Pairing Technique**

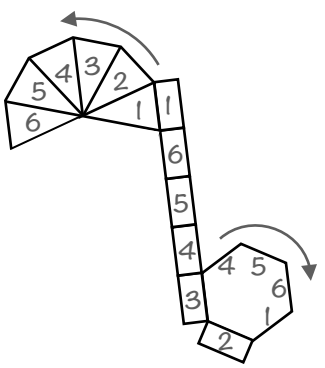
1. Instead of interpreting each face individually, examine the patterns on each ***pair*** of adjacent faces
2. Choose a pair in the folded answer choices and determine if that pair exists in the unfolded net
3. Eliminate answer choices with pairs that do not exist or are in the wrong position, until the correct answer choice remains

• If it is difficult to visualize each pair, assign numbers to matching faces:

1. Identify where the first pair of faces touch each other and number each face with a "1"
2. Number the rest of the faces on one "ribbon" in a clockwise direction (numbers increase as you rotate clockwise), and the other ribbon in a counterclockwise direction (numbers increase as you rotate counterclockwise). It does not matter which ribbon is clockwise and which is counterclockwise. This technique will work as long as they are labelled in opposite directions
3. The faces that have the same numbers are adjacent pairs

Example

- In this example, it's hard to tell which faces are pairs (adjacent to each other)
- Therefore, we need to start numbering faces
- First, we identify the first pair of faces that touch each other. We label these faces "1"
- Next, we decide to rotate counterclockwise to number the ribbon on the left
- This means we must rotate clockwise to number the ribbon on the right
- Now we can simply reference the numbers to identify which faces are adjacent pairs



CHAPTER 5 | **KEYHOLES**

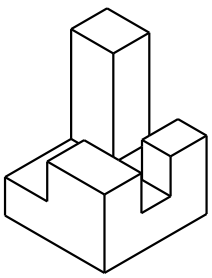
INTRODUCTION

- ***Instructions:*** A three-dimensional object and various two-dimensional keyholes will be presented. You must visualize how the three-dimensional object would look from all sides, then choose a keyhole which would allow the object to pass through
- ***Rules:***
  - Before passing through the keyhole, the object may be rotated in any direction
  - Once the object starts passing through the keyhole, it cannot be rotated
  - Both the object and the keyhole are drawn to scale. Their dimensions can be compared against each other
  - There are no irregularities in the hidden parts of the objects. In other words, hidden faces will be consistent with the overall shape and symmetry of the visible faces
- ***Mindset:*** This section can be very time-consuming and difficult. We do not recommend attempting this section first on the PAT. If you have difficulty with any particular keyhole question, do not linger on it for more than 60 seconds. If you are truly stuck after this amount of time, guess an answer and move on

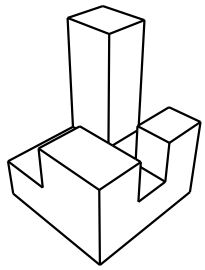
TYPES OF PROJECTION

- An important concept to understand for the keyhole section is the difference between perspective and orthographic projection:
  - ***Perspective projection*** portrays objects as larger in the foreground and smaller in the background. Lines that are parallel in reality appear to converge and intersect at a distant vanishing point. We naturally use this type of projection to interpret the three-dimensional world around us
  - ***Orthographic projection*** portrays objects according to their "true scale". Lines that are parallel in reality also appear parallel in the projection. All lengths and distances appear in the same unit, and are therefore comparable. This type of projection is very common in engineering, and is used on the PAT

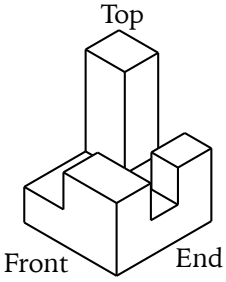
Isometric



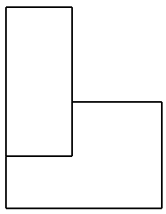
Perspective



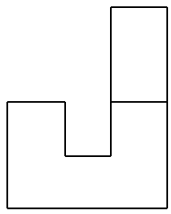
- Both the three-dimensional object and the answer choices (keyholes) are projected orthographically on the PAT. The keyholes will be displayed as an outline of either the top, front, or end views of the object:



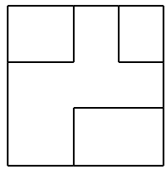
Front



End



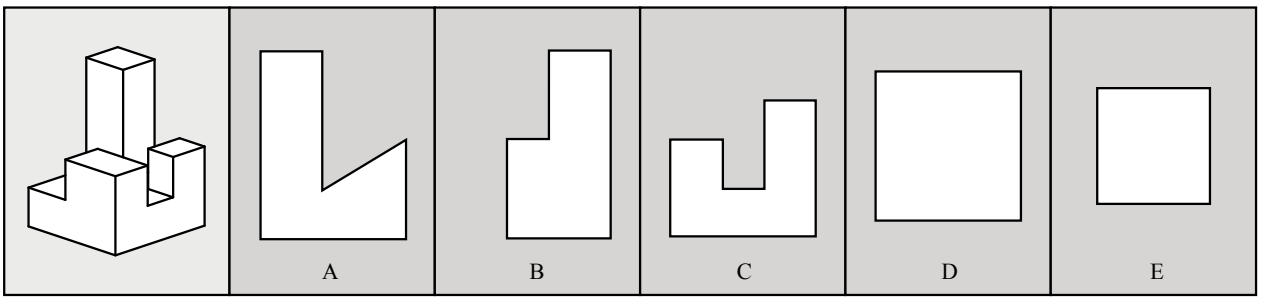
Top



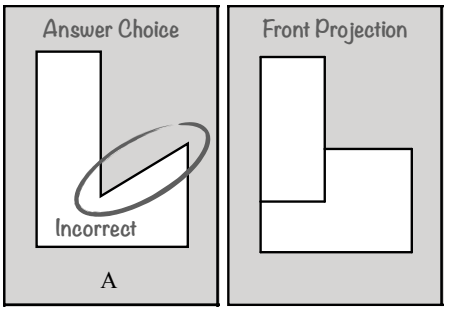
PROCESS OF ELIMINATION

- Answer choices for keyhole questions are incorrect either because the ***shape*** of the keyhole does not match that of the object, or the ***proportions*** of the keyhole do not match that of the object. Eliminate these answer choices
- When only two answer choices remain, look for differences between the keyholes and refer back to the object to see which "version" is correct. This technique is more efficient at finding subtle differences, compared to glancing back and forth between the object and each individual keyhole

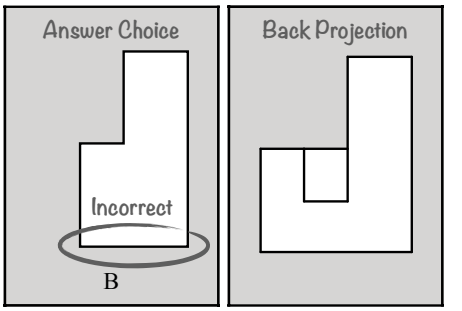
Example



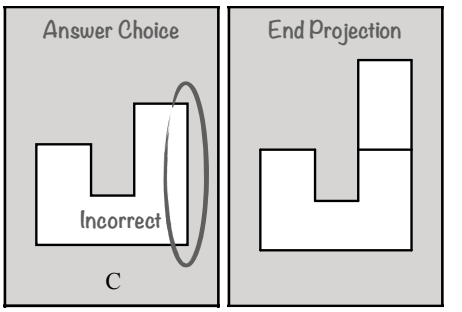
Let's first consider option A). This looks the most similar to the object's *front* projection. However, we see a sharp angle that is not found in the object. Therefore, the keyhole is not the correct shape. Based on this inconsistency, we can eliminate answer choice A)



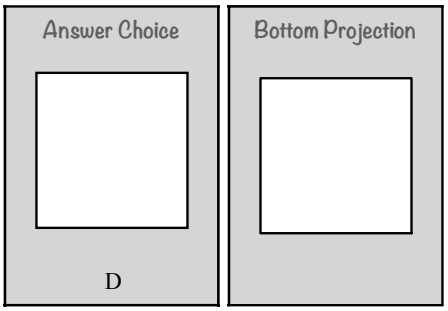
Next let's consider option B). This looks like either the object's *end* or *back* projection. However, we notice that the circled dimension is not wide enough. Therefore, we can eliminate answer choice B)



Now let's consider option C). This looks like the object's *end* projection. However, we notice that the circled dimension is not tall enough. Therefore, we eliminate answer choice C)

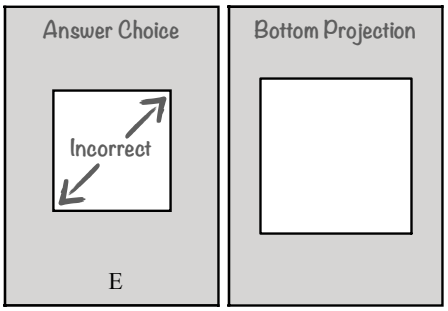


Moving onto option D), we see that this looks like the object's *top* or *bottom* projection. There is nothing to indicate that this keyhole does not have the correct shape or proportions, so we will keep this answer choice for now



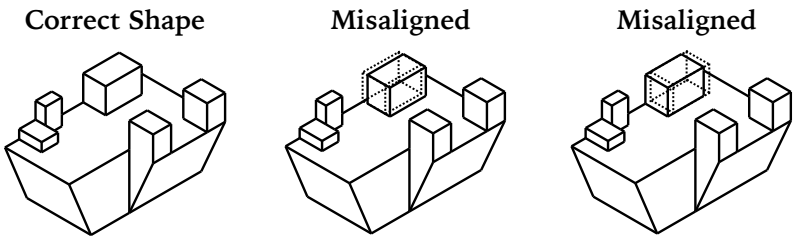
Finally, let's consider option E). It's the same shape as option D). However, if we compare its width and and length with that of all the other keyholes, we can see that it is too small to fit the object. Therefore, it has the wrong dimensions and can be eliminated

After examining all answer choices, we can conclude that option D) is the correct answer

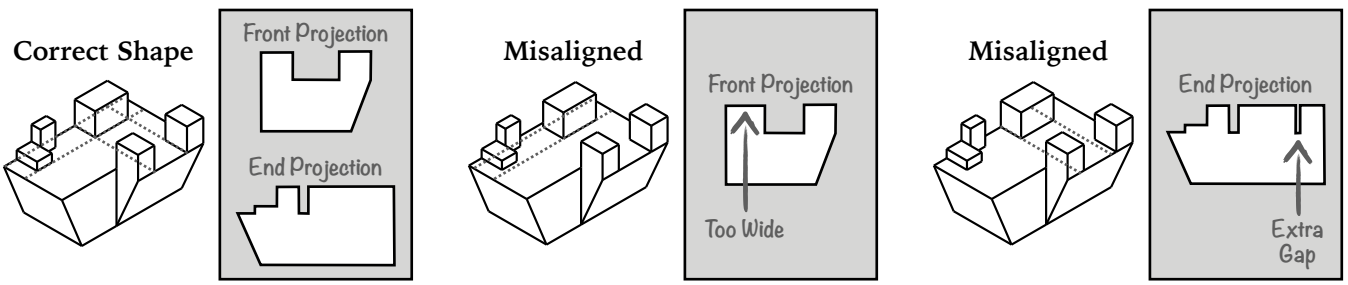


DRAWING REFERENCE LINES

- Often an answer choice will be incorrect because its shape differs from the object very subtly. The most common example of this is ***misalignment***, when two or more features in the answer choice are displayed in the wrong position relative to each other



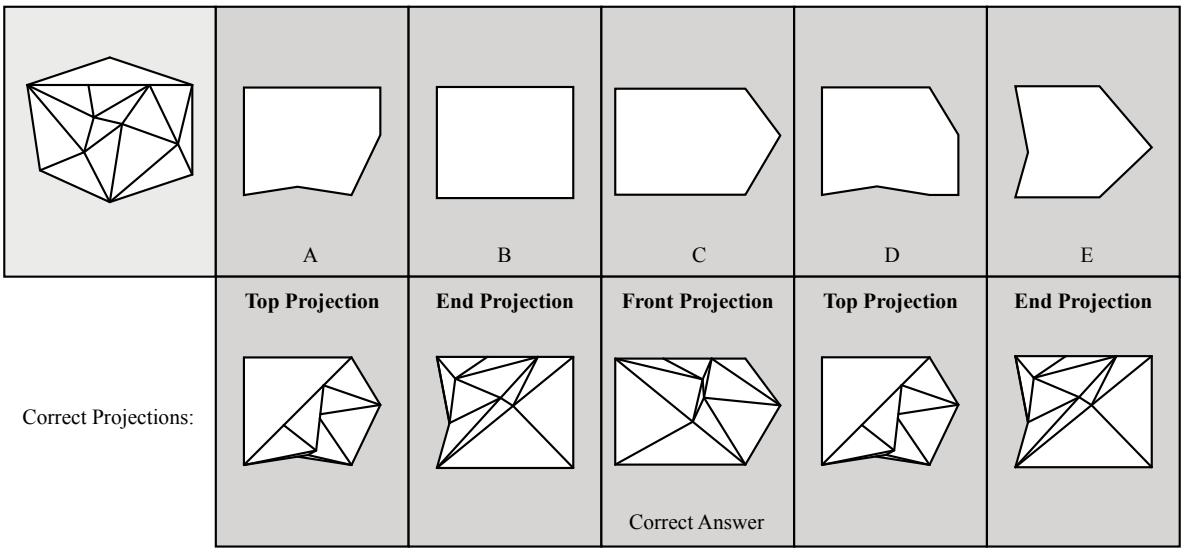
- ***Reference lines*** can be used to find misalignment, even when it is very subtle. To draw reference lines, first choose a line on the perimeter of the object. Then, use a pencil or your finger to shift the line to an edge on the feature in question
- Use as many reference lines as you need. After you have throughly practiced this technique, you should be able to mentally visualize the line shifting, without the assistance of a pen or finger. If you find that you have trouble doing this, practice more angle ranking problems



ROCK KEYHOLES

- ***Rock keyholes*** are a special type of keyhole problem introduced in the 2015 Canadian DAT. They exist to intimidate you, waste valuable time, and help the test administrators increase variability in PAT scores
- It is important to realize that you are dealing with a rock keyhole question when presented with one during the exam. If you understand the reason why these questions exist, you can respond appropriately by limiting the amount of time you spend on that particular question
- The identifying characteristics of a rock keyhole question are:
  - High number of irregular faces
  - High variability in angles and side lengths
  - Absence of symmetry
  - Difficulty comprehending depth and overall form

Example

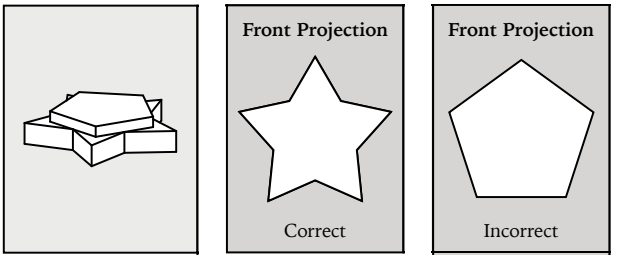
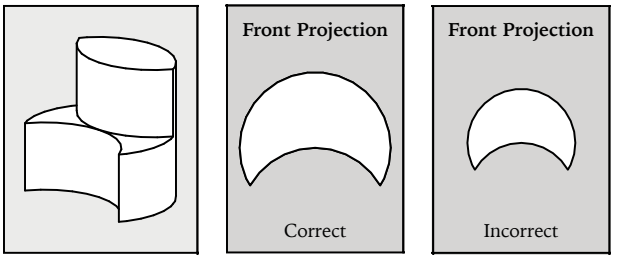
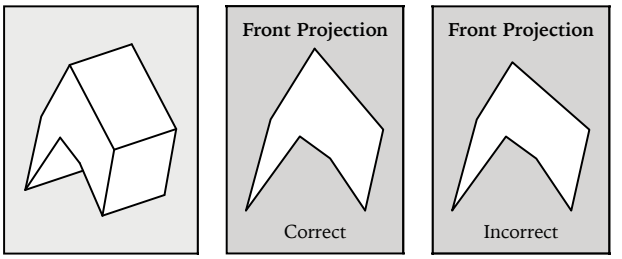
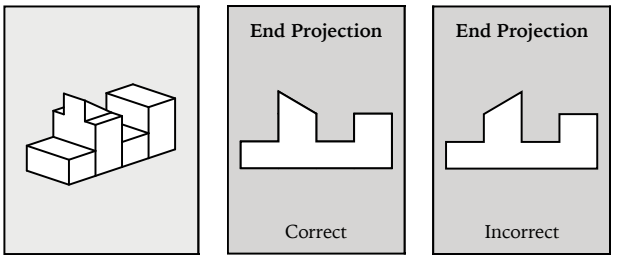
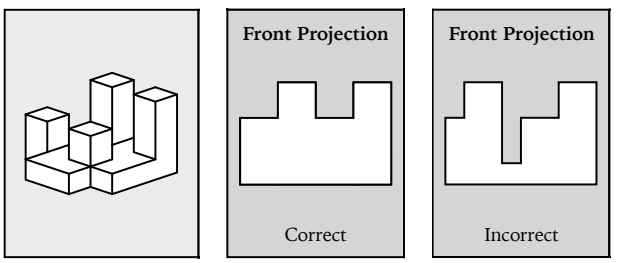
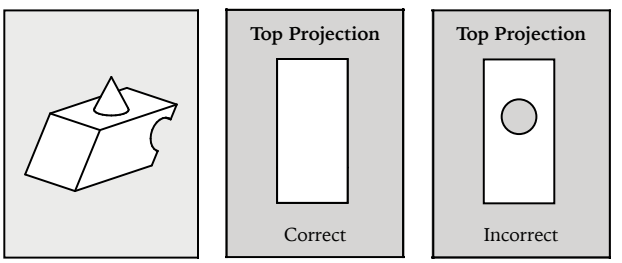


- First let's consider option A). Judging from the convergence of lines on the *end* face of the object, there is a protrusion that is not illustrated in the answer choice. Therefore A) is incorrect
- Now let's consider option B). There appears to be an indentation on the *front* face of the object. This is not illustrated in the answer choice, as it shows all four sides to be flat. Therefore B) is incorrect
- Looking at option C), it appears that the protrusion on the *end* face is illustrated. This may be the front projection of the object. We will keep this answer choice
- Considering option D), we see that there should not be a protrusion in the lower right corner of the keyhole. Therefore D is incorrect
- Finally, we consider option E). There are way too many indentations and protrusions compared to what is illustrated on the object. Therefore E) is incorrect

- When solving rock keyholes, try to use the many sides and vertices to make an inference about the overall form of the three-dimensional object. Then, use this inference to eliminate answer choices
- Always spend less than 60 seconds on a rock keyhole, and never waste time coming back to the question

WRONG ANSWER PATHOLOGIES

- The following page contains a summary of the common types of wrong answer choices that you should look out for in the keyholes section

Wrong Answer Type	Example
Incorrect Shape When the keyhole is clearly the wrong shape	
Incorrect Proportions or Scale When the keyhole is wider, longer, smaller, or larger than it should be	
Incorrect Angles When the slope of angles in the keyhole does not match the slope of angles in the object	
Incorrect Directionality When a feature of the object is facing the wrong direction	
Incorrect Alignment When one or more features are in the wrong position relative to each other	
Incorrect Occlusion When there are extra or missing "gaps" in the keyhole	

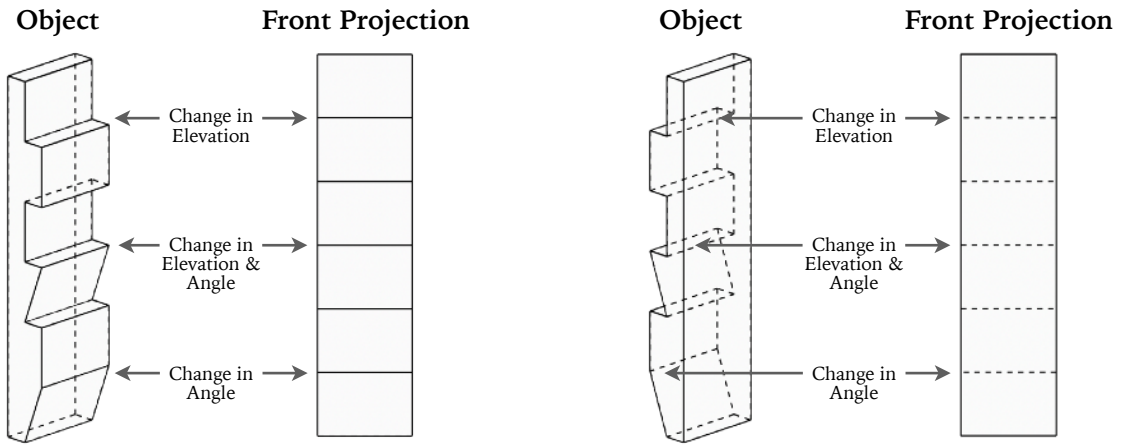
CHAPTER 6 | **TOP-FRONT-END**

INTRODUCTION

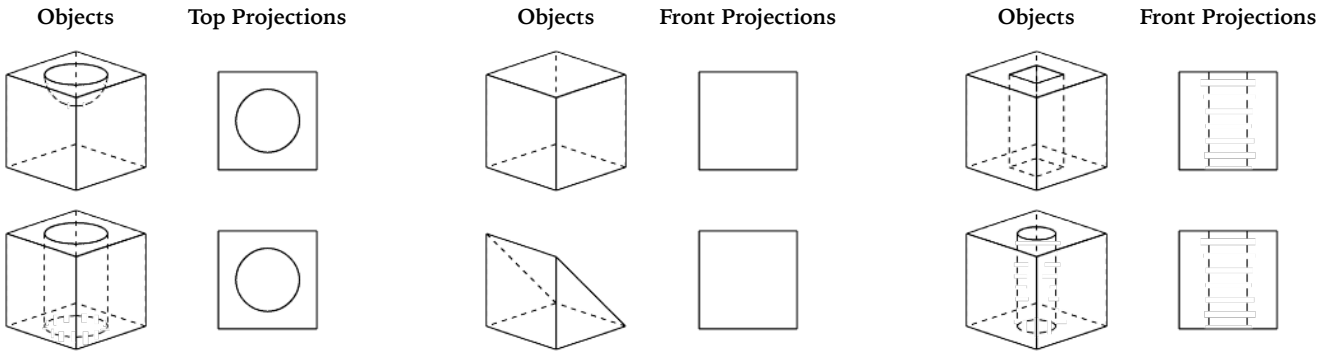
- ***Instructions:*** The top, front, and end projections of a three-dimensional object are shown. In each question, one of the three projections will be missing. Your task is to choose the projection that would complete the full set of three projections in a manner consistent with the three-dimensional object, which is not shown
- ***Rules:***
  - Solid lines represent visible edges of the object
  - Dotted lines represent edges that are obscured by other faces
  - If solid and dotted lines overlap, the solid lines will always cover the dotted lines
  - Each projection is drawn to scale. Their dimensions can be compared against each other
- ***Mindset:*** This section is usually less time-consuming and difficult than keyholes. With that in mind, try to speed up your pace again as soon as you hit this section. You will find that your accuracy and efficiency with top-front-end questions can be greatly increased through practice

TOP-FRONT-END PROJECTION

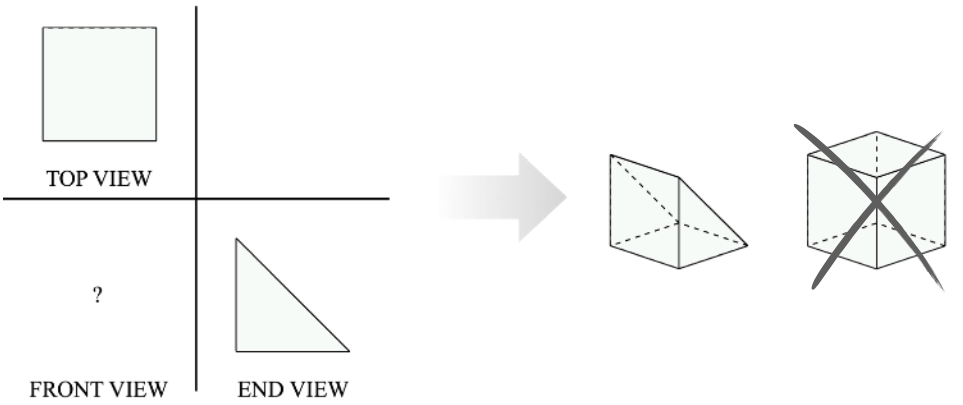
- Like the keyholes section, top-front-end questions also use orthographic projection
- A key concept to understand is that both ***solid lines*** and ***dotted lines*** represent changes in the elevation and/or angle of a surface. The only difference is that for dotted lines, this change in elevation and/or angle is obscured by another face:



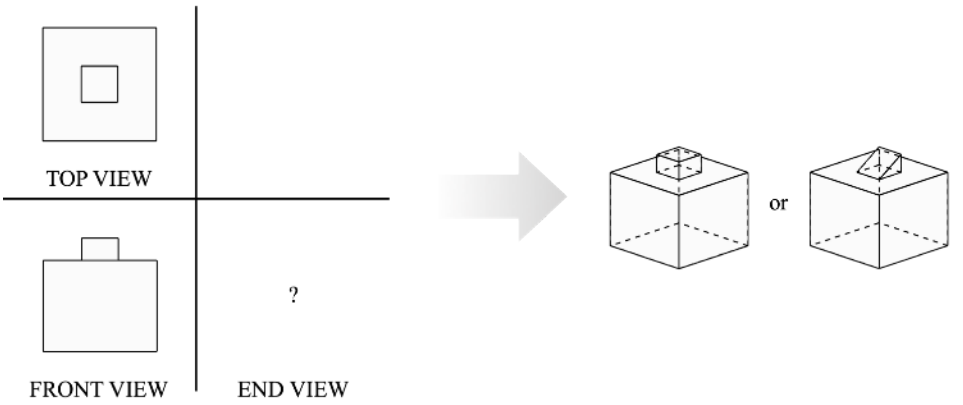
- Although solid and dotted lines give us information about changes in elevation and/or angle, we do not know the exact nature of that change. For instance, consider the following objects and their projections:



- Notice how the projections for each object are indistinguishable, despite obvious differences in how the change of elevation and/or angle occurs. Therefore, you must recognize the ambiguity that may exist certain situations
- Usually, it is possible to eliminate any ambiguity by combining information from more than one projection:



- In the example above, we were able to eliminate one of the object possibilities by looking at lines from both the top and end projections. In rare situations, both projections will contain ambiguous lines:

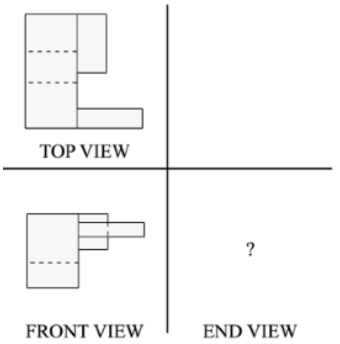


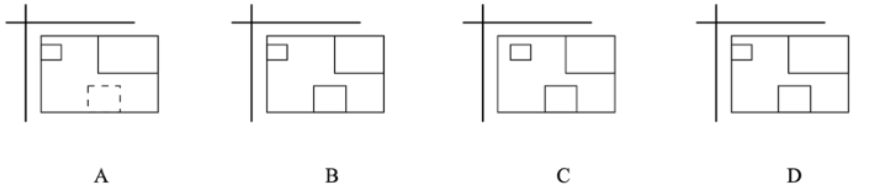
- When this is the case, avoid making decisions or eliminating answers based on ambiguous lines

PROCESS OF ELIMINATION

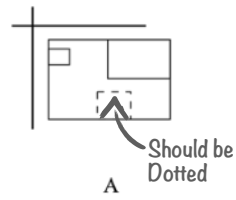
- Like the keyhole section, properly using the process of elimination is key to increasing your speed and accuracy
- When examining answer choices, only pay attention to how each option is different from the others. In some top-front-end questions, a single error will be repeated across more than one answer choice. For instance, half the answer choices may show a solid line, whereas the other half show a dotted line. Once we find out which "version" is correct, we can instantly eliminate all answer choices that contain the error
- When only two answer choices remain, ignore the top-front-end projections and focus on finding a difference between the two answers. Once you find the difference, reference the projections to see which "version" is correct. This is very similar to the elimination technique used for keyhole questions

Example

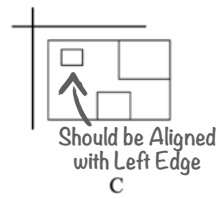




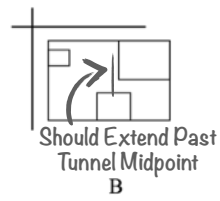
The first noticeable difference between the answer choices is the rectangle shown near the bottom of the *end* view. In option A) it is dotted, while in options B), C), and D), it is solid. Referencing the projections, we see that this rectangle corresponds to the two dotted lines in the *top* view. This suggests a hollow "tunnel" structure, the opening of which would be visible in the *end* view. Therefore, this rectangle should be solid and not dotted. Answer A) is incorrect.



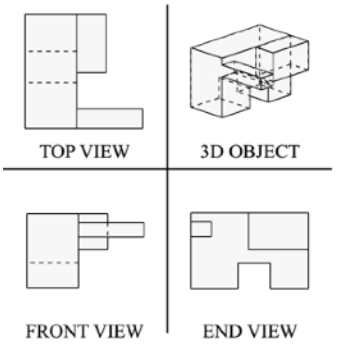
Next, we see that the rectangle in the upper left corner of option C) is in a different position than that of the remaining options. Referencing the *top* and *front* projections, we see that this rectangle corresponds to a very long protrusion. From the *top* view, we see that this protrusion is aligned right against the bottom edge. Therefore, the upper left rectangle in the *end* view should be perfectly aligned against the left edge. Answer C) is incorrect.

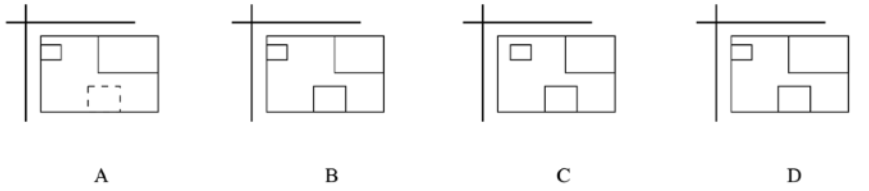


Finally we try to find a difference between B) and D). In answer choice D), the upper left rectangle appears to extend farther to the left than in B). Looking back to our projections, we see that this rectangle corresponds to a protrusion that is approximately half as tall as the other one. Since we know that the rectangle near the bottom of our *end* view and the two dotted lines in our *top* view both represent a tunnel structure, we can use it as a landmark. In the *top* projection, the protrusion extends past the midpoint of the tunnel. However, in answer choice B), it falls short of the tunnel's midpoint. Therefore option B) is incorrect.



After eliminating all answer choices, we can conclude that option D) is the correct answer.





CHAPTER 7 | **ANGLE RANKING**

INTRODUCTION

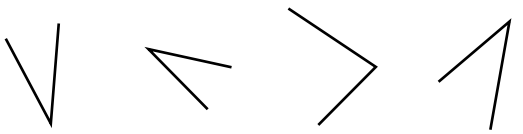
- ***Instructions:*** Four angles will be shown, labelled 1-4. Your task is to examine the *internal* angles and determine the correct order ranked from smallest to largest
- ***Rules:***
  - Consider internal angles only. All angles are less than 180 degrees
- ***Mindset:*** It is very easy to get "caught up" on any particular question in this section, wasting valuable time. Some angles may be so close together that it is nearly impossible to tell them apart. In these cases, remember that the PAT section is graded out of 90 questions, not 1. Make an educated guess and move on. The reason why we recommend completing angle ranking last is because it forces you to move along at a reasonable pace

KNOWING HOW TO PRACTICE

- Although our ability to discern angles may seem hard-wired in genetics, practice really does make a big difference in this section. It's all about doing enough questions such that you recognize and learn to avoid your intrinsic biases when it comes to judging angles
- When doing practice questions, ask yourself:
  - Are you particularly bad at analyzing acute, right, or obtuse angles?
  - Are you better at analyzing an angle when looking at it vertically or horizontally?
  - Are you better at analyzing an angle when you use another line as a reference?
  - Are you easily confused in any of the following situations?
    - When one side of the angle is shorter than the other:



    - When the angles are orientated differently:



- After each practice session, make a conscious effort to identify your most common mistakes and develop a method to avoid them in the future

COMMON STRATEGIES

TECHNIQUE **Guidelines**

- Sometimes, two or more angles will contain segments that are very close to parallel with each other. If you recognize these segments, use them as a guideline to compare the other segments against:



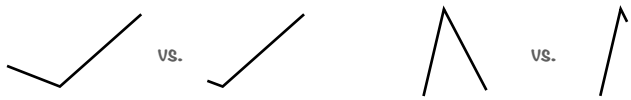
- Another way to use guidelines is by visualizing a 90 or 180 degree reference line and comparing the angle against it. This makes it easier to see the difference between two obtuse angles:



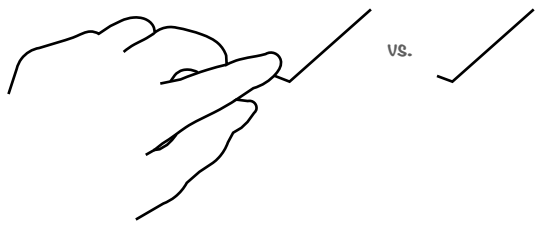
- The most difficult angle ranking questions are orientated randomly and have no parallel segments. You may have to simply go with your intuition or make an educated guess for these types of questions

TECHNIQUE **Equalization**

- Angles in which one segment is shorter than the other are often associated with an optical illusion that makes it appear as if the angle is larger or smaller than it actually is:



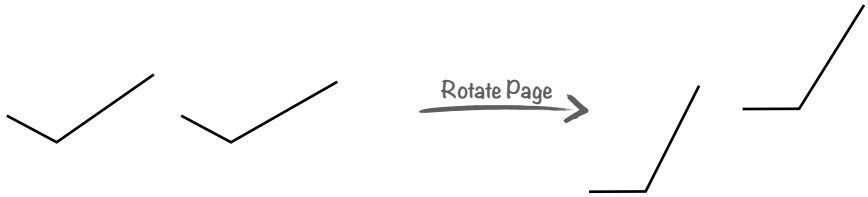
- To avoid this illusion when comparing two angles, only look at portions that are present in both angles. Use your pencil or finger to equalize the lengths of the two angles being compared:



- The rotation of an angle may also cause it to look larger or smaller that it actually is:



- Before deciding if an angle is larger than another, rotate the test booklet at least once so you can confirm that the angle does indeed still look larger even when presented differently
- If you are dealing with angles that have parallel segments, you can also rotate the page such that the parallel lines are horizontal. This will make subtle differences in angle more obvious:



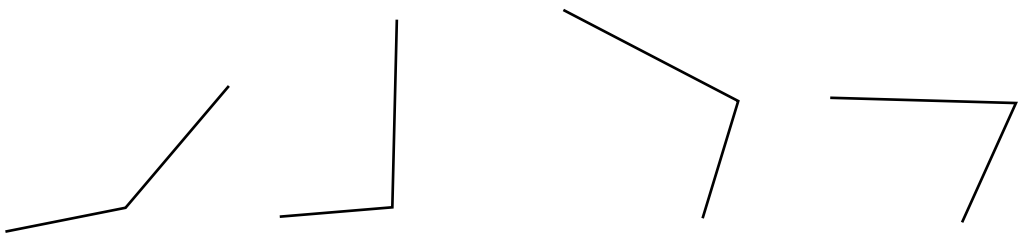
PROCESS OF ELIMINATION

- Although practice is really the only way to get better at angle ranking, we can use some clever probability tricks to increase our chances of selecting the correct answer
- The answer choices will always be presented in the format illustrated below. Each row is an answer choice, and each column represents a ***position*** within the ranking system, from 1 to 4. Some positions will have a 1-in-2 split, while others have a 1-in-3 split:

A. 4-3-1-2 Answer Choice	**A.** 4-3-1-2	**A.** 4-3-1-2
B. 4-2-1-3	**B.** 4-2-1-3	**B.** 4-2-1-3
C. 4-2-3-1	**C.** 4-2-3-1	**C.** 4-2-3-1
D. 4-3-2-1	**D.** 4-3-2-1	**D.** 4-3-2-1
Position	1-in-2 Split	1-in-3 Split

- Always start your process of elimination with positions that have a 1-in-2 split. The probability of choosing the correct answer (while guessing randomly) is 50% greater than starting with positions that have a 1-in-3 split. Furthermore, comparing only two angles at a time is much easier than comparing three angles at a time
- If two angles are so close to each other that they are nearly indiscernible, then there is a high likelihood that these two angles will appear next to each other in the ranking order

Example



A. 4-3-1-2

B. 4-2-1-3

C. 4-2-3-1

D. 4-3-2-1

1 **2** **3** **4**

Note that this is a simplified example. Actual angle ranking questions on the DAT will contain differences that are much more subtle

Worked Solution

- We see that the first position in all four answer choices contains "4". Therefore we know with 100% c smallest
- Moving on to the second position, we see a 1-in-2 split between angle 2 and 3. Since the third and fort between angles 1, 2, and 3, we start our elimination process with the second position. Ask yourself: "which that angle 3 is larger because it is farthest from a right angle. However, angles 2 and 3 are fairly close, sc next to each other in the ranking order. Since angle 3 is larger than angle 2, eliminate all answer choices wh A) and D) are therefore incorrect
- Looking between the remaining options B) and C), the only difference is in the order of the last two p larger – angle 1 or 3?" We see that angle 1 is larger because it is more obtuse than angle 3. Option B) is the
- Since we have eliminated all other options, C) is the correct answer

SECTION 5 READING



CHAPTER 1 | **PRINCIPLES OF RCT**

MINDSET

The purpose of the reading comprehension section (RCT) on the American DAT is to test your critical thinking skills. A secondary purpose exists on the Canadian DAT (cDAT), which is to test your ability to rapidly triage information when given a limited amount of time. This difference exists because the cDAT RCT is ten minutes shorter than the American version, but contains the same number of passages and questions. Therefore, you must train not only your critical thinking skills, but also your ability to prioritize information.

There are three passages on the RCT, ranging from 1,100 to 1,700 words in length. Each passage will have 15-17 questions associated with it, for a total of 50 questions. You should budget an average of 15 minutes per passage. This gives you eight minutes to read and seven minutes to answer the accompanying questions. Many students run out of time on this section because they let themselves get "caught up" in a particular paragraph of a passage. If you do not fully understand a sentence or two, re-read it a maximum of three times before moving on. Lingering on a passage and wasting valuable time is more detrimental than not fully understanding what the author is trying to convey. Often, you will find that reading the questions may clarify parts of the passage that you find difficult to understand at first.

STUDY STRATEGY

Unlike the Survey of Natural Sciences section of the cDAT, the RCT does not require any external knowledge of the topics covered in the passages. All decisions made should rely only on information presented within the text itself. Nevertheless, it is beneficial for you gain familiarity in topics that have appeared on the cDAT in the past by reading lengthy articles under timed conditions. This will allow you to practice your comprehension skills and learn the vocabulary associated with these topics, thus improving your level of understanding on the actual exam. Passages that have appeared on the cDAT in previous years include the following topics and themes:

Topics	Types of Writing
Biochemistry	Scientific research article
Physiology	Persuasive writing
Psychology	Textbook passages
Epidemiology	Historical non-fiction
Public health	
Oral health	
Medical imaging	

The following publications are good resources for finding articles that are similar to the RCT:

- *Journal of the Canadian Dental Association (JCDA)*
- *Journal of the American Dental Association (JADA)*
- *Public Library of Science (PLOS)*
- *Scientific American*
- *PubMed*

CHAPTER 2 | **READING TECHNIQUES**

PASSAGE SKIMMING

Given the fast-paced nature of the cDAT RCT, your first read-through of a passage should be focused on its overall message and purpose rather than details. This technique is called ***passage skimming***, and it is necessary in order to finish the RCT section on time. The goal of skimming is to gain an overall understanding of the structure and purpose of the passage, and to underline important words that you might need to search for when revisiting the text. You do not need to memorize everything because you can simply refer back to the passage later when answering questions. Furthermore, you do not need to fully understand every point the author makes. If the questions do not ask anything about the part that you had trouble understanding, then it is detrimental to get stuck on that particular paragraph. The following table summarizes the goals and recommended strategies for passage skimming:

Goal	Strategy
Determine the ***topic***. What is general subject matter of the passage and the overall message that the author is trying to convey?	→ Passage Mapping
Determine the ***scope***. What specific aspect of the topic does the passage focus on? A passage can have a narrow or broad scope, and each paragraph can have a different one.	→ Passage Mapping
Determine the ***purpose***. Why did the author write the passage and what were they trying to accomplish?	→ Passage Mapping
Determine the ***tone***. What is the author's attitude towards the passage's topic? In general, an article can have a positive, negative, or neutral tone.	→ Passage Mapping
Identify important information that may be relevant and useful for answering questions later on.	→ Underlining

PASSAGE MAPPING

The goal of passage mapping is to build a "roadmap" of the ideas of each paragraph. This will make it easier to find relevant details later on when you reference the passage. This strategy also helps you focus on the "big ideas" as you are reading the text. Passage mapping should be done relatively quickly, either during or immediately after passage skimming. As you read, use your pencil to follow along with the lines of text. Our eyes are naturally attracted to motion, so this helps you focus and increase your reading speed.

A passage map can be formatted as a list, with each line corresponding to a paragraph number. These points should be very concise, ideally less than four words each. Use the following shorthand notation to summarize each paragraph:

Shorthand Notation	Meaning
⊕	Positive tone, author supports the topic
○	Neutral tone, author is objective and informative
⊖	Negative tone, author does not support or is against the topic
> or <	Entity is better than or worse than another entity

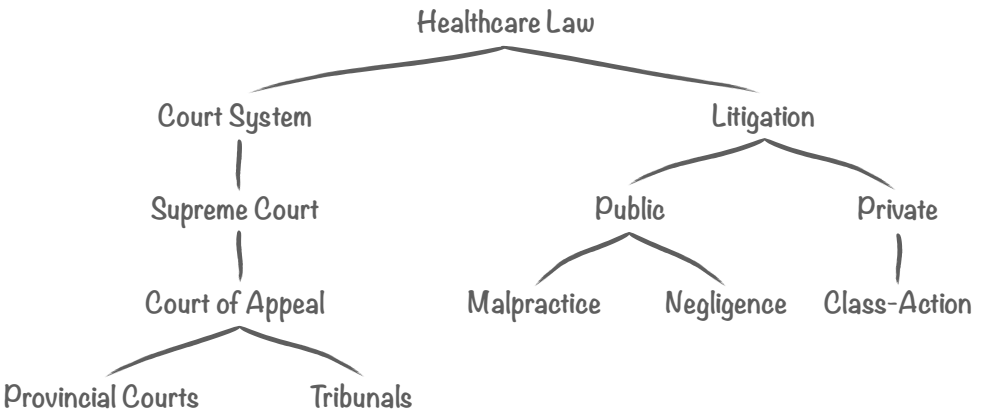
The following is an example of the passage map for an eight-paragraph article:

Title: Medical Imaging

1: History & examples ⊕
2: How X-rays work ◯
3: Fluoroscopy & applications ◯
4: CAT > X-rays ◯
5: How ultrasounds work ⊖
6: Doppler > ultrasound ◯
7: MRI & applications ◯
8: Future advancements ⊕

Scope: Describe types of imaging

If the author starts discussing the classification or hierarchical structure of a concept, sketch out a quick tree diagram to help with visualization and comprehension. Take the following example for instance:



UNDERLINING

You will not be supplied with a highlighter on the cDAT. Since only pencils are allowed, you will need to underline important parts of the passage. The goal with underlining is to select key pieces of information that have a high probability of showing up in the questions that relate to the passage. The following list describes the different kinds of information that are frequently used in recall-type questions:

- ***Names*** (ex: *"The double-helix model of DNA was first proposed by James Watson and Francis Crick"*)
- ***Locations*** (ex: *"The Bhopal disaster occurred in India and is considered to be the worst industrial accident"*)
- ***Numbers/quantities*** (ex: *"Among HIV-positive individuals, 62% have access to antiretroviral therapy"*)
- ***Dates/time periods*** (ex: *"Although released in the 80s, Park was not recognized for the film until 2004"*)
- ***Acronyms*** (ex: *"Hu's study was published in the Journal of Contemporary Music (JCM) after she received her tenure"*)
- ***Words/phrases that summarize the paragraph's topic*** (ex: *"Mass incarceration was also seen in the 1970s during Richard Nixon's government. All considered, criminalization is not a long-term solution for preventing drug abuse"*)
- ***Objects or subjects of importance***, often repeated within the paragraph or passage (ex: *"NDL1 is the only CYPXL inhibitor that has broad clinical applications. Prions that cause CJD have been shown to be susceptible to NDL1 activity"*)
- ***Words/phrases that introduce a list***. Underline the introduction and skim over the contents of the list, as they are time consuming to read and only important when asked in a recall question (ex: *"some of the most abused prescription opioid drugs include: fentanyl, carfentanyl, hydrocodone, methadone, acetaminophen, and codeine"*)

- ***Sequence keywords*** that convey an order to the author's arguments or ideas (ex: *first, second, third, next, then, finally, historically, recently, currently, before, after, subsequently, simultaneously, meanwhile,* etc.)
- ***Transition keywords*** that continue an idea or argument (ex: *furthermore, in addition, moreover, likewise, similarly, also, as well as, at the same time, along the same vein, in the same fashion, in other words, that is to say,* etc.)
- ***Illustration keywords*** that precede an example (ex: *for instance, for example, according to, in the words of,* etc.)
- ***Explanation keywords*** that indicate evidence or support provided by the author for an argument (ex: *because, since, for, the reason being, by virtue of, as a result of, due to, on the grounds that, by cause of, pursuant to,* etc.)
- ***Emphasis keywords*** that indicate something of importance to the author (ex: *crucially, most importantly, above all, most of all, especially, primarily, particularly, interestingly, strangely, notably, indeed, incredibly, surprisingly,* etc.)
- ***Contrast keywords*** that signal a shift in the author's argument or train of thought (ex: *but, however, although, despite, in contrast, even though, yet, unless, still, alternatively, in contrast, on the contrary, notwithstanding,* etc.)
- ***Conclusion keywords*** that signal the summary or main idea of the passage or paragraph (ex: *therefore, thus, in summary, in conclusion, hence, clearly, so, it can be seen, consequently, accordingly, we can conclude, it follows that,* etc.)

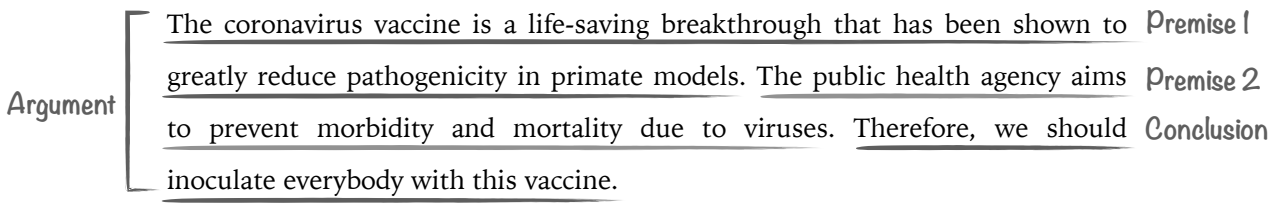
PASSAGE REFERENCING

After you have completed passage skimming and have read the first question, this is when you switch into detail-searching mode. Now that you already mapped out the passage, finding important, relevant information should be easy and quick. Look for keywords in the question stem such as a name, date, location, etc. Then, reference your passage map and find the relevant paragraph. When you find the correct paragraph, skim until you hit the keyword, or something similar to it. Begin a detailed read-through, starting a few sentences before the keyword and ending a few sentences after it. Sometimes, you may choose to re-read the whole paragraph if you are concerned that other relevant information would be missed. During this detailed read-through of the text, focus on comprehending the author's idea or argument as it relates to the question. If the question stem contains multiple keywords, make sure you reference the passage for all of them to avoid missing important information.

When looking over the answer choices, make sure you read every single word. Some wrong answers are very similar to the correct one, but differ by a misspelling or similar-looking word. Furthermore, never answer a question without first revisiting the text. Relying only on your short term memory is a recipe for simple mistakes. Always *visually* confirm that whatever you chose as an answer is supported by the text. Finally, never answer questions based on your own experiences or external knowledge.

INFERENCING

An ***inference*** is a conclusion reached by combining evidence with reasoning and critical thinking. For the cDAT, it is important that you are able to infer ideas presented through the author's arguments. An ***argument*** consists of a conclusion supported by one or more statements, called ***premises***. In order for the argument to be valid, all premises must be correct and supported by pieces of evidence. Premises can either require inference by the reader (***implicit***), or be stated directly within the text (***explicit***). An implicit premise that is required for an argument to be valid is called an ***assumption***. The following text is an example of an argument with an assumption that must be inferred by the reader:



In this example, the main assumption that is required for the argument to be valid is "the coronavirus vaccine will be just as effective in humans as it is in primate models". If you arrived at the same assumption, you have successfully inferred a premise that was implicitly stated by the author.

Practice

For the following arguments, determine the premise or conclusion that must be inferred.

1. Antidepressants such as citalopram and fluoxetine have been shown in clinical trials to cause weight gain. Half the participants were enrolled in an intense exercise program. However, both exercise and non-exercise cohorts experienced the same average increase in weight.

   Infer the conclusion:
   _____
   _____
   _____

2. Methane is a more potent greenhouse gas than carbon dioxide. Considering that animal agriculture produces significantly more methane than the automotive industry, meat consumption is thus a larger contributor to global warming than transportation.

   Infer the premise:
   _____
   _____
   _____

3. All vision-related pathologies are caused by problems in either the eye or central nervous system. Glaucoma is a vision-related disease that commonly causes blindness and is often diagnosed in individuals with healthy eyes.

   Infer the conclusion:
   _____
   _____
   _____

4. An engram is a specific location in the brain containing neurons that store a particular memory. In 1950, Karl Lashley found that creating a lesion in the lateral interpositus nucleus of a rabbit resulted in the loss of a behaviour learned through classical conditioning. Therefore, the lesion destroyed an engram.

   Infer the premise:
   _____
   _____
   _____

5. The 1986 Chernobyl nuclear disaster resulted in worldwide pressure to decommission all RBMK-type reactors. Since then, Russia has remained the only country to operate these reactors, which have since been retrofitted with a number of safety mechanisms. The 2011 meltdown in Fukushima, Japan was another tragedy involving flawed reactor design.

   Infer the conclusion:
   _____
   _____
   _____

6. Water fluoridation has been shown to prevent tooth decay and the formation of dental caries. However, fluoridated tap water also increases risk of fluorosis, a cosmetic condition that can discolour teeth. Therefore, artificial fluoride should be removed from all tap water.

   Infer the premise:
   _____
   _____
   _____

Solutions

1. Exercise does not prevent weight gain caused by antidepressants.
2. Animal agriculture and the automotive industry produce the same amount of carbon dioxide.
3. Glaucoma is caused by problems in the central nervous system.
4. The learned behaviour is dependent on a particular memory.
5. The reactors involved in the Fukushima meltdown were not RBMK-type.
6. The cosmetic harms of fluoridated water outweigh the benefits of decay prevention.

FACTS VS OPINIONS

The premises for an author's argument can be either fact or opinion. ***Facts*** are objective statements that have been proven to be true. ***Opinions*** are subjective evaluations or beliefs that are not necessarily based in evidence or knowledge. Opinions are useful for gauging the author's tone on a particular subject. Keywords that often signal the arrival of an opinion include: *"I believe, I feel, rightly, wrongly, should, fortunately, unfortunately,* etc…*"*

Practice

For the following statements, determine if each one is a fact or opinion

1. In 1990, many architectural critics regarded I. M. Pei's design for 1 Garden Road to be distinctive and ahead of its time. Fact or opinion? _____
2. To claim that the preference to vaccinate is one of the individual is to undermine the responsibility of government to prevent mass tragedies of public health. Fact or opinion? _____
3. The most common oral diseases worldwide are dental carries, periodontal disease, and trauma. 80% of children and nearly all adults have some form of tooth decay. Fact or opinion? _____
4. Economists estimate that job automation is estimated to cause a nearly two-fold increase in unemployment rates within the next five years. Fact or opinion? _____
5. Medical researchers have rightly concluded that routine screening for breast cancer in women under 60 leads to over-diagnosis and unnecessary treatment. Fact or opinion? _____
6. The dangers associated with direct-to-consumer dental appliances are an unfortunate example of the potential harms that can be caused by an absence of regulation in a privatized dental industry. Fact or opinion? _____
7. Hannah Arendt's concept of the banality of evil is an unfortunate truth that remains ubiquitous in modern capitalist societies. Fact or opinion? _____
8. Oral health in Canada falls outside of our publicly funded single-payer system, with around 11 billion dollars billed through private insurance companies each year. Fact or opinion? _____

Solutions

1. Fact. The author objectively repeats an unrefuted truth about the architect I. M. Pei.
2. Opinion. The author refutes an argument against mandatory vaccination.
3. Fact. The author objectively presents statistics on global oral health.
4. Fact. The author objectively presents an estimated statistic.
5. Opinion. The word "rightly" indicates that the author agrees with the statement and is presenting it in a favourable light.
6. Opinion. The author views direct-to-consumer aligners as an unfortunate occurrence.
7. Opinion. The author describes the banality of evil as an "unfortunate" truth, indicating a dislike.
8. Fact. The author objectively presents an unrefuted truth, followed by a statistic

CHAPTER 3 | **QUESTION TYPES**

INTRODUCTION

Most RCT questions fall under one of ten categories, each of which will be discussed in this chapter. It is important for you to understand the goal of each question type so you spend less time on the actual exam trying to interpret the questions and more time solving them.

RECALL QUESTIONS

Recall questions ask you to regurgitate a fact, statistic, or quote directly from the passage. These types of questions are very straightforward and are more common on the Canadian DAT than the American DAT. However, some recall questions may be designed to circumvent ***search and destroy techniques*** in which you quickly skim the passage looking for the matching answer. Question writers can easily prevent this by presenting the answer choices in a different format than what appears in the passage. For example, the question may ask *"what percentage of the Amazon is NOT currently at risk of deforestation: 5%, 10%, 33%, or 66%?"* while the passage includes a sentence that states *"roughly one third of the Amazon is currently at risk for deforestation."* If you simply skim the passage looking for the correct percentage, you will never find it. You must recognize that this is a *disguised* recall question and deduce that if one third of the Amazon is at risk, then 66% is *not* at risk of deforestation.

DOUBLE RECALL QUESTIONS

Double recall questions are a more specific and time-consuming type of recall question. Instead of asking you to confirm the validity of a single statement, you are asked to confirm the validity of two. The two statements will be presented in the question as follows:

> *Superior and inferior alveolar nerves are responsible for pain sensation in teeth* (statement 1)
> *Odontoblasts are responsible for the production of dentin* (statement 2)

There are four possible answer choices for this type of question on the cDAT:

- ***Both statements are TRUE***
- ***Both statements are FALSE***
- ***The first statement is TRUE, the second is FALSE***
- ***The first statement is FALSE, the second is TRUE***

TONE QUESTIONS

Tone questions will ask you to interpret the author's attitude towards a particular subject within the passage. Tone must be implied from the connotation of specific adjectives, comparisons, and phrases that the author choses to use to convey their stance on a particular topic. The following list contains common answer choices and descriptions for tone questions on the cDAT:

- ***Argumentative*** – Expressing disagreement and heavy bias towards an issue. The author will often use rhetoric to convince the reader that their opinion is correct
- ***Accusatory*** – Indicating or suggesting that a subject is guilty or should be blamed. Author will often look for fault by critically examining the actions and decisions of others
- ***Ambivalent*** – Expressing uncertainty or fluctuation between two conflicting ideas
- ***Agnostic*** – Unwilling to commit to an opinion about something. This is very similar to an *impartial tone*
- ***Cynical*** – The belief that human actions are motivated by self-interest, and the distrust of human sincerity or integrity. Author will often point to conflicts of interests, question the motivations of others, and have an overall pessimistic view of the topic

- ***Critical*** – Expressing adverse or disapproving comments/judgement. Author will often try to undermine arguments from both sides, evaluate the quality of evidence, and analyze both the merits and pitfalls of a topic
- ***Casual*** – Author sounds relaxed and unconcerned about the topic
- ***Descriptive*** – Seeking to "paint a picture" regarding a topic in a positive or negative light. Author's goal is to allow the reader to mentally "recreate" their view of a topic
- ***Defensive*** – Expecting or resisting criticism or attack. The author will often shift blame away from themselves or from subjects that they support
- ***Informative*** – Seeking to inform a reader on a topic in an objective, nonjudgemental way. Text will sound very similar to a newspaper or textbook
- ***Impartial*** – Author is objective and nonjudgmental, treating both sides of an issue equally. This is very similar to an *informative tone*
- ***Ironic/Sarcastic*** – Conveying that the author believes the opposite of what is written to be true. The author will often use hyperbole and exaggeration.
- ***Satirical*** – Author uses a topic's shortcomings and ironies to ridicule or mock individuals, corporations, governments, or society with the intention of both entertaining and prompting improvement
- ***Scornful*** – Expression of dislike, disrespect, and contempt regarding a topic
- ***Serious*** – Implying that the topic demands careful consideration and has profound implications. Author will almost never use humour to lighten the mood of the passage
- ***Skeptical*** – Having doubts or reservations and not being easily convinced. Author will often use tempering words such as "purportedly", "allegedly", and "may." Authors will also quote partisan sources instead of simply stating their findings as fact
- ***Solemn/Melancholy*** – Speaking in a serious, formal, and dignified manner often with sadness
- ***Sympathetic*** – Author shows pity, understanding, or support for a topic

STATEMENT AND REASON QUESTIONS

Statement and reason questions will present a sentence that consists of both a statement and a reason, such as: "*apples fall from trees because gravitational pull is created from the earth's mass.*" In this example, the statement is "*apples fall from trees*" and the reason is "*gravitational pull is created from the earth's mass.*" There are five possible answer choices for this type of question on the cDAT:

- ***Both the statement and reason are correct and related***
  - Ex: "*humans can perceive colour because the various cone cells in the fovea are sensitive to different wavelengths of light*"
- ***Both the statement and reason are correct but NOT related***
  - Ex: "*humans can perceive colour because hemoglobin allows red blood cells to carry oxygen*"
- ***The statement is correct but the reason is NOT***
  - Ex: "*humans can perceive colour because the various rod cells in the fovea are sensitive to different wavelengths of light*"
- ***The statement is NOT correct, but the reason is correct***
  - Ex: "*humans can perceive ultraviolet light because the various cone cells in the fovea are sensitive to different wavelengths*"
- ***NEITHER the statement NOR the reason is correct***
  - Ex: "*humans can perceive ultraviolet light because the various rod cells in the fovea are sensitive to different wavelengths*"

EXCEPTION QUESTIONS

Exception questions show a list of statements and ask which statement was *not* true (not mentioned in the passage). These questions types are very time consuming as they require you to go through the entire process of elimination until only one answer choice remains. You are also more likely to make a mistake on these questions if you forget that you are looking for the *incorrect* answer. Thus, it is recommended that for each answer you eliminate, write "T" beside it after you cross it off so you remember the answer choice is wrong because it is *true*.

STRUCTURE QUESTIONS

Structure questions ask about how the author organizes the passage and their ideas or arguments. For instance, a question might ask: "*In which paragraph does the author begin her discussion of EVLP?*" You may also be asked to identify the order in which certain events occur. Referencing your passage map will help you locate the ideas and arguments that are relevant to these types of questions.

PURPOSE QUESTIONS

Purpose questions ask why the author decides to mention a specific detail or make a specific comparison. When dealing with these questions, first identify how the detail is relevant to the overall scope and goal of the passage. Then, determine the author's tone and consider what effect the detail has on the author's position on the topic. Does it support or undermine the author's message? Purpose questions often also ask why a specific paragraph exists within the passage. For instance, a common question stem could be "*What is the purpose of paragraph five?*" To answer this, refer back to your passage map for a concise reminder of what the paragraph was about.

MAIN IDEA QUESTIONS

Main idea questions ask you to summarize the ***thesis*** or overall message of the passage. These questions are designed to test your comprehension of the passage as a whole. Often the thesis is presented in the author's concluding statements, which is commonly found in the final few paragraphs. It is important that you select an answer choice that is broad enough to cover most of the topics discussed, yet narrow enough that it remains within the scope of the passage.

INFERENCE QUESTIONS

Inference questions are designed to test critical thinking. You will be asked to infer either the conclusion or premise of an argument. To do this, we must understand the topics discussed in the last chapter (facts, opinions, structure of arguments). Keep in mind that any inferences made must be consistent with the author's tone and cannot reach out of the passage's scope. Answer choices that sound too extreme or far-fetched are likely to be incorrect. When dealing with multiple answer choices that all seem reasonable, the "most correct" inference is one that *must* be true in all circumstances, while the remaining answer choices *may* be true in certain situations.

APPLICATION QUESTIONS

Application questions are more commonly found on the American DAT, but may also appear in your exam. You will be asked to apply knowledge from the passage to a new situation. Do not use outside knowledge to help answer these questions – you must rely only on information provided within the passage. Another common mistake is allowing your intrinsic opinions or biases to affect your answer choice. Remember that you must select the option that is most consistent with the author's views, not your own.

CHAPTER 4 | **WRONG ANSWER PATHOLOGIES**

INTRODUCTION

In this chapter we will discuss the most common types of "distractor" answer choices and the reasons why these answers are incorrect. Learning to recognize and avoid these common traps is very important for your elimination process. This will ultimately improve your speed and accuracy on the RCT.

DECOYS

Decoys are very common on the cDAT. These answer choices will use familiar-sounding vocabulary to trick test writers that the content is relevant. Often, the answer choice will relate to a completely different part of the passage. In other circumstances, it might not even answer the question. To avoid this trap, we recommend always referencing the passage and visually confirming that an answer choice is correct. Never "blindly" select an answer without going through the proper confirmation process.

OUT OF SCOPE

Often an answer choice may relate to the passage, but strays too far beyond the author's scope. These ***out of scope answers*** often seem perfectly logical and may even be widely accepted as true. However, they are not supported by the evidence presented within the confines of the passage. To avoid this mistake, never choose answers based on prior knowledge or what you think should be correct. Remember to always look for support from within the passage.

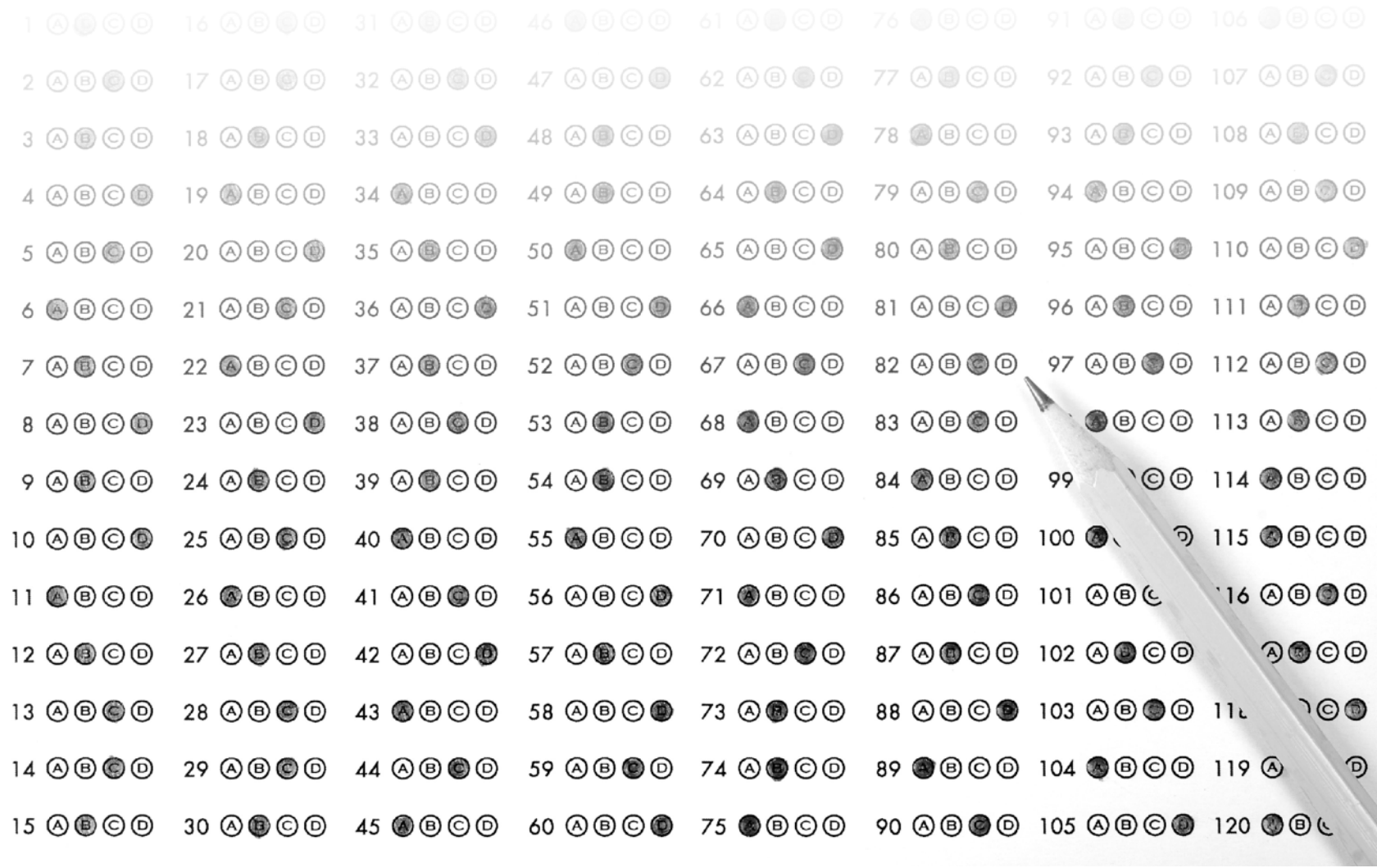
RIGHT ANSWER WRONG QUESTION

These answer choices are often correct and within the scope of the passage. However, since they do not answer the exact question presented within the question stem, they are the ***right answer for the wrong question***. For instance, if a question asks for the main idea of a paragraph and the answer choice describes the main idea of the entire passage, it is incorrect. To avoid this trap, always make sure you fully understand what the question is asking. Then, make a prediction for what you imagine would be the correct answer. Use this prediction to eliminate answer choices that do not appear to be relevant.

TOO EXTREME

Sometimes the answer choices may properly answer the question, but do so in a manner that exaggerates the author's message. These ***extreme answers*** often follow the same train of thought as the passage, but contain absolutist language. To avoid this trap, be skeptical of answer choices that contain superlatives (ex: *all, every, always, never, none, must, impossible,* etc.)

SECTION 6 PRACTICE EXAMS



CHAPTER 1 | **INTRODUCTION**

HOW TO USE THESE FULL-LENGTHS

The following four full-length practice exams are designed to give you a hyper-realistic experience of what to expect during the real Canadian DAT. At the beginning of every full-length, you will find three DAT ***answer sheets*** and a ***periodic table***. Remove these pages from the textbook by cutting along the dotted lines. Each answer sheet corresponds to the SNS, PAT, and RCT sections of the exam. When completing these full-lengths, practice bubbling in the answer sheet like you will on the actual DAT. This is especially important during the PAT and RCT section, since the five minutes it takes for you to transfer your answers can mean the difference between finishing the exam and running out of time. Practicing with the answer sheet is also critical for avoiding ***transposition errors*** during the real exam, which is an extremely time-consuming mistake to fix and would be devastating to your score. Students who use mock answer sheets also have the added benefit of building muscle memory prior to the exam, increasing speed, accuracy, and confidence on test day.

The actual DAT exam may vary in its level of difficulty. To compensate for this variability, each exam is calibrated from 0-30 according to a different score conversion scale, determined each year by the CDA. This means that receiving an easier exam will not necessarily make it easier to score higher. The full-lengths in this book follow the same principle. There are three levels of practice exam difficulty, labeled with the following icons:

LOWER DIFFICULTY	MEDIUM DIFFICULTY	HIGHER DIFFICULTY
Lower difficulty Canadian DAT. Some individual questions may feel slightly easier than that of other exams. However, the score conversion scale will be adjusted accordingly, making it as difficult as the other full-lengths. In this textbook, there is one exam provided at this difficulty level	Medium difficulty Canadian DAT. This is representative of the average DAT exam. In this textbook, there are two exams provided at this difficulty level	Higher difficulty Canadian DAT. Some individual questions may feel extremely difficult or near impossible. Do not panic, as the score conversion scale will reflect this. In this textbook, there is one exam provided at this difficulty level

TESTING CONDITIONS

It is important that you try to simulate real testing conditions as much as possible. This means writing the exam with nothing at your desk except tissues, pencils, and an eraser. No water bottles, snacks, earplugs, or calculators are allowed. You should also time yourself for each section (60 min for SNS, 60 min for PAT, and 50 min for RCT). It is highly recommended that you simulate the ambient sound and potential distractions of the exam room.

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PERIODIC TABLE OF THE ELEMENTS

IA												IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H 1.0079	IIA						VIIIB			IB	IIB						2 He 4.0026
3 Li 6.941	4 Be 9.0122											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
11 Na 22.990	12 Mg 24.305	IIIB	IVB	VB	VIB	VIIB						13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.065	17 Cl 35.453	18 Ar 39.948
19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.39	31 Ga 69.723	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.80
37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.91	46 Pd 106.42	47 Ag 107.87	48 Cd 112.41	49 In 114.82	50 Sn 118.71	51 Sb 121.76	52 Te 127.60	53 I 126.90	54 Xe 131.29
55 Cs 132.91	56 Ba 137.33	57-71 La-Lu	72 Hf 178.49	73 Ta 180.95	74 W 183.84	75 Re 186.21	76 Os 190.23	77 Ir 192.22	78 Pt 195.08	79 Au 196.97	80 Hg 200.59	81 Tl 204.38	82 Pb 207.2	83 Bi 208.98	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra (226)	89-103 Ac-Lr	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)	110 Uun (281)	111 Uuu (272)	112 Uub (285)		114 Uuq (289)				

57 La 138.91	58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.96	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
89 Ac (227)	90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (262)

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FULL-LENGTH 1 LOWER DIFFICULTY

SURVEY OF THE NATURAL SCIENCES

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Survey of Natural Sciences:

1. Each item is a question and/or incomplete statement followed by possible answers or completions. Read the item, decide which answer choice is the best, and bubble in the corresponding circle on the answer sheet
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 60 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. **DO NOT TURN PAST THE STOP PAGE AND ON TO THE NEXT SECTION UNTIL INSTRUCTED**
6. At the end of this section, the answer sheet is collected. The booklet remains at your table for use during the next section

TIME LIMIT:
60 minutes

TEST NAME:
SNS

TEST NUMBER:
01

This is a DAT simulation.

This section is composed of 70 questions:
Biology (1-40) and General Chemistry (41-70)

1. The RNA world hypothesis involves:
   A. Panspermia
   B. Ribozymes
   C. Metabolic pathways
   D. Centrioles
   E. Protocells

2. Maltose is a ___ that is composed of ___
   A. Protein; amino acids
   B. Disaccharide; glucose and fructose
   C. Nucleic acid; nitrogenous bases
   D. Disaccharide; glucose
   E. Disaccharide; glucose and galactose

3. Primary structure is best described as:
   A. The order of nucleic acids in DNA
   B. The order of amino acids in protein
   C. Hydrogen bonding between the polypeptide backbone of a protein
   D. Multiple polypeptide chains interacting together
   E. The high-level body plan of an organism

4. Which of the following is NOT a special property of water:
   A. Solid form is less dense than liquid form
   B. High specific heat capacity
   C. Low specific heat of vaporization
   D. Cohesion
   E. Adhesion

5. The most abundant substance in the extracellular matrix is:
   A. Proteoglycans
   B. Elastin
   C. Collagen
   D. Desmosomes
   E. Fibronectin

6. Which of the following would NOT occur if cholesterol was added to a lipid bilayer?
   A. Higher membrane fluidity at low temperatures
   B. Lower membrane fluidity at high temperatures
   C. Inversion of integral proteins
   D. Translation of integral proteins
   E. Atherosclerosis

7. Animal cells are labelled with a fluorescent stain that visualizes nucleic acids. You observe the chromosomes moving to opposite ends of the cell. Which phase of the cell cycle is occurring?
   A. G1
   B. G2
   C. S
   D. Anaphase
   E. Metaphase

8. How do electric impulses move from cell to cell in cardiac tissue?
   A. Adherens junctions
   B. Tight junctions
   C. Gap junctions
   D. Hemidesmosomes
   E. Plasmodesmata

9. A large, positively charged molecule is most likely to cross a lipid bilayer via which process?
   A. Simple diffusion
   B. Osmosis
   C. Facilitated diffusion
   D. Complex diffusion
   E. Quorum sensing

10. Why does DNA migrate to the positive electrode during gel electrophoresis?
    A. The nitrogenous bases are negatively charged
    B. The nitrogenous bases are positively charged
    C. The phosphate groups are negatively charged
    D. The phosphate groups are positively charged
    E. The ribose sugars are negatively charged

11. Which of the following DNA strands have the highest T_m:
    A. TAGATATA
    B. GCGGGTGC
    C. TGCTGCAC
    D. GTGACTTA
    E. GTATTTTG

12. In mice, brown fur is recessive to black fur, and albinism is recessive to coloration. A mouse that is recessive for both traits appears albino. What best describes this phenomenon?
    A. Pleiotropy
    B. Epistasis
    C. Polygenetic inheritance
    D. Expressivity
    E. Nondisjunction

13. If two heterozygous individuals mate, what is the percentage of offspring that will express the dominant trait?
    A. 0%
    B. 25%
    C. 50%
    D. 75%
    E. 100%

14. In photosystem II, chlorophyll serves as the:
    A. Prosthetic group
    B. Coenzyme
    C. Inhibitor
    D. Substrate
    E. Activator

15. How many ATP are produced by the glycolysis of two maltose molecules?
    A. 2
    B. 4
    C. 8
    D. 12
    E. 16

16. Which pair of anatomical traits is the best example of homologous structures?
    A. Human eye and squid eye
    B. Bat wing and insect wing
    C. Bat wing and whale fin
    D. Snake hindlimb bones and human appendix
    E. Dolphin dorsal fin and shark dorsal fin

17. What must be true for a population to be in Hardy-Weinberg equilibrium?
    A. Immigration
    B. Non-random mating
    C. No genetic drift
    D. Sexual selection
    E. Artificial selection

18. Which of the following is NOT a form of prezygotic isolation?
    A. Temporal isolation
    B. Ecological isolation
    C. Reproductive isolation
    D. Gamete isolation
    E. Behavioural isolation

19. A forest ecosystem is rapidly destroyed after a small wildfire spreads, but begins to re-populate almost immediately after the fire is extinguished. This ecosystem has:
    A. High resistance and high resilience
    B. High resistance but low resilience
    C. Low resistance but high resilience
    D. Low resistance and low resilience
    E. Rapid primary succession

20. Energy transfer between trophic levels in an ecosystem is inefficient mostly due to:
    A. Waste in the form of excrements
    B. Energy consumed by metabolism
    C. Waste in the form of heat
    D. Energy stored as biomass
    E. Waste in the form of kinetic energy

21. Ants feed on honeydew produced by aphids. In return, the ants protect aphids from predation by ladybugs. This relationship can be described as:
    A. Predation
    B. Herbivory
    C. Amensalism
    D. Commensalism
    E. Mutualism

22. You plate a colony of *E. coli* onto an agar plate and observe the bacteria growing slowly. What growth phase is this population in?
    A. Log phase
    B. Lag phase
    C. Exponential phase
    D. Stationary phase
    E. Death phase

23. Which of the following is NOT a chordate:
    A. Shark
    B. Lobster
    C. Fish
    D. Crocodile
    E. Snake

24. During the double fertilization of angiosperms, why is the endosperm triploid?
    A. Because two sperm fuse with two polar bodies
    B. Because two sperm fuse with one polar body
    C. Because one sperm fuses with two polar bodies
    D. Because one sperm fuses with one polar body
    E. Because nondisjunction has occurred

25. Type ___ pneumocytes secrete surfactant, which _____ lung compliance.
    A. One; Increase
    B. One; Decrease
    C. Two; Increase
    D. Two; Decrease

26. What is the purpose of the papillary muscles?
    A. Pull on Bachmann's bundle to close the atrioventricular valves
    B. Conduct electrical signals to the Purkinje fibres
    C. Pull on chordae tendineae to close the atrioventricular valves
    D. Conduct electrical signals to the atrioventricular node
    E. Pump blood during systole

27. Which of the following is NOT a function of the lymphatic system?
    A. Drain excess interstitial fluid
    B. Mature leukocytes
    C. Filter blood
    D. Fat absorption
    E. Prevent edema

28. What is the most abundant leukocyte in the bloodstream?
    A. Mast cells
    B. Eosinophils
    C. Red blood cells
    D. Dendritic cells
    E. Neutrophils

29. What occurs during the repolarization phase of an action potential?
    A. Sodium channels open and potassium channels close, allowing an inflow of Na^+
    B. Sodium channels close and potassium channels open, allowing an outflow of K^+
    C. Sodium channels close and potassium channels open, allowing an inflow of K^+
    D. Sodium channels open and potassium channels close, allowing an outflow of Na^+
    E. Sodium and potassium channels close

30. Tadpoles will die when placed in salt water, because their cells are _____ to the surroundings, causing _____.
    A. Hypertonic; Plasmolysis
    B. Hypotonic; Plasmolysis
    C. Isotonic; Apoptosis
    D. Hypertonic; Cytolysis
    E. Hypotonic; Cytolysis

31. Which of the following strata is NOT a layer of the epidermis?
    A. Corneum
    B. Granulosum
    C. Basale
    D. Reticular
    E. Lucidum

32. In the male reproductive system, which structure is responsible for secreting alkaline fluid that helps neutralize the acidity of the vaginal tract?
    A. Bulbourethral glands
    B. Seminiferous tubules
    C. Prostate
    D. Testes
    E. Spermatogonium

33. What mechanism is responsible for preventing polyspermy in humans?
    A. Acrosome reaction
    B. Electrical block
    C. Determinate cleavage
    D. Cortical reaction
    E. Medullary reaction

34. Which of the following structures is NOT derived from the mesoderm?
    A. Heart
    B. Trachea
    C. Testes
    D. Dermis
    E. Tonsils

35. What extraembryonic membrane is responsible for waste management in egg-laying amniotes?
    A. Chorion
    B. Yolk sac
    C. Allantois
    D. Amnion
    E. Corona radiata

36. A dog can be trained to salivate in response to hearing a bell. It can also be trained to navigate a maze to retrieve a treat. These are examples of _____ and _____ learning, respectively.
    A. Habituation; Observational
    B. Sensitization; Insight
    C. Operant; Classical
    D. Observational; Operant
    E. Classical; Operant

37. What is the function of guard cells?
    A. Defence against herbivory
    B. Secrete wax, which waterproofs the cuticle
    C. Control airflow in leaves
    D. Carbohydrate storage
    E. C4 photosynthesis

38. Which of the following characteristics are unique to angiosperms?
    A. Cones, double fertilization, and pollination
    B. Pollination, flowers, and gametophytes
    C. Vasculature, flowers, and double fertilization
    D. Fruit, double fertilization, and flowers
    E. Vasculature, fruit, and flowers

39. During angiosperm fertilization, how does the pollen reach the embryo sac?
    A. Travels through the micropyle
    B. Initiates an acrosome reaction
    C. Travels through the pollen tube
    D. Initiates a cortical reaction
    E. Travels via flagellar motion

40. A population consisting of which of the following species would most likely exhibit a uniform distribution?
    A. Dandelions
    B. Honey bees
    C. Humans
    D. Conifers
    E. Termites

41. Which of the following is NOT a diatomic gas?
    A. Fluorine
    B. Nitrogen
    C. Oxygen
    D. Neon
    E. Iodine

42. List the following elements in order of increasing atomic radius: Ag, Na, Rb, Li, O.
    A. O < Li < Na < Rb < Ag
    B. O < Li < Na < Ag < Rb
    C. O < Na < Li < Ag < Rb
    D. O < Na < Li < Rb < Ag
    E. Na < O < Li < Rb < Ag

43. What is the maximum number of electrons that the p subshell can hold?
    A. 2
    B. 4
    C. 6
    D. 8
    E. 10

44. If the pressure of a gas is tripled while holding temperature constant, the volume is:
    A. Reduced to 1/2
    B. Reduced to 1/3
    C. Doubled
    D. Tripled
    E. Unchanged

45. If an orbital's principle quantum number is 3, then which of the following can NOT be its angular quantum number?
    A. 1
    B. 0
    C. 2
    D. 3

46. What is the correct electron configuration for sodium?
    A. $1s^2 2s^2 2p^6 3s^2$
    B. $1s^2 2s^2 2p^6 3s^1$
    C. $1s^2 2s^2 2p^6$
    D. $1s^2 2s^2 2p^5$
    E. $1s^1 2s^1 2p^6 3s^1$

47. What bond angle does SO_3 have?
    A. 104.5
    B. 90
    C. 120
    D. 105
    E. 109.5

48. Which set of coefficients would balance the following reaction?

$$\_\ NaBr + \_\ Cl_2 \rightarrow \_\ NaCl + \_\ Br_2$$

A. 2, 1, 2, 1
B. 2, 2, 2, 1
C. 1, 1, 1, 1
D. 1, 2, 1, 2

49. An alkaline buffer solution may consist of which of the following?

A. A strong acid and its conjugate base
B. A weak acid and its conjugate acid
C. A strong base and its conjugate acid
D. A weak base and its conjugate acid

50. According to the following equation, how many grams of H_2O will be produced when 10 g of CH_4 is combusted?

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

A. $\frac{(10)(2)(18)}{(16)}$
B. $\frac{(10)(18)}{(16)}$
C. $\frac{(10)(18)}{(16)(2)}$
D. $\frac{(16)}{(10)(2)(18)}$
E. $\frac{(12)(2)(18)}{(16)}$

51. Under standard conditions, which of the following is true for a reaction that has a positive enthalpy change (ΔH)?

A. The reaction will be non-spontaneous for any value of ΔS
B. The reaction will be spontaneous for any value of ΔS
C. The reaction will be spontaneous if $\Delta S < \Delta H$
D. The reaction will be spontaneous if $\Delta H < \Delta S$
E. The reaction will be spontaneous if $\Delta S = \Delta H$

52. A 100 g sample of aluminum was heated from 20°C to 50°C with 1 kJ of energy. What is the specific heat of aluminum in J/g°C?

A. $\frac{(100)(30)}{(1000)}$
B. $\frac{(1000)(30)}{(100)}$
C. $\frac{(1000)}{(100)(30)}$
D. $\frac{(100)}{(1000)(30)}$
E. $\frac{(1)}{(100)(30)}$

53. Sublimation is a ____ process describing a transformation from ____ to ____.

A. Chemical, Reducing Agent, Oxidizing Agent
B. Chemical, Reactant, Product
C. Physical, Gas, Solid
D. Physical, Gas, Liquid
E. Physical, Solid, Gas

54. Which of the following is NOT an intermolecular force?

A. Ion-dipole interactions
B. Hydrogen bonding
C. Ionic bonding
D. London dispersion forces
E. Dipole-induced dipole

55. How many molecules of aluminum are in two moles of Al_2O_3?

A. $(6.02 \times 10^{23})(2)(3)$
B. $(6.02 \times 10^{22})(2)(2)$
C. $(6.02 \times 10^{23})(2)$
D. $(2.06 \times 10^{23})(2)(2)$
E. $(6.02 \times 10^{23})(2)(2)$

56. Assuming the following reaction is at equilibrium, what will occur if the volume of the system is increased?

$$2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$$

A. $[SO_2]$ increases
B. $[SO_3]$ increases
C. $[O_2]$ increases
D. $[SO_2]$ decreases
E. $[SO_3]$ decreases

57. What form of radioactive decay involves the production of a high-energy photon?

A. Alpha decay
B. Beta positive decay
C. Gamma decay
D. Beta negative decay

58. A sealed cylinder contains 1 mol of N_2, 3 mol of O_2, and 2 mol of Cl_2. If the total pressure is 350 kPa, what is the partial pressure of Cl_2 in kilopascals?

A. $\left(\frac{2}{6}\right)(350)$
B. $\left(\frac{2}{4}\right)(350)$
C. $\left(\frac{6}{2}\right)(350)$
D. $\left(\frac{4}{6}\right)(350)$
E. $\left(\frac{2}{6}\right)(350000)$

59. Which of the following best describes a Lewis base?

A. Proton acceptor
B. Electron acceptor
C. Proton donor
D. Electron donor
E. Hydroxyl group donor

60. Given the experimentally determined initial rates, what is the rate law for the following reaction?

$$A + B \rightarrow C$$

Trial	[A]	[B]	Initial Rate
1	0.5 M	0.3 M	2.0×10^{-2} M/s
2	2 M	0.3 M	8.0×10^{-2} M/s
3	0.5 M	0.6 M	8.0×10^{-2} M/s

A. $r = k[A][B]$
B. $r = k[A]^2[B]$
C. $r = k[A]^2[B]^2$
D. $r = k[A][B]^2$
E. $r = k[A]^3[B]^2$

61. Which of the following is a colligative property?

A. Specific heat capacity
B. Color
C. Viscosity
D. Surface tension
E. Osmotic pressure

62. What is the oxidation state of Ag_2S in the following redox reaction?

$$Ag + H_2S \rightarrow Ag_2S + H_2$$

A. 0
B. +1
C. −2
D. +2
E. −1

63. When homogenized cow liver is added to hydrogen peroxide, oxygen gas and water is produced. Cow liver contains the catalase enzyme. What is the function of catalase?
    A. Decreases the reaction's rate constant
    B. Increases the reaction's rate constant
    C. Shifts the reaction equilibrium
    D. Decreases activation energy
    E. Increases activation energy

64. Which of the following compounds is polar?
    A. CO_2
    B. CH_4
    C. CH_2O
    D. BF_3
    E. PCl_5

65. How many resonance structures can be drawn for the compound NO^{3-}?
    A. 0
    B. 1
    C. 2
    D. 3
    E. 4

66. When a gas is exposed to a temperature and pressure beyond the _, the gas turns into a _.
    A. Equivalence Point; Subcritical Fluid
    B. Triple Point; Supercritical Fluid
    C. Critical Point; Subcritical Fluid
    D. Half-Equivalence Point; Supercritical Fluid
    E. Critical Point; Supercritical Fluid

67. In the following nuclear reaction, what is the identity of the second product?

$$^{238}_{92}\text{U} \rightarrow {}^{4}_{2}\text{He}^{2+} + \_$$

    A. $^{238}_{90}\text{Th}$
    B. $^{234}_{90}\text{Th}$
    C. $^{234}_{92}\text{Th}$
    D. $^{234}_{94}\text{Pu}$
    E. $^{234}_{91}\text{Pa}$

68. The equivalence point is defined as:
    A. Equal moles of the acid and its conjugate
    B. Equal moles of the titrate and its conjugate
    C. Equal moles of the acid and base
    D. pH of 7
    E. Equal volumes of the titrant and titrate

69. Which of the following compounds is NOT ionic?
    A. NaCl
    B. HBr
    C. K_2S
    D. NH_3
    E. KOH

70. If the bond length of H_2 is 74 pm and the bond length of Cl_2 is 199 pm, what is the bond length of HCl?
    A. $\frac{74 + 74}{199}$
    B. $\frac{74 + 199}{199}$
    C. $74 + 199$
    D. $\frac{74 + 199}{2}$
    E. $\frac{74 + 199}{4}$

STOP

You have completed the SNS section of the DAT.
You will receive a 10 min break before the next section.

FULL-LENGTH 1 LOWER DIFFICULTY

PERCEPTUAL ABILITY TEST

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Perceptual Ability Test:

1. Each item is a question requiring perceptual skills. This section contains six sub-sections. Read the specific instructions before starting each sub-section. Decide which answer choice is correct and bubble in the corresponding circle on the answer sheet. **Do not stop after each subsection; continue to answer all 90 questions**
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 60 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. **DO NOT TURN PAST THE STOP PAGE AND ON TO THE NEXT SECTION UNTIL INSTRUCTED**
6. At the end of this section, the answer sheet is collected. The booklet remains at your table for use during the next section

TIME LIMIT:
60 minutes

TEST NAME:
PAT

TEST NUMBER:
01

This is a DAT simulation.

PART 1

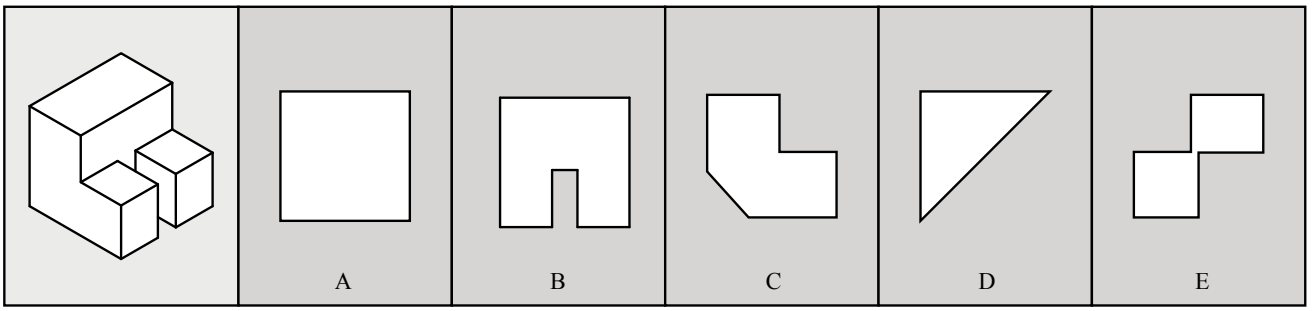
For questions 1 to 15, the test contains questions similar to the example shown below. A three-dimensional object is shown in the light-coloured box on the left. Various two-dimensional answer choices are shown on the right, in dark-coloured boxes.

In each question, your task is to visualize how the three-dimensional object would look from all sides. Then from the answer choices, you must choose a two-dimensional keyhole which would allow the three-dimensional object to pass through. Finally, bubble in the corresponding circle on your answer sheet.

The rules are as follows:

1. Before passing through the keyhole, the object may be rotated in any direction
2. Once the object starts passing through the keyhole, it cannot be rotated
3. Both the object and the keyhole are drawn to scale. They should have the same dimensions
4. There are no irregularities in the hidden parts of the objects

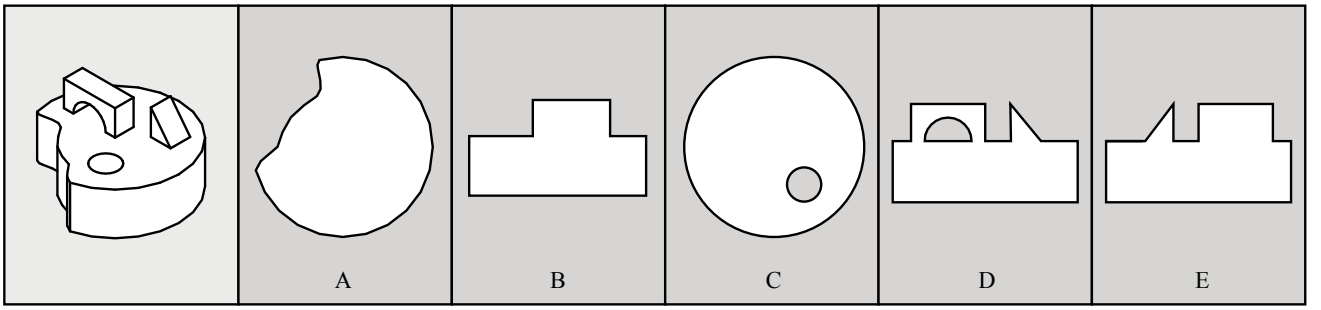
Example Question (Do NOT mark the answer to this example on your answer sheet)



The correct answer is B because the object would pass through this keyhole if the bottom or top side was rotated and inserted first

Please proceed to the questions

1.



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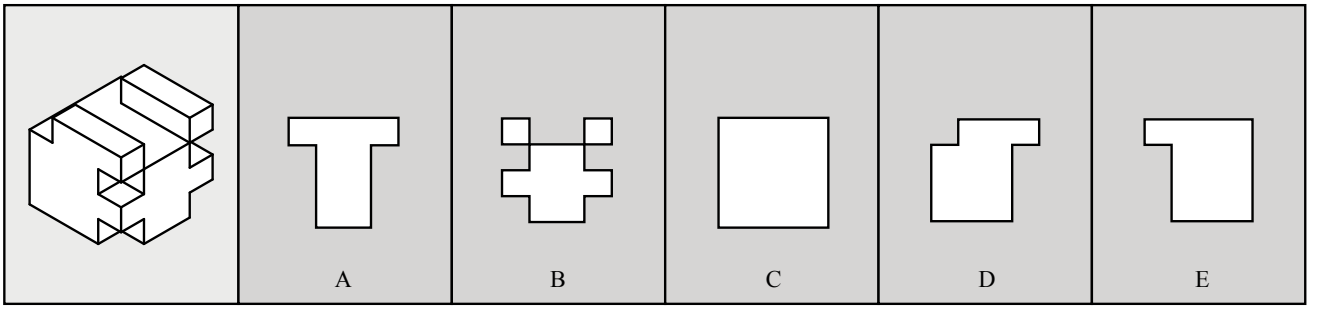

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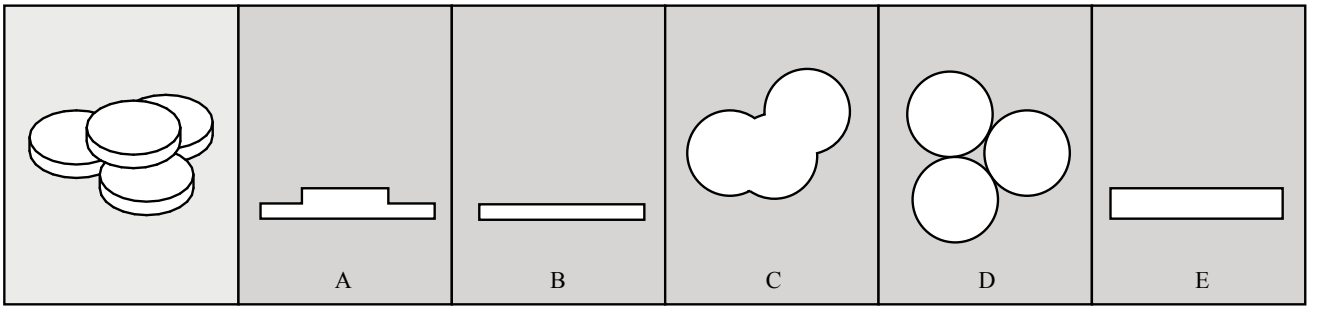

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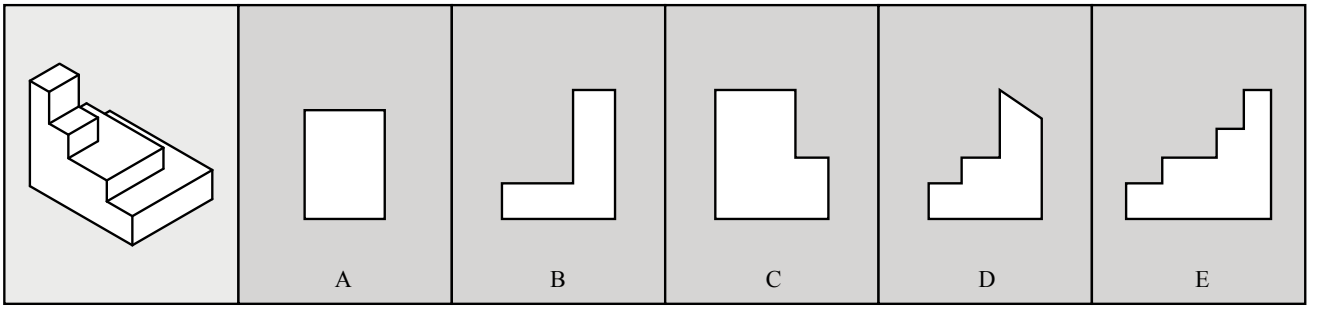

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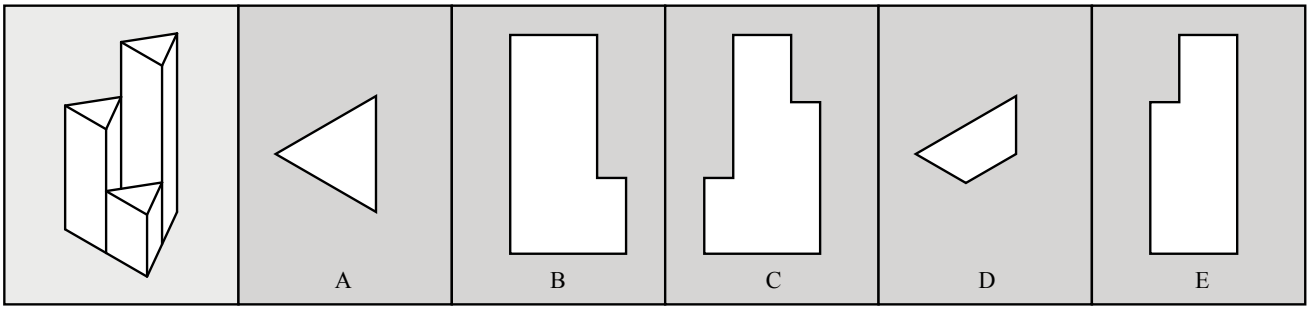

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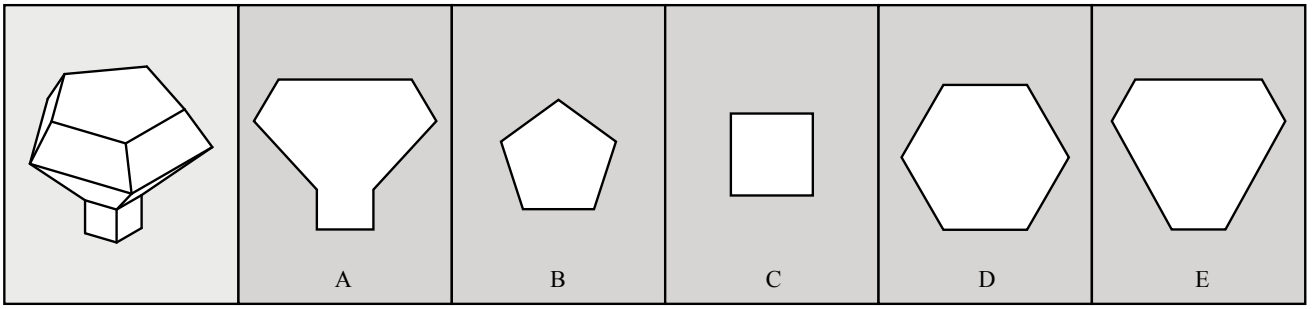

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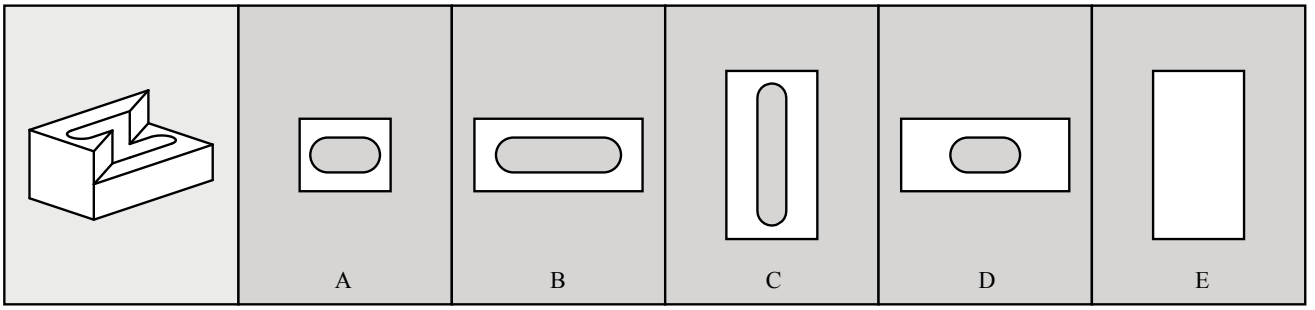

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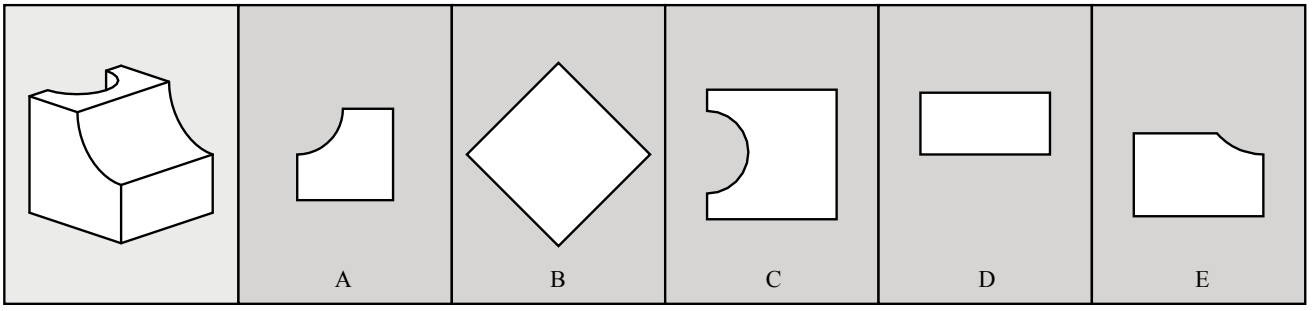

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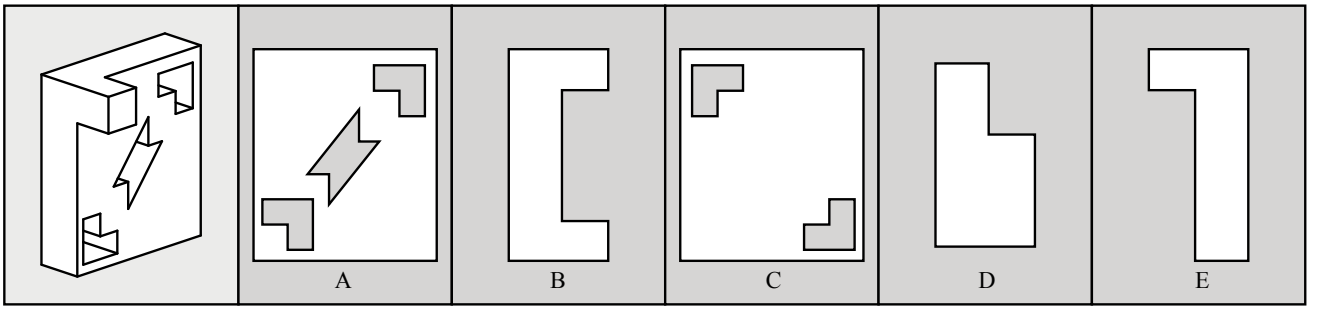

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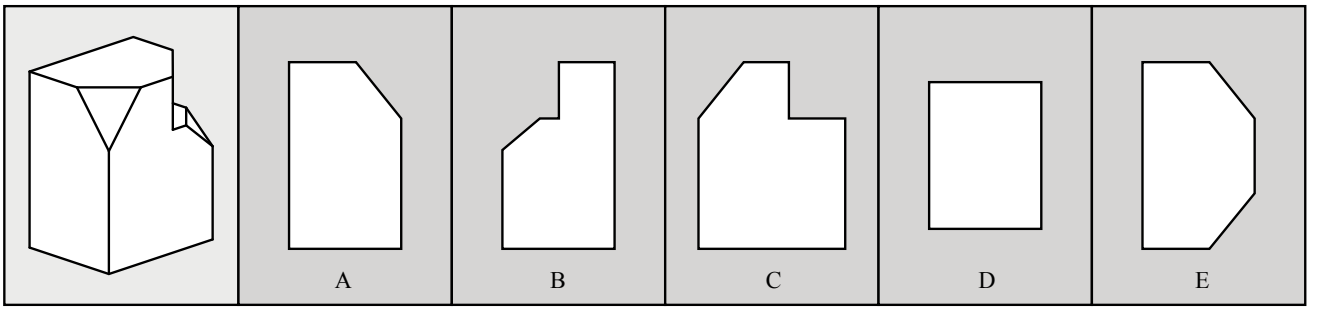

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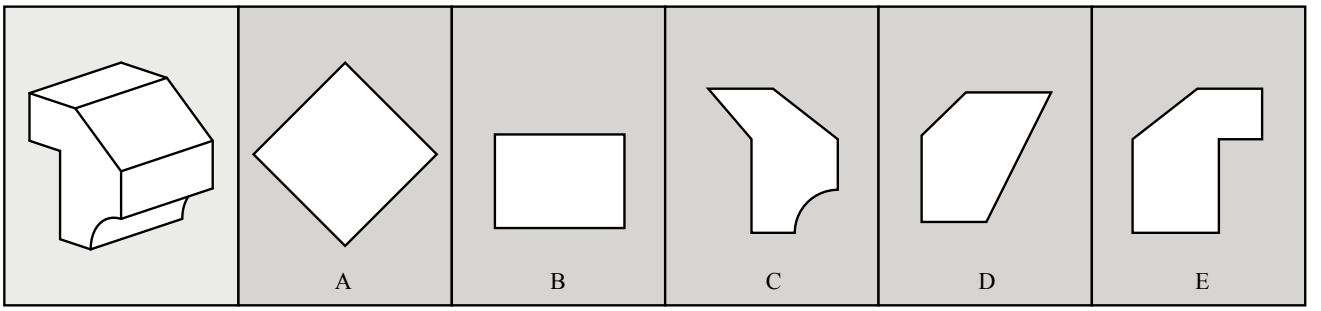

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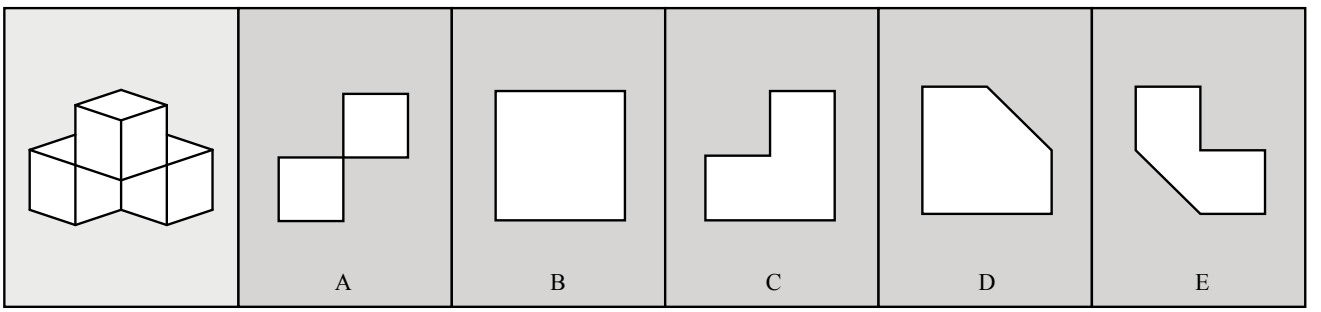

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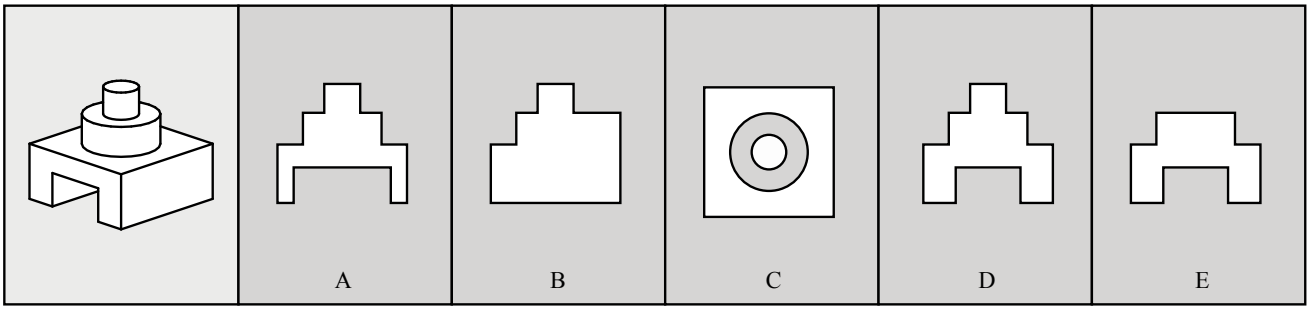

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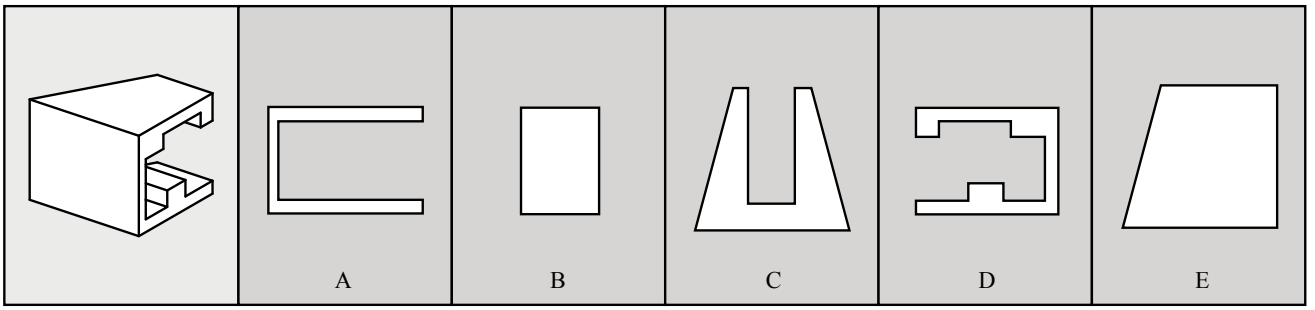

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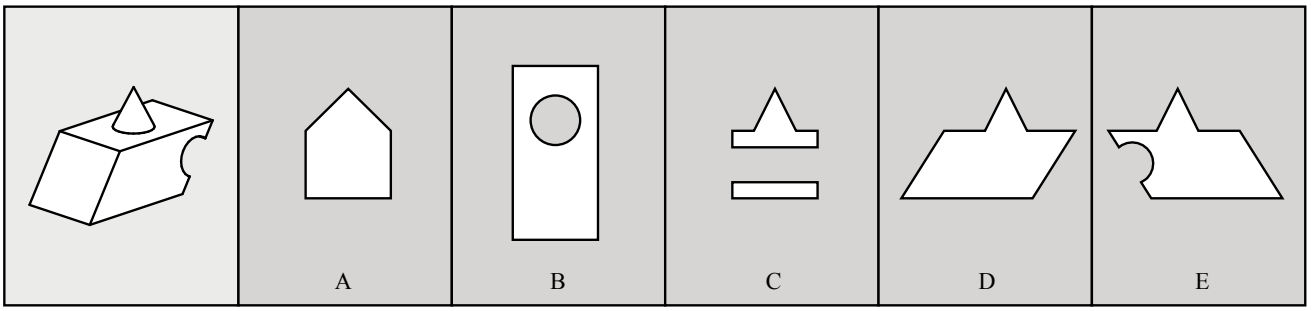
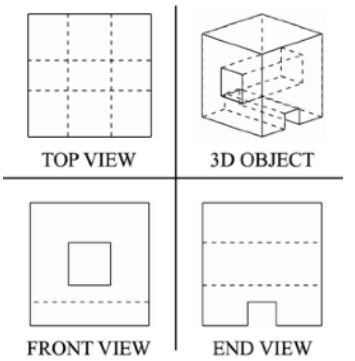


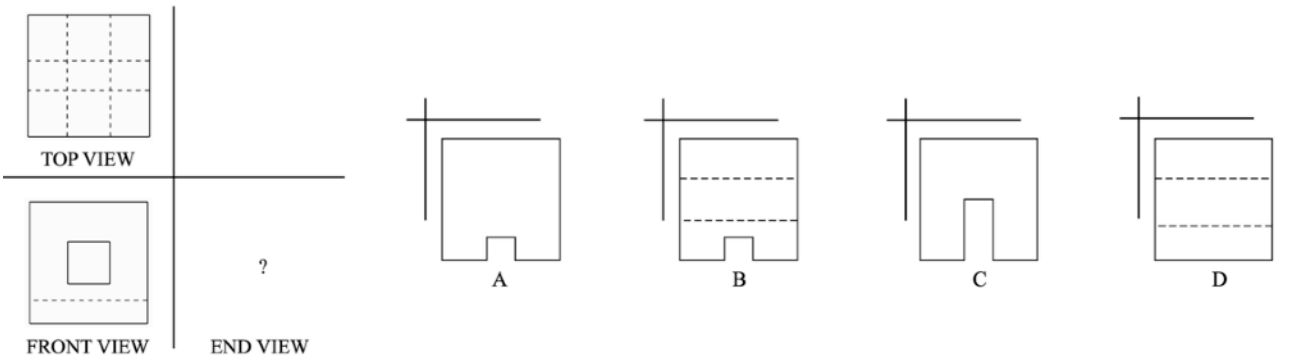
PART 2

For questions 16 to 30, the test contains questions similar to the example shown below. The top, front, and end projections of a three-dimensional object are shown. Edges that are obscured by parts of the object are shown as dotted lines, while edges that can be directly seen are shown as solid lines.



In each question, one of the three projections will be missing. Your task is to choose the projection that would complete the set of three projections in a manner consistent with the three-dimensional object (not shown).

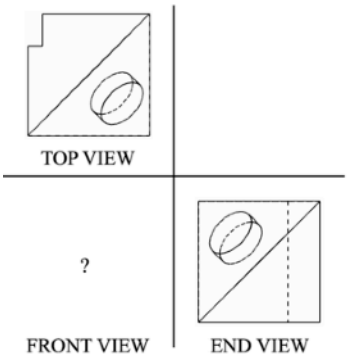
Example Question (Do NOT mark the answer to this example on your answer sheet)

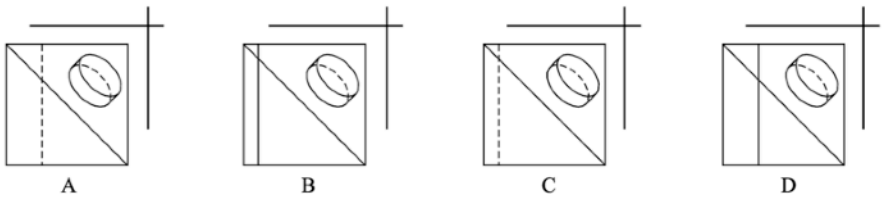


The correct answer is B because the object should have a rectangular tunnel at the bottom running left-to-right, and another square tunnel running front-to-back.

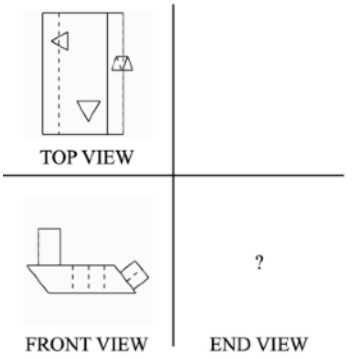
Please proceed to the questions

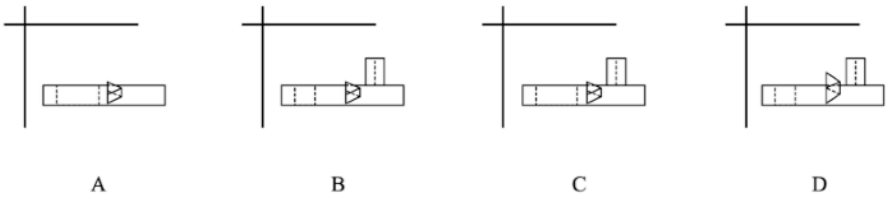
16. Choose the correct FRONT VIEW



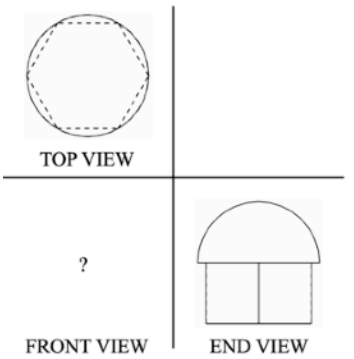


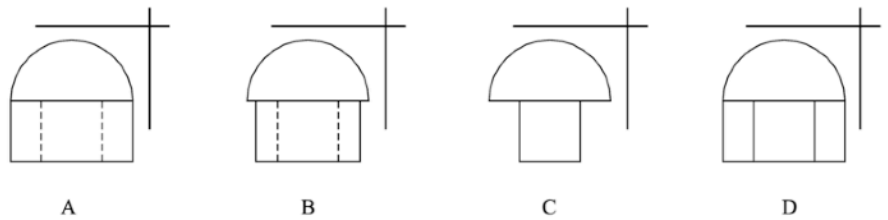
17. Choose the correct END VIEW



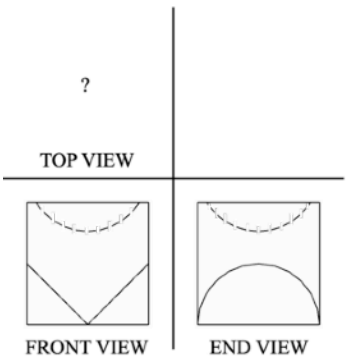


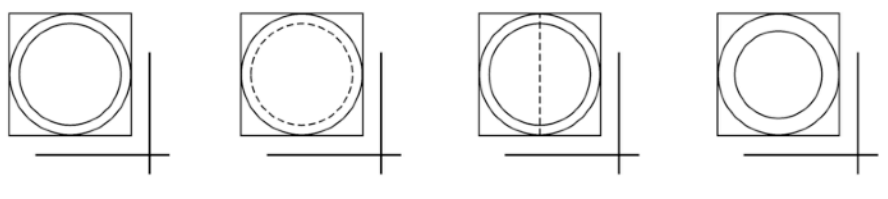
18. Choose the correct FRONT VIEW



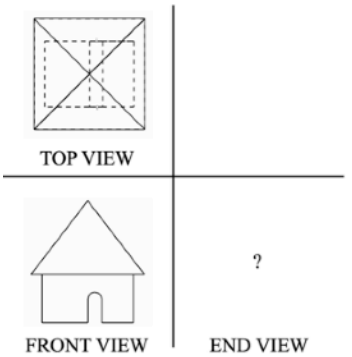


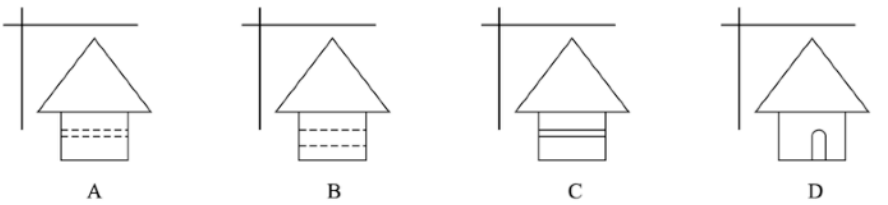
19. Choose the correct TOP VIEW





20. Choose the correct END VIEW





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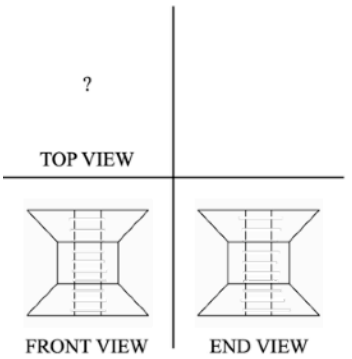

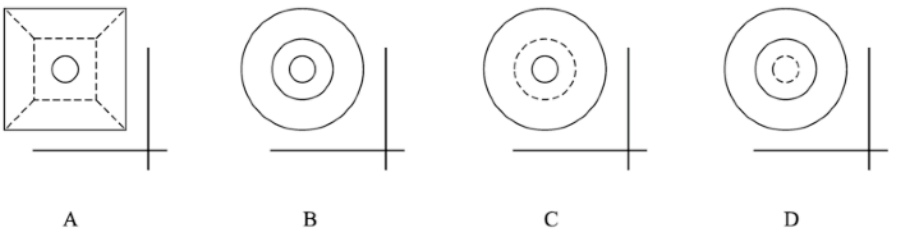

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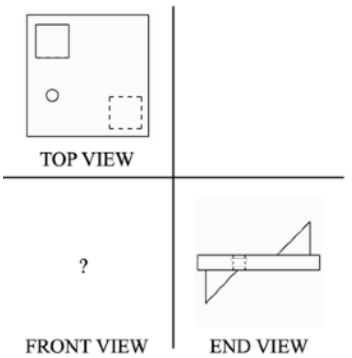

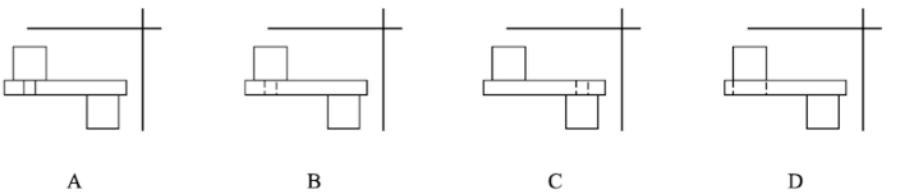

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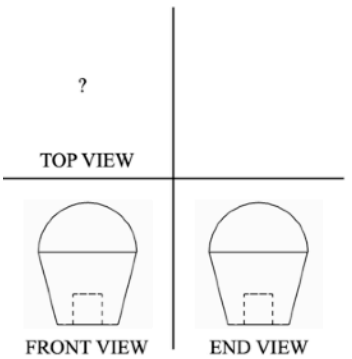

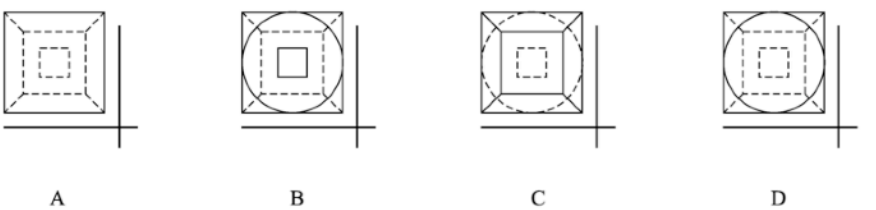

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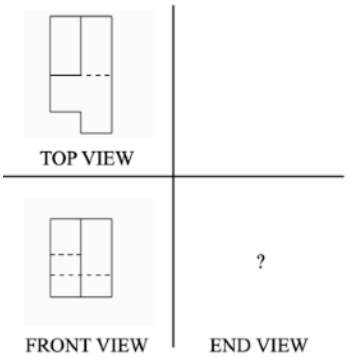

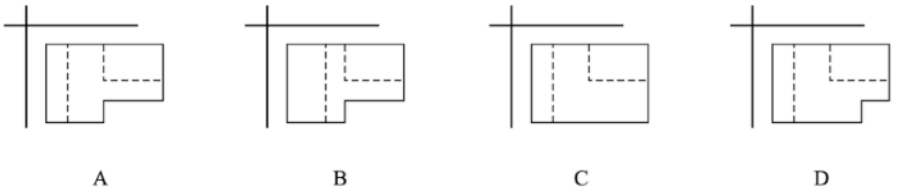

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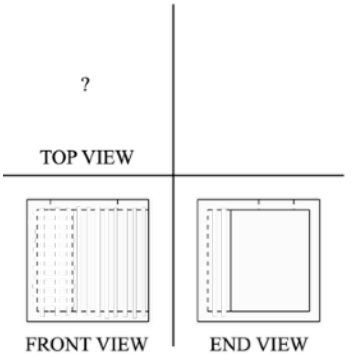

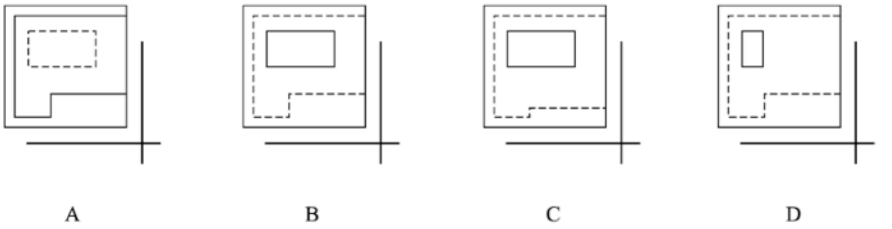

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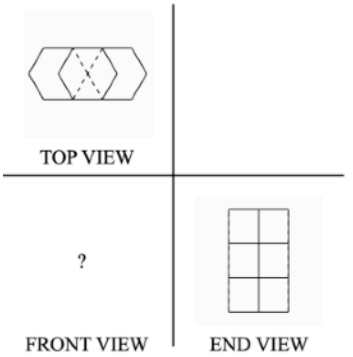

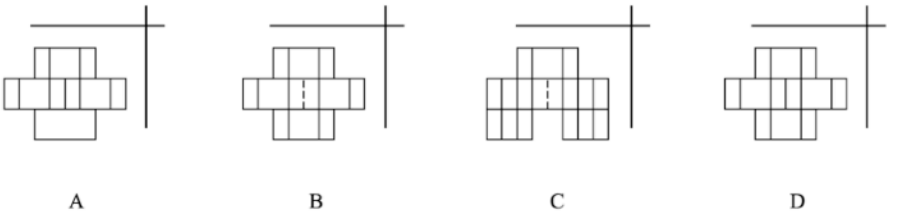

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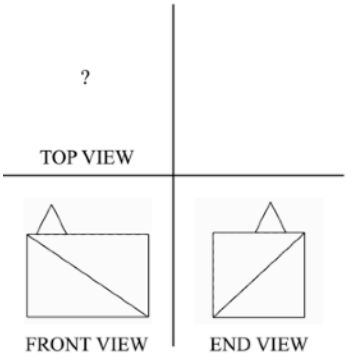

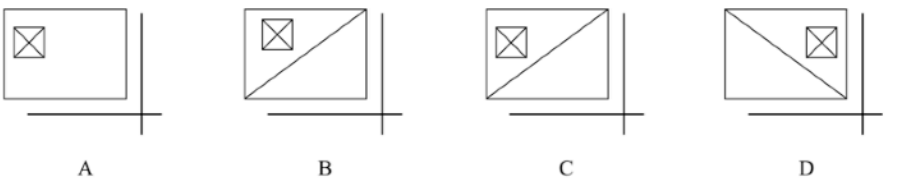

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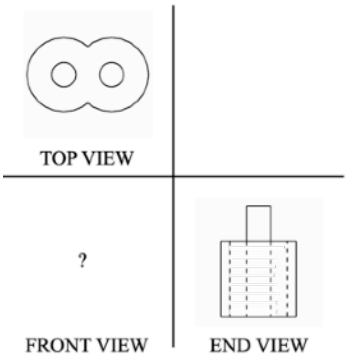
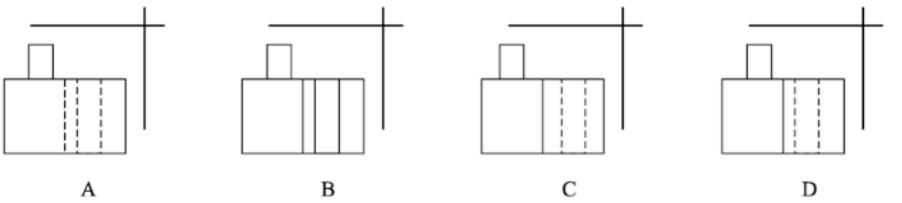
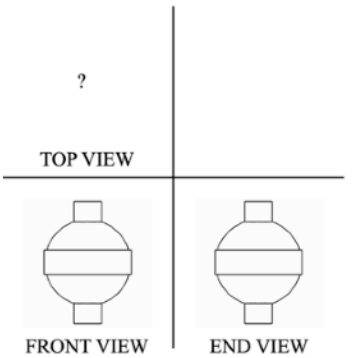
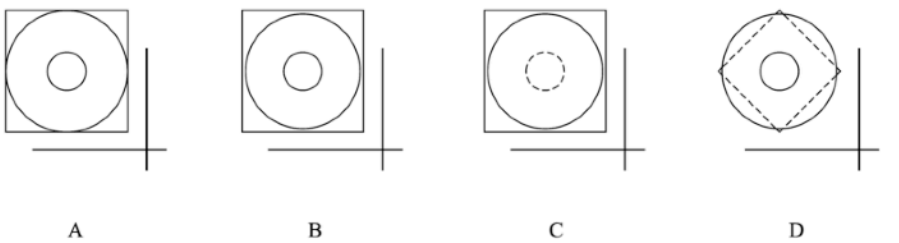




29. Choose the correct TOP VIEW





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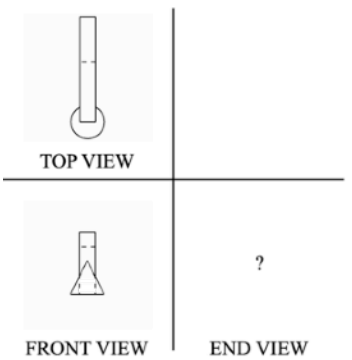
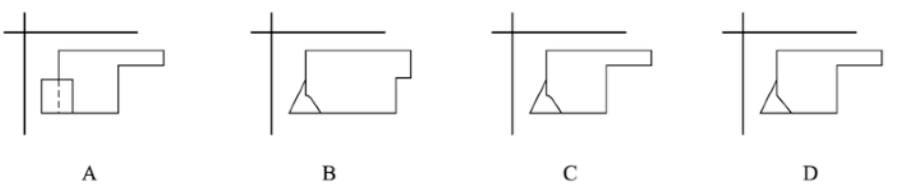
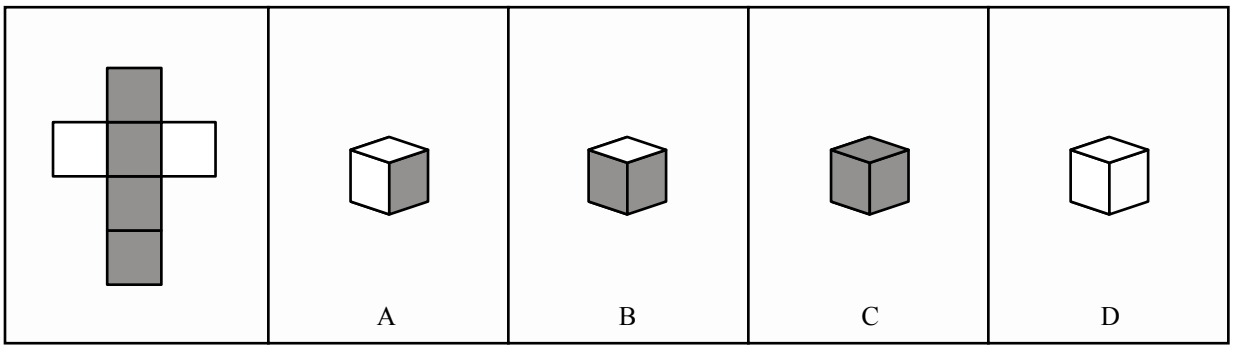




PART 6

For questions 76 to 90, the test contains two-dimensional patterns similar to the example shown below. This pattern is folded into the page, forming a three-dimensional figure. Your task is to mentally fold the two-dimensional patterns and select the correct three-dimensional figure out of the four presented.

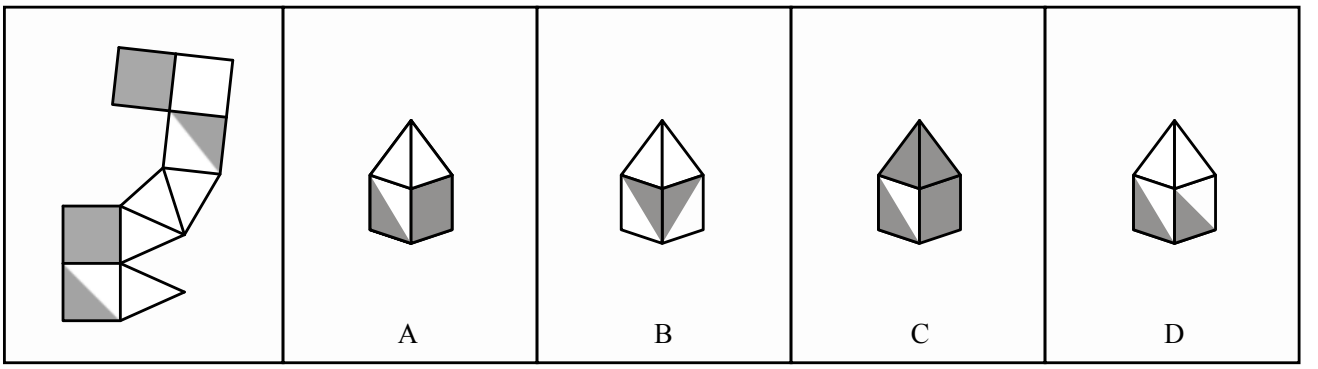
Example Question (Do NOT mark the answer to this example on your answer sheet)



The correct answer is B, since it represents both the correct shape and pattern of shaded faces in the folded three-dimensional figure. There should be four shaded sides that exist side-by-side, and two unshaded sides on opposite ends of the cube.

Please proceed to the questions

76.



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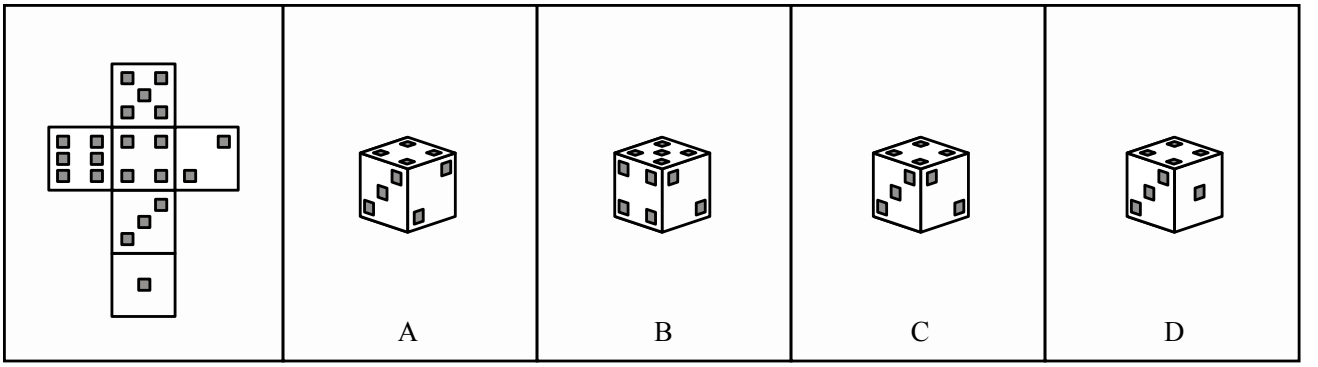
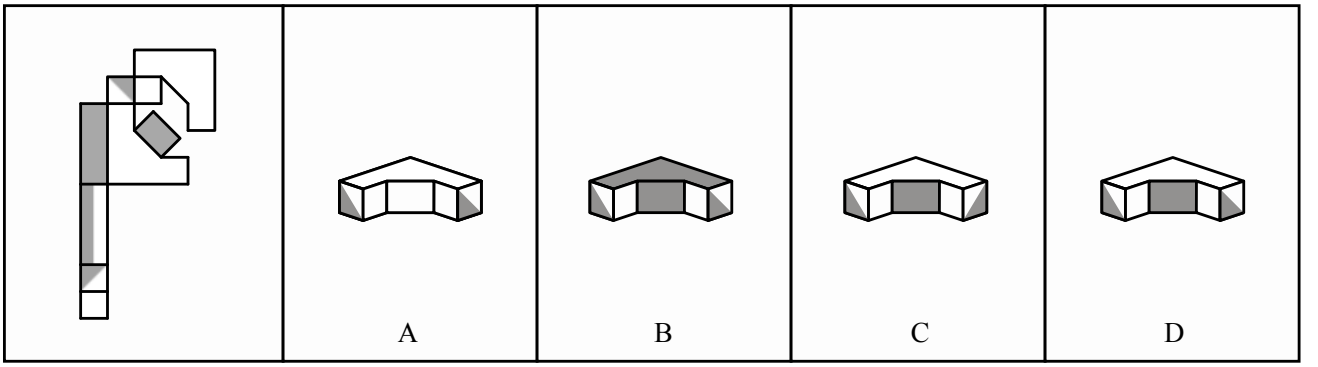


78.



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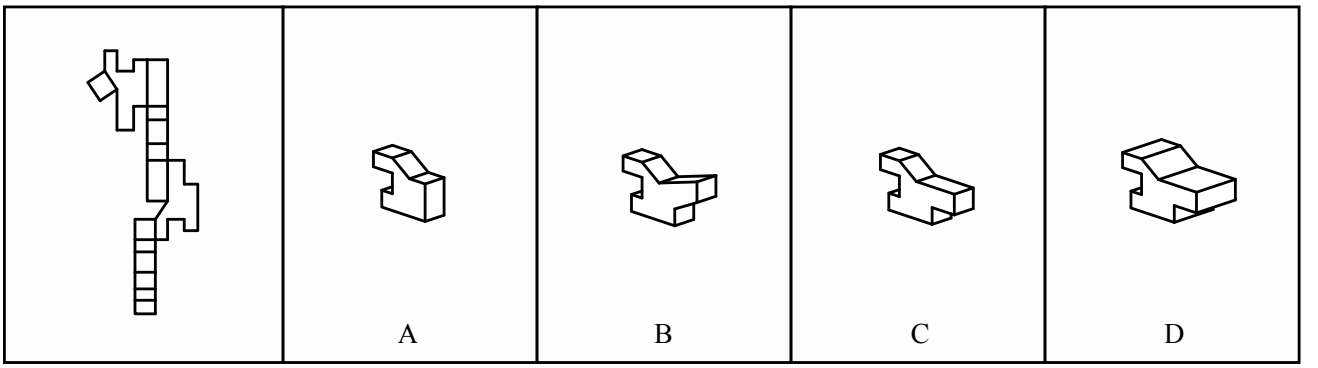

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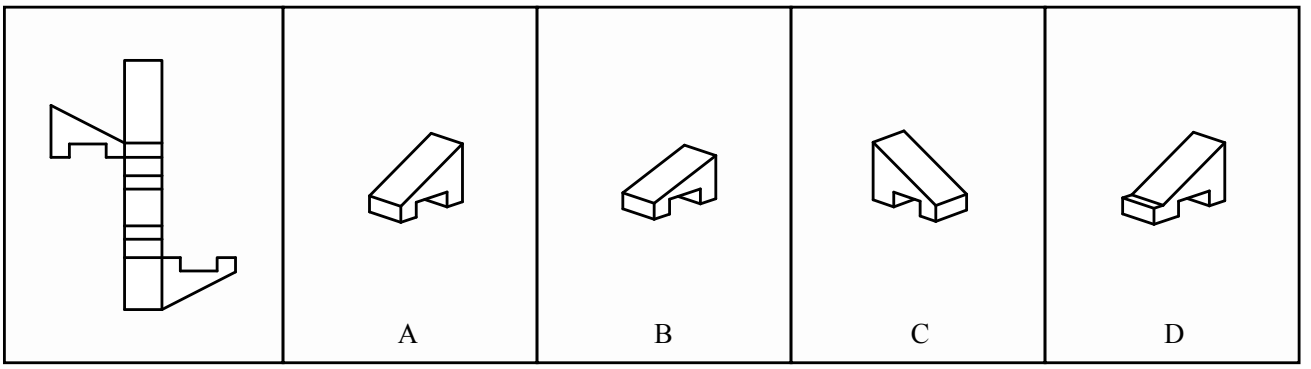

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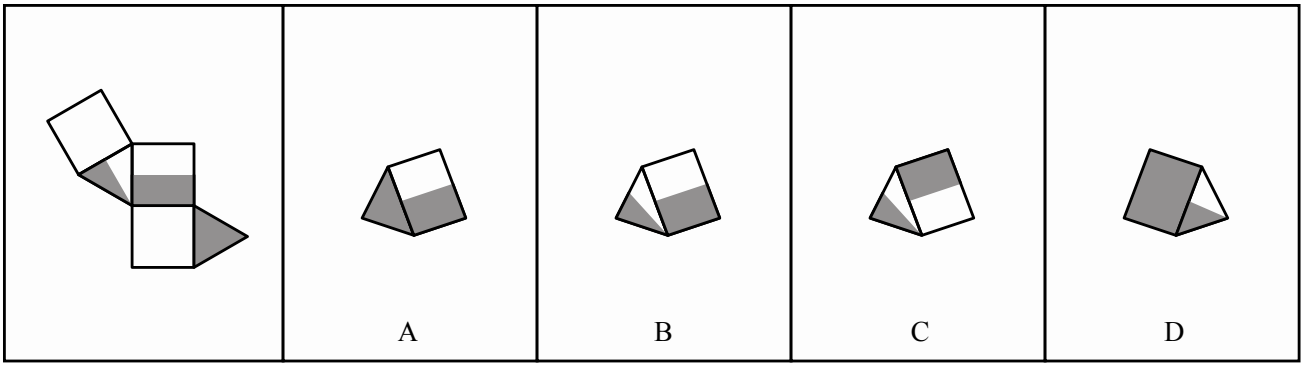

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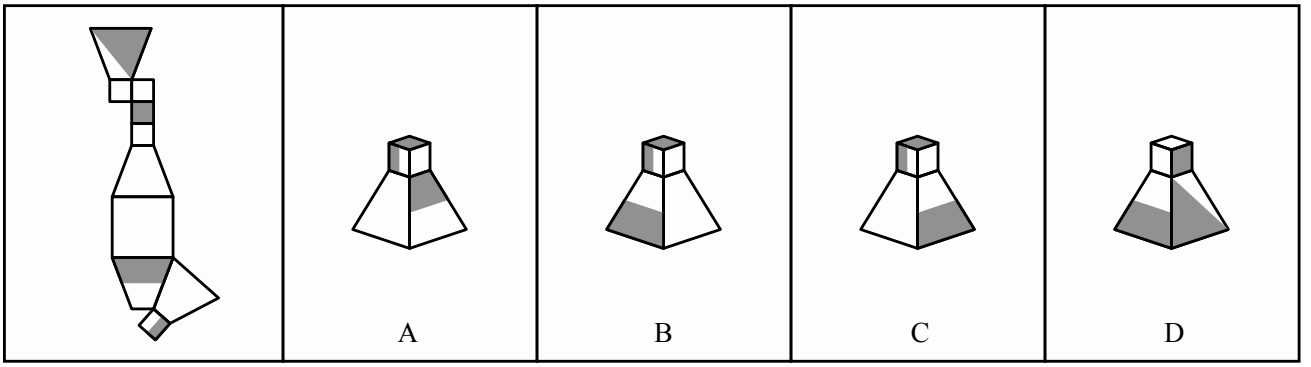
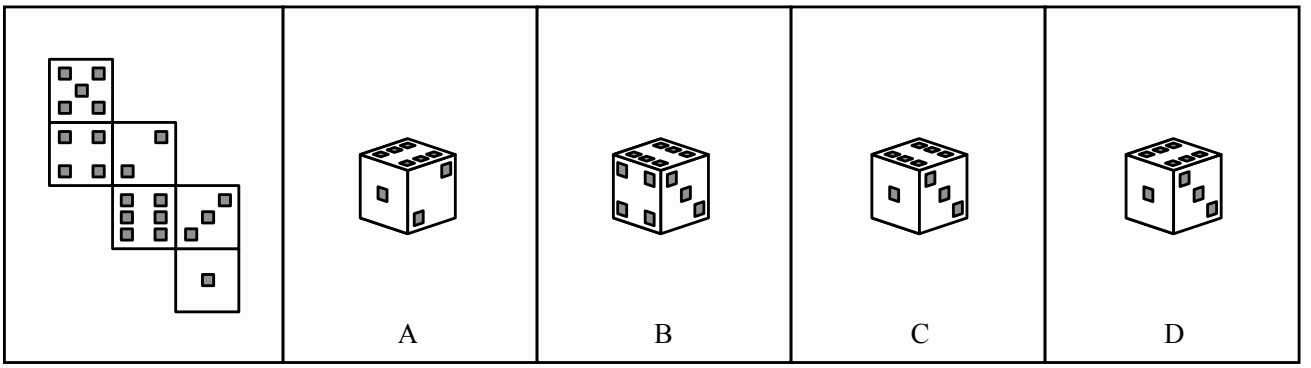


83.



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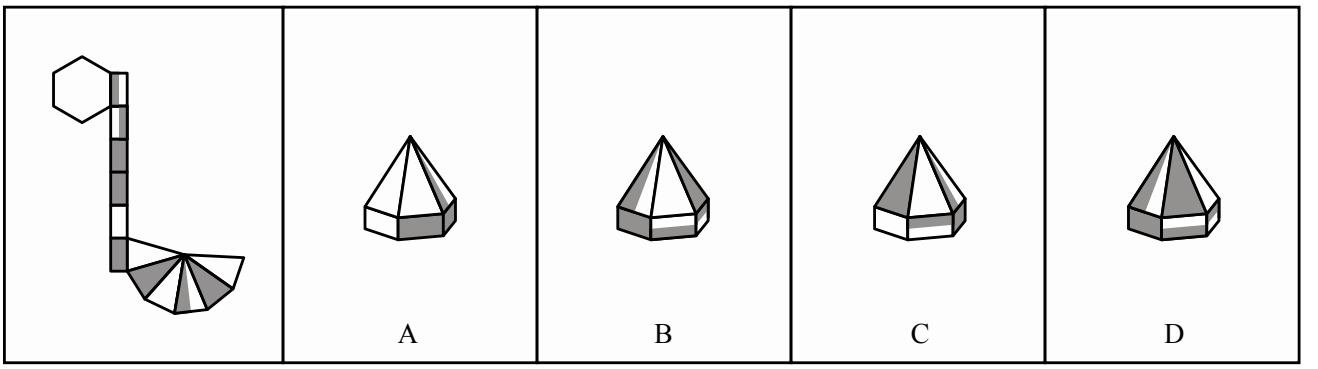

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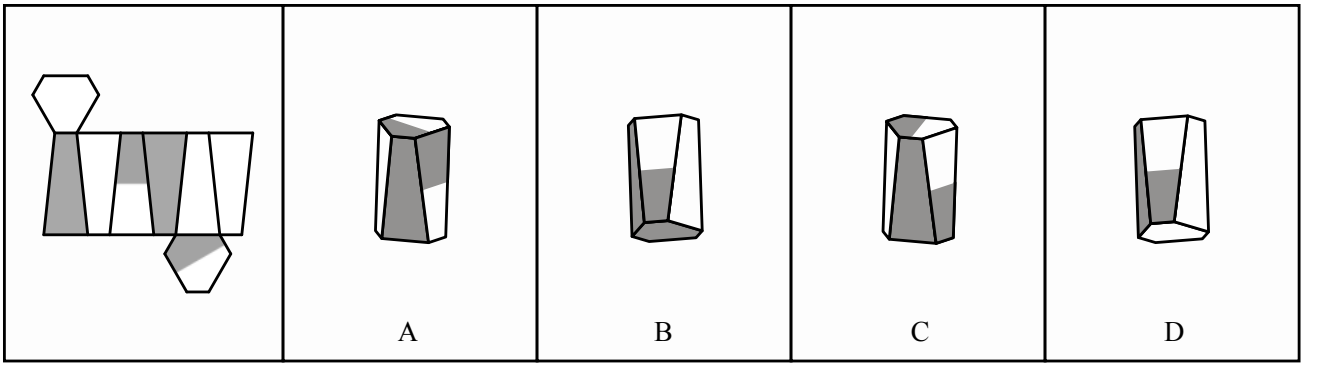

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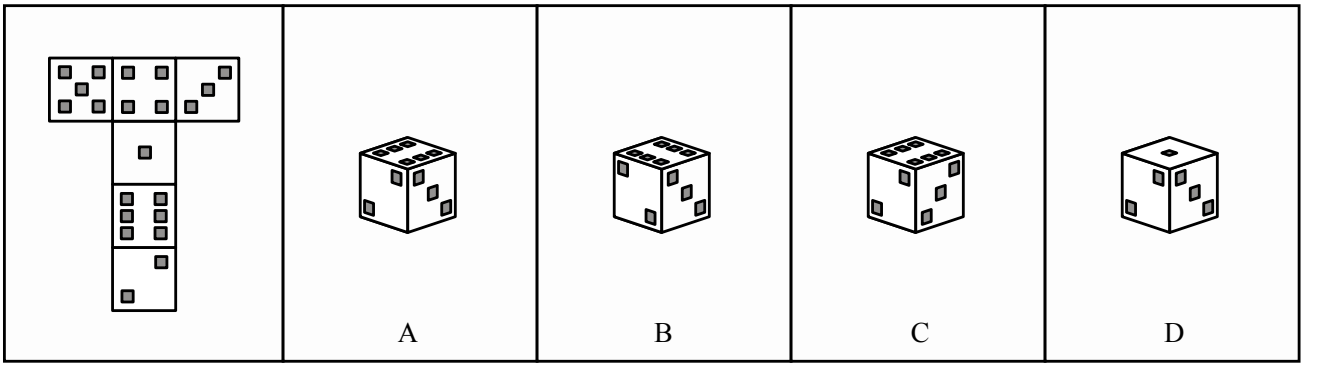

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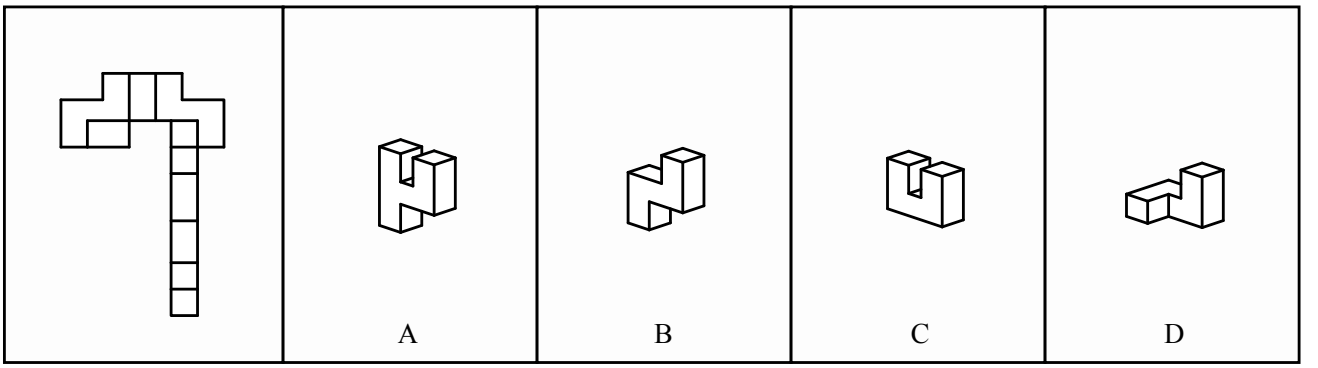

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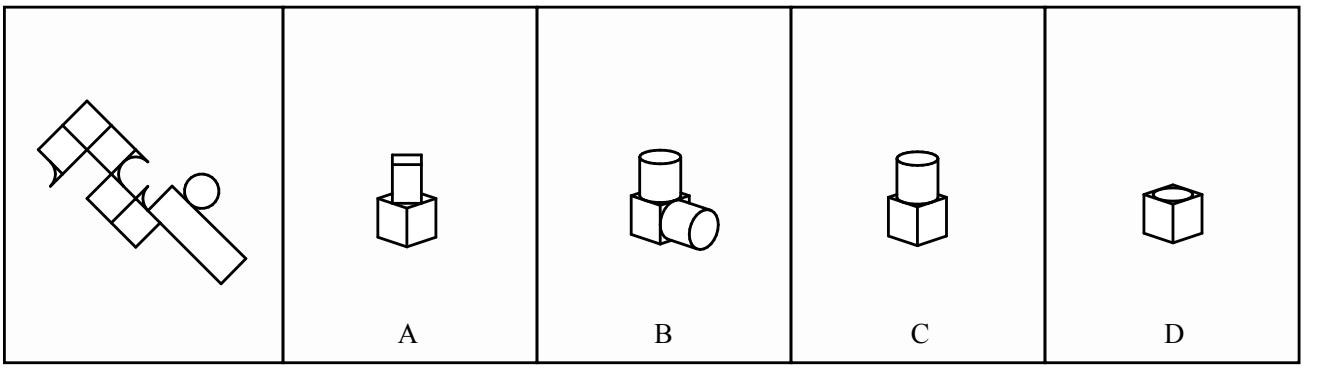
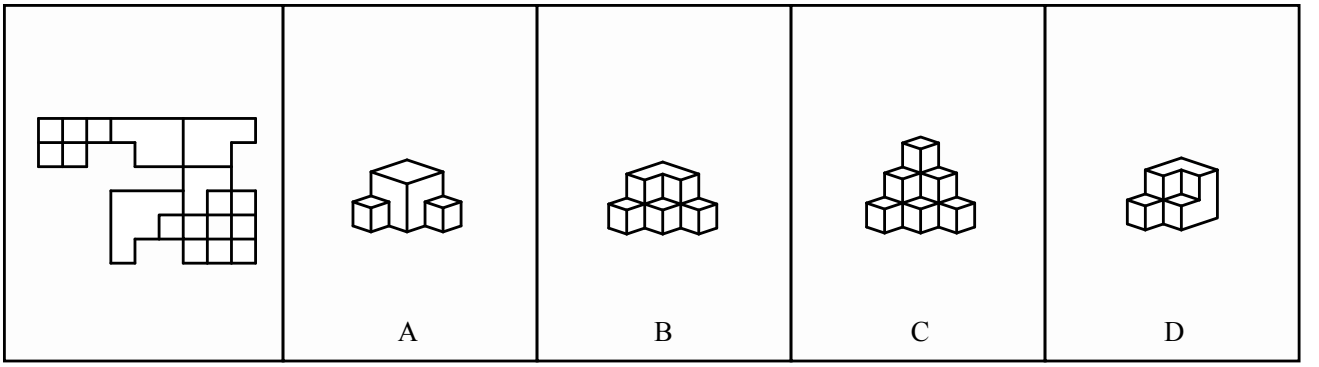
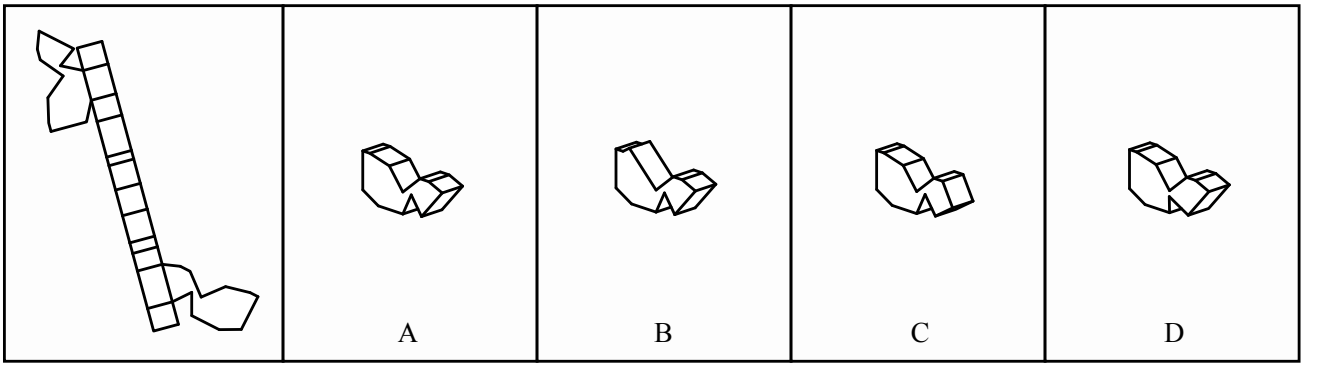


89.



90.



STOP

You have completed the PAT section of the DAT.
You will receive a 10 min break before the next section.

FULL-LENGTH 1 LOWER DIFFICULTY

READING COMPREHENSION TEST

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Reading Comprehension Test:

1. This test will evaluate your reading comprehension skills. It is composed of three passages. Reach each passage carefully, then proceed to the corresponding questions. Decide which of the presented choices best answers/completes the question/statement. Bubble in the appropriate answer choice on the answer sheet
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 50 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. At the end of this section, the answer sheet is collected and the Dental Aptitude Test simulation is now complete

TIME LIMIT:
50 minutes

TEST NAME:
RCT

TEST NUMBER:
01

This is a DAT simulation.

Passage 1

The Great Barrier Reef

The Australian coral reef, also known as the Great Barrier Reef, is the world's largest coral reef formation. It is also one of humankind's greatest conservation challenges globally, due to the effects of climate change. A coral reef is an aquatic ecosystem characterized by colonies of coral polyps. Coral reefs are unique because they consist of both biotic and abiotic structures that together have an impact on everything from niche environments to entire ecosystems. In terms of the biotic components of a reef system, coral is an invertebrate animal within the class Anthozoa of the phylum Cnidaria. Each visible coral "cluster" is actually composed of many individual polyps, an animal with tentacles arranged in a floral pattern around a gastric opening. The polyps feature a prominent exoskeleton, composed of secreted calcium carbonate. Many polyps can also coalesce, held together by the same substance. These congregations form a reef structure. According to Deloitte Access Economics, the "Great Barrier Reef is the largest living structure on Earth. It is as big in size as Japan, and bigger than the United Kingdom, Switzerland and the Netherlands put together".

Coral reef formations are complex ecosystems that are composed of multiple zones, hosting different kinds of habitats. Three distinct zones are recognized: the fore reef, reef crest, and inner reef. The inner reef is the shallowest zone, which experiences surges and tides. It is also the zone where corals grow the fastest, due to the abundance of sunlight, plankton, and turbulent water, which helps circulate nutrients and assists in reproduction. This turbulence is caused by a phenomenon known as shoaling, in which waves increase in frequency and intensity as they enter shallow water. The reef crest is located at the transition from the shallow reef floor to deeper waters. It typically contains beds of seagrass, which are important foraging areas for fish. Finally, the fore reef is the most biologically diverse region. It consists of a steep slope to deeper waters with strong circulating currents that bring nutrients while dispersing waste material. Additionally, coral and calcareous algae form complex structures which provide protection for other forms of marine life.

There are many types of reefs. Fringing reefs are directly attached to the shore by a shallow lagoon. Barrier reefs, such as the Australian reef system, are separated from the mainland by a deep lagoon. This separation may be several kilometres wide and 40 meters deep on average. Platform reefs are completely separate from any mainland, forming anywhere on the continental shelf or open ocean. These types of reefs may form shallow lagoons if they break the surface and become islands.

Coral polyps can feed on a range of marine organisms, from microscopic zooplankton to even small fish. However, most of their sustenance comes from a symbiotic relationship with algae that live within the cytoplasm of coral cells. In fact, the vibrant colours of coral reef systems come from these symbiotic algae, and not from the coral polyps themselves. These algae provide coral with oxygen, glucose, glycerol, and amino acids from photosynthetic pathways. In return, the coral provides carbon dioxide and a protective habitat. Clearly, symbiotic algae are tightly integrated with the host coral's metabolic pathways. When coral polyps are stressed, they expel the algae cells, resulting in the bleaching phenomenon.

Various stressors affect the biodiversity and coral health of the Great Barrier Reef. One of the primary global stressors is climate change, where increased sea surface temperatures and excessive sunlight can cause mass coral bleaching and mortality. Four major events of mass coral bleaching in the Great Barrier Reef have been documented. The first was in 1998, where the majority of corals bleached were mostly along the coast; the most severe bleaching occurred in the central and southern regions. The second was in 2002, where more widespread bleaching was observed, which affected offshore reefs in the central regions. The third was in 2016, where the increase in ocean temperatures due to El Nino led to the most extensive and severe levels of coral bleaching; four times higher compared to the bleaching events in 1998 and 2002 with greater than 60% of corals bleached. The fourth was in 2017, where bleaching was the most severe in the northern and central regions, with some severe bleaching in the southern region.

Additional stressors include: 1) Ocean acidification, which causes a decrease in the aragonite

saturation of seawater. This reduces the ability for coral to calcify and form calcium carbonate skeletons, thus, reducing their growth rate and leading to fragile and deformed structures. 2) Tropical cyclones, which can damage coral reefs through the breakage of coral tips and branches, dislodgement of coral colonies, burial of corals in sand, and partial or whole removal of sections of the reef. 3) Crown-of-Thorns Starfish (COTS) (*Acanthaster planci*), which are an invasive species that feed on coral. Periodic outbreaks of COTS are one of the major causes of coral mortality. Nitrogen run-offs from farm pollution can contribute to the survival and outbreak of COTS by promoting algae blooms, which COTS larvae feed on.

Coral bleaching and loss of coral because of various stressors have led to a decrease in fish diversity and a decline in fish populations. The fish and reef organisms that rely on coral for food, shelter, and sites for reproduction were the most affected. Some fish may disperse to unaffected reefs, which have negative consequences on the recovery of damaged reefs. Degraded reefs become dominated by non-symbiotic algae; grazing reef fish are required for the removal of these algae. Therefore, they are vital for new corals to grow and for reef recovery.

The Great Barrier Reef Marine Park Authority is funded by the Australian government, and is responsible for the protection, conservation, and care of the reef. This is done through the implementation of legislations, policies, regulations, fish-zoning plans, traditional owner agreements, partnerships, education, research, monitoring, and reporting. They place strict regulations on fishing, removal of artefacts or wildlife, and set defined routes for commercial shipping. To protect and sustain the great barrier reef, the marine park authority works alongside other Australian and Queensland government agencies, industries, and the community to implement the Reef 2050 Plan, which includes an integrated monitoring and reporting program aimed to detect environmental changes, threats, and future risks to the reefs. As well, report cards are released annually outlining these changes in the reef and its management. The program also helps focus investments on effective strategies that can deliver measurable results.

Another on-going initiative is the Sea-quence Project run by the ReFuGe 2020 Consortium. Researchers investigate genetic differences between nine reef-building corals (and their associated zooxanthellae and microbes) on the Great Barrier Reef and the same coral species in the Red Sea that allow these corals to survive at higher temperatures.

With respect to reef restoration, coral transplantation has been considered as a method for the fortification and protection of coral reef structures. So far, results are mixed, with one case study following 530 transplants over 28 months finding a survivorship of only 51%, with 25% mortality occurring in the first 7 months as a result of wave action. Furthermore, whole colony transplantation was found to greatly influence survival. Another study has shown that transplantation at shallow depths is more effective and provides a more rapid coral growth rate, though, transplantation is still only recommended if recovery by means of natural recruitment is unlikely.

Of greatest interest is an incredibly novel field restoration effort that has recently begun to minimize the effects of global warming on our coral reefs through reef regrowth. Using a steel mesh framework coupled with low voltage, direct current, severely eroded beaches have been restored. This new technology, safe to both animals and humans, is known as Biorock. It is designed specifically so that it does not disrupt water flow, and mimics the natural morphology of the coral reef. With Biorock, the electricity creates an increased accumulation of dissolved minerals in the seawater, causing coral settlement to increase by 25.86 times when compared to uncharged sites. This creates an incredibly strong limestone structure for coral to attach to and multiply. In response, reef-building coral showed an increase in their mean growth rate by 3.17 times, and coral growing on Biorock frames had a survival rate of 50 times that of natural corals after a bleaching event. Furthermore, this Biorock restoration method is incredibly cost-effective in comparison to seawalls or breakwaters, and the electricity required is only about that of powering an air conditioner. The only real drawback that exists with Biorock is that this restoration method requires time, however this is the exact reason that its further implementation should be completed as fast as possible.

1. Which of the following is NOT a reef structure?
   A. Fore reef
   B. Outer reef
   C. Reef crest
   D. Inner reef
   E. Reef floor

2. Coral reef systems are unique because:
   A. They are composed of calcium carbonate
   B. They are composed of multiple zones
   C. They are one of humankind's greatest conservation challenges
   D. They are composed of both biotic and abiotic structures
   E. They are composed of individual polyps

3. What allows multiple coral polyps to attach to each other?
   A. Protein-based glue
   B. Desmosomes
   C. Calcium carbonate
   D. Calcified hydroxyapatite
   E. Tentacles

4. Which of the following most accurately describes the scale of the Great Barrier Reef?
   A. Larger than Japan
   B. Larger than the United Kingdom, Switzerland, and Netherlands
   C. Larger than the United States, Switzerland, and the Netherlands
   D. As large as the United Kingdom, Switzerland, and Netherlands
   E. As large as the United States, Switzerland, and the Netherlands

5. If you were a coral farmer, where would you choose to grow coral to maximize production?
   A. Reef crest
   B. Fore reef
   C. Reef floor
   D. Inner reef

6. Which of the following is NOT a similarity between a fringing reef and a platform reef?
   A. Both may have a lagoon
   B. Both are attached to the mainland
   C. Both are aquatic ecosystems
   D. Both may host invertebrate animals
   E. Both have multiple zones

7. What is responsible for the coloration of coral?
   A. Coral polyps
   B. Calcium carbonate exoskeleton
   C. Amino acids
   D. Metal-based chromophores
   E. Symbiotic algae

8. The Crown-of-Thorns starfish is an invasive species that feed on coral

   The Great Barrier Reef Marine Park authority allows fishing and removal of artefacts
   A. Both statements are TRUE
   B. Both statements are FALSE
   C. The first statement is TRUE, the second is FALSE
   D. The first statement is FALSE, the second is TRUE

9. When was the first documented mass coral bleaching event of the Great Barrier Reef?
   A. 1999
   B. 2002
   C. 2016
   D. 1998
   E. 2017

10. The third documented mass bleaching event was the most extensive and severe because it coincided with a decrease in ocean temperatures due to El Nino
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

11. Which of the following will NOT lead to coral bleaching, either directly or indirectly?
    A. Global warming
    B. Invasive species
    C. Tropical cyclones
    D. Industrial farming
    E. Interspecific competition

12. How do fish contribute to a positive feedback cycle that speeds up reef degradation?
    A. Bleached coral poison nearby fish, which contribute to algae blooms
    B. Bleached coral cause fish to migrate to unaffected reefs, hindering coral recovery
    C. Bleached coral become dominated by non-symbiotic algae, which attract grazing fish
    D. Fish form a symbiotic relationship with COTS larvae, which colonize the reef
    E. Fish farming leads to algae blooms, which COTS larvae feed on

13. The Great Barrier Reef Marine Park authority is responsible for:
    A. Conservation, care, and protection
    B. Protection, legislation, and conservation
    C. Conservation, care, and reclamation
    D. Conversion, maintenance, and tourism
    E. Protection, regulation, and reclamation

14. What is not included in the Reef 2050 plan?
    A. Monitoring of environmental changes
    B. Reporting of environmental threats
    C. Report cards
    D. Press releases
    E. Strategic investments

15. Which of the following is the most likely goal of the Sea-quence project?
    A. Create man-made reef structures
    B. Create transgenic coral that can tolerate increasing sea temperatures
    C. Create transgenic coral that can tolerate increasing sea levels
    D. Create transgenic microbes to augment coral growth
    E. Create a genetic repository of all reef-building coral species

16. The author of this passage is most likely to recommend which of the following reef restoration strategies?
    A. Coral transplantation
    B. Genetic engineering
    C. Voltage-mediated reef regrowth
    D. Increased government legislation
    E. Population control of invasive species

17. What is the correct order of structures, from smallest to largest?
    A. Cluster < polyp < zone < reef
    B. Reef < polyp < zone < cluster
    C. Polyp < zone < reef < cluster
    D. Polyp < cluster < zone < reef
    E. Polyp < cluster < reef < zone

18. A study on coral transplantation showed a:
    A. 25% 28-month survivorship of 530 subjects
    B. 51% 28-month survivorship of 530 subjects
    C. 25% 7-month survivorship of 530 subjects
    D. 51% 28-month survivorship of 350 subjects
    E. 25% 7-month survivorship of 350 subjects

19. Which of the following best describes the author's tone?
    A. Sombre
    B. Casual
    C. Informative
    D. Skeptical
    E. Satirical

20. This passage is best suited for which of the following contexts?
    A. Tourism pamphlet
    B. Government website
    C. Investor annual report
    D. Magazine article
    E. Debate script

Passage 2

The Discovery of the Double Helix

The discovery in 1953 of the double helix, the twisted-ladder structure of deoxyribonucleic acid (DNA), by James Watson and Francis Crick marked a milestone in the history of science and gave rise to modern molecular biology, which is largely concerned with understanding how genes control the chemical processes within cells. In short order, their discovery yielded ground-breaking insights into the genetic code and protein synthesis. During the 1970s and 1980s, it helped to produce new and powerful scientific techniques, specifically recombinant DNA research, genetic engineering, rapid gene sequencing, and monoclonal antibodies, techniques on which today's multi-billion dollar biotechnology industry is founded. Major current advances in science, namely genetic fingerprinting and modern forensics, the mapping of the human genome, and the promise, yet unfulfilled, of gene therapy, all have their origins in Watson and Crick's inspired work. The double helix has not only reshaped biology, it has become a cultural icon, represented in sculpture, visual art, jewelry, and toys.

Researchers working on DNA in the early 1950s used the term "gene" to mean the smallest unit of genetic information, but they did not know what a gene actually looked like structurally and chemically, or how it was copied, with very few errors, generation after generation. In 1944, Oswald Avery had shown that DNA was the "transforming principle," the carrier of hereditary information, in pneumococcal bacteria. Nevertheless, many scientists continued to believe that DNA had a structure too uniform and simple to store genetic information for making complex living organisms. The genetic material, they reasoned, must consist of proteins, much more diverse and intricate molecules known to perform a multitude of biological functions in the cell.

Crick and Watson recognized, at an early stage in their careers, that gaining a detailed knowledge of the three-dimensional configuration of the gene was the central problem in molecular biology. Without such knowledge, heredity and reproduction could not be understood. They seized on this problem during their very first encounter, in the summer of 1951, and pursued it with single-minded focus over the course of the next eighteen months. This meant taking on the arduous intellectual task of immersing themselves in all the fields of science involved: genetics, biochemistry, chemistry, physical chemistry, and X-ray crystallography. Drawing on the experimental results of others (they conducted no DNA experiments of their own), taking advantage of their complementary scientific backgrounds in physics and X-ray crystallography (Crick) and viral and bacterial genetics (Watson), and relying on their brilliant intuition, persistence, and luck, the two showed that DNA had a structure sufficiently complex and yet elegantly simple enough to be the master molecule of life.

Other researchers had made important but seemingly unconnected findings about the composition of DNA; it fell to Watson and Crick to unify these disparate findings into a coherent theory of genetic transfer. The organic chemist Alexander Todd had determined that the backbone of the DNA molecule contained repeating phosphate and deoxyribose sugar groups. The biochemist Erwin Chargaff had found that while the amount of DNA and of its four types of bases – the purine bases adenine (A) and guanine (G), and the pyrimidine bases cytosine (C) and thymine (T) – varied widely from species to species, A and T always appeared in

ratios of one-to-one, as did G and C. Maurice Wilkins and Rosalind Franklin had obtained high-resolution X-ray images of DNA fibres that suggested a helical, corkscrew-like shape. Linus Pauling, then the world's leading physical chemist, had recently discovered the single-stranded alpha helix, the structure found in many proteins, prompting biologists to think of helical forms. Moreover, he had pioneered the method of model building in chemistry by which Watson and Crick were to uncover the structure of DNA. Indeed, Crick and Watson feared that they would be upstaged by Pauling, who proposed his own model of DNA in February 1953, although his three-stranded helical structure quickly proved erroneous.

The time, then, was ripe for their discovery. After several failed attempts at model building, including their own ill-fated three-stranded version and one in which the bases were paired like with like (adenine with adenine, etc.), they achieved their break-through. Jerry Donohue, a visiting physical chemist from the United States who shared Watson and Crick's office for the year, pointed out that the configuration for the rings of carbon, nitrogen, hydrogen, and oxygen (the elements of all four bases) in thymine and guanine given in most textbooks of chemistry was incorrect. On February 28, 1953, Watson, acting on Donohue's advice, put the two bases into their correct form in cardboard models by moving a hydrogen atom from a position where it bonded with oxygen to a neighbouring position where it bonded with nitrogen. While shifting around the cardboard cut-outs of the accurate molecules on his office table, Watson realized in a stroke of inspiration that A, when joined with T, very nearly resembled a combination of C and G, and that each pair could hold together by forming hydrogen bonds. If A always paired with T, and likewise C with G, then not only were Chargaff's rules (that in DNA, the amount of A equals that of T, and C that of G) accounted for, but the pairs could be neatly fitted between the two helical sugar-phosphate backbones of DNA, the outside rails of the ladder. The bases connected to the two backbones at right angles while the backbones retained their regular shape as they wound around a common axis, all of which were structural features demanded by the X-ray evidence. Similarly, the complementary pairing of the bases was compatible with the fact, also established by the X-ray diffraction pattern, that the backbones ran in opposite direction to each other, one up, the other down.

Watson and Crick published their findings in a one-page paper, with the understated title "A Structure for Deoxyribose Nucleic Acid," in the British scientific weekly Nature on April 25, 1953, illustrated with a schematic drawing of the double helix by Crick's wife, Odile. A coin toss decided the order in which they were named as authors. Foremost among the "novel features" of "considerable biological interest" they described was the pairing of the bases on the inside of the two DNA backbones: A=T and C=G. The pairing rule immediately suggested a copying mechanism for DNA: given the sequence of the bases in one strand, that of the other was automatically determined, which meant that when the two chains separated, each served as a template for a complementary new chain. Watson and Crick developed their ideas about genetic replication in a second article in Nature, published on May 30, 1953.

The two had shown that in DNA, form is function: the double-stranded molecule could both produce exact copies of itself and carry genetic instructions. During the following years, Crick elaborated on the implications of the double-helical model, advancing the hypothesis, revolutionary then but widely-accepted since, that the sequence of the bases in DNA forms a code by which genetic information can be stored and transmitted.

Although recognized today as one of the seminal scientific papers of the twentieth century, Watson and Crick's original article in Nature was not frequently cited at first. Its true significance became apparent, and its circulation widened, only towards the end of the 1950s, when the structure of DNA they had proposed was shown to provide a mechanism for controlling protein synthesis, and when their conclusions were confirmed in the laboratory by Matthew Meselson, Arthur Kornberg, and others.

Crick himself immediately understood the significance of his and Watson's discovery. As Watson recalled, after their conceptual breakthrough on February 28, 1953, Crick declared to the assembled lunch patrons at The Eagle that they had "found the secret of life." Crick himself had no memory of such an announcement, but did recall telling his wife that

evening "that we seemed to have made a big discovery." He revealed that "years later she told me that she hadn't believed a word of it." As he recounted her words, "You were always coming home and saying things like that, so naturally I thought nothing of it."

Retrospective accounts of the discovery of the structure of DNA have continued to elicit a measure of controversy. Crick was incensed at Watson's depiction of their collaboration in The Double Helix (1968), castigating the book as a betrayal of their friendship, an intrusion into his privacy, and a distortion of his motives. He waged an unsuccessful campaign to prevent its publication. He eventually became reconciled to Watson's bestseller, concluding that if it presented an unfavourable portrait of a scientist, it was of Watson, not of himself.

A more enduring controversy has been generated by Watson and Crick's use of Rosalind Franklin's crystallographic evidence of the structure of DNA, which was shown to them, without her knowledge, by her estranged colleague, Maurice Wilkins, and by Max Perutz. Her evidence demonstrated that the two sugar-phosphate backbones lay on the outside of the molecule, confirmed Watson and Crick's conjecture that the backbones formed a double helix, and revealed to Crick that they were antiparallel. Franklin's superb experimental work thus proved crucial in Watson and Crick's discovery. Yet, they gave her scant acknowledgment. Even so, Franklin bore no resentment towards them. She had presented her findings at a public seminar to which she had invited the two. She soon left DNA research to study tobacco mosaic virus. She became friends with both Watson and Crick, and spent her last period of remission from ovarian cancer in Crick's house (Franklin died in 1958). Crick believed that he and Watson used her evidence appropriately, while admitting that their patronizing attitude towards her, so apparent in The Double Helix, reflected contemporary conventions of gender in science.

Adapted from *The Discovery of the Double Helix, 1951-1953* by the U.S. National Library of Medicine. This passage is made available under public domain.

21. Which scientist first demonstrated that DNA was the carrier of hereditary information?
    A. Francis Crick
    B. James Watson
    C. Alexander Todd
    D. Oswald Avery
    E. Jerry Donohue

22. Which of the following technologies was NOT enabled by the discovery of the double helix?
    A. Monoclonal antibodies
    B. Gene sequencing
    C. Western blotting
    D. Genetic engineering
    E. Recombinant DNA

23. Which of the following partially explains why Crick attempted to prevent the publication of Watson's book?
    A. The book was scientifically unsound
    B. The book invaded Crick's privacy
    C. The book portrayed Watson in a poor light
    D. The title was understated
    E. Crick was listed as second author

24. Watson and Crick first met each other in:
    A. 1944
    B. 1950
    C. 1953
    D. 1951
    E. 1968

25. According to the author, which of the follow was responsible for Watson and Crick's success?
    A. Their extensive DNA experimentation
    B. Their identical scientific backgrounds
    C. Their ambition, intelligence, and bravery
    D. Their tenacity, collaborative spirit, and charisma
    E. Their persistence, luck, and intuition

26. Which of the following correctly pairs the scientist with their contribution?
    A. Pauling; X-ray images of DNA
    B. Wilkins; Purine/pyrimidine ratios
    C. Pauling; Discovery of alpha helix
    D. Wilkins; Model building technique
    E. Donohue; Composition of DNA backbone

27. At what angle do nitrogenous bases connect with the DNA backbone in a double helix?
    A. 30°
    B. 45°
    C. 60°
    D. 90°
    E. 120°

28. The author views Watson and Crick's use of Franklin's data as controversial because:
    A. No consent was provided
    B. The evidence was used inappropriately
    C. Little acknowledgement was given
    D. It was an intrusion into her privacy
    E. Franklin's cancer was likely due to the X-rays

29. Watson and Crick first published their findings in Nature on May 30

    The original Nature article was immediately met with great enthusiasm and praise
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

30. Prior to 1953, most scientists believed:
    A. DNA had a heterogenous structure
    B. DNA is a complex molecule
    C. DNA was a double helix
    D. Hereditary material is carbohydrate-based
    E. Hereditary material is protein-based

31. What eventually solidified Watson and Crick's theory as correct?
    A. Crystallography by Franklin
    B. Laboratory experiments by Meselson and Kornberg
    C. Elucidation of a replication mechanism
    D. Laboratory experiments by Wilkins
    E. Discovery of base pair hydrogen bonding

32. According to Watson and Crick, what was essential for understanding heredity?
    A. Understanding gene sequences
    B. Understanding DNA composition
    C. Understanding gene structure
    D. Understanding the central dogma
    E. Understanding DNA replication

33. Chargaff discovered that complementary bases always appeared in a ratio of two-to-one

    Pauling proposed a model of DNA months before Watson and Crick published
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

34. Crick used cardboard models to arrive at the proper base pairing structure because Donohue pointed out that the textbook configuration for the rings of bases were incorrect
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

35. The X-ray diffraction pattern of DNA showed that the backbone:
    A. Ran in the same direction
    B. Ran in opposite directions
    C. Was arranged as a triple helix
    D. Was arranged as a beta helix
    E. Was arranged as a single-stranded helix

Passage 3

Free Will

How much control do people exercise over who they are and what they do? Suppose it is the night before an exam, and Quinn should be studying, but her roommate asks her to come out with her and some friends. It certainly seems like it is up to Quinn what she does. She could stay home and study or she could spend the night out with friends. The choice seems hers to make and up to her. And when Quinn arrives exhausted to her exam the following morning, Quinn should feel justified blaming herself for failing to do what she should have done and what she could have done.

But maybe this sense of freedom is a mere illusion. Maybe Quinn's decision to go out with her friends the night before a big exam is an inevitable, deterministic consequence of the past and the laws of nature in such a way that her supposed freedom is undermined. Or perhaps it is the case that the real reason someone chooses a career in philosophy over a career in accounting has more to do with unconscious brain processes and the environment and social situation they find themselves in then it has to do with any conscious decision they may have made. And if so, if our choices are really the causal results of unconscious brain processes or external environmental factors, are any of us really free? Are we really in control of who we are and what we do? Or are free-will skeptics correct to claim that the things we do and the way that we are is ultimately the consequent of external factors beyond our control?

To investigate whether or not humans sometimes act freely, we need to first clarify what is meant by free will. The discussion of freedom has a long history and free will has been used to apply to a multitude of, often radically different, abilities and capacities that people may, or may not, have. A helpful place to start is to note that most philosophers today who write on free will have in mind the kind of control required for morally responsible action. That is, to ask whether or not someone is free is to ask whether or not they have control over their actions such that they are deserving of blame or praise for what they do (or fail to do).

Most accounts of freedom fall into one of three camps. Some people take freedom to require merely the ability to "do what you want to do." For example, if you wanted to walk across the room, right now, and you also had the ability, right now, to walk across the room, you would be free as you could do exactly what you want to do. We will call this easy freedom.

Others view freedom on the infamous "Garden of Forking Paths" model. For these people, free action requires more than merely the ability to do what you want to do. It also requires that you have the ability to do otherwise than what you actually did. So, If Quinn is free when she decides to take a sip from her coffee, on this view, it must be the case that Quinn could have refrained from sipping her coffee. The key to freedom, then, is alternative possibilities and we will call this the alternative possibilities view of free action.

Finally, some people envision freedom as requiring, not alternative possibilities but the right kind of relationship between the antecedent sources of our actions and the actions that we actually perform. Sometimes this view is explained by saying that the free agent is the source, perhaps even the ultimate source of her action. We will call this kind of view a source view of freedom.

Determinism and free will are often thought to be in deep conflict. Whether or not this is true has a lot to do with what is meant by determinism and an account of what free will requires. First of all, determinism is not the view that free actions are impossible. Rather, determinism is the view that at any one time, only one future is physically possible. To be a little more specific, determinism is the view

that a complete description of the past along with a complete account of the relevant laws of nature logically entails all future events.

We are certainly influenced by the world we are a part of, but to be influenced by the world is different from being determined by it, and this may allow us to, at least sometimes, exercise some control over the actions we perform. No one knows for certain whether or not humans exercise the control over their actions required for moral responsibility. And so I leave it to you, dear reader: Are you free?

Adapted from *Introduction to Philosophy: Philosophy of Mind by Eran Asoulin, Paul Richard Blum, Tony Cheng, et al.* This passage is licensed under a Creative Commons Attribution 4.0 International License.

36. Which of the following is NOT one of the widely accepted definitions of free will?
    A. The ability to do what you want
    B. A relationship between the sources of our actions and the actions themselves
    C. The ability to evoke alternative possibilities to reality
    D. A relationship between morality and reality

37. What is the purpose of the first paragraph?
    A. To suggest that Quinn did not consciously decide not to study
    B. To introduce the idea of free will
    C. To provide an example of determinism
    D. To introduce a counterargument against a widely accepted view
    E. To present a definition for free will

38. Which of the following is necessary in order to understand why humans act freely?
    A. Understand the concept of determinism
    B. Define moral responsibility
    C. Understand the difference between internal and external factors
    D. Define free will
    E. Understand the physiology of unconscious brain processes

39. According to most philosophers, free will enables humans to:
    A. Have direct control over reality
    B. Choose between right and wrong
    C. React to blame or praise
    D. Always make the responsible decision
    E. Anticipate the consequences of their actions

40. What does the author refer to as "easy freedom"?
    A. Situations in which our decisions have no moral and ethical implications
    B. A simplified definition of free will
    C. Situations in which the free agent is the source of our actions
    D. The Garden of Forking Paths
    E. The theory of determinism

41. Free-will skeptics suggest that:
    A. Internal factors are a major influence over our thoughts and actions
    B. Determinism is incompatible with free will
    C. Our thoughts and actions are mainly the result of external factors
    D. The Garden of Forking Paths model is incompatible with free will
    E. People should not be held accountable for their actions

42. Which of the following statements regarding determinism is INCORRECT?
    A. Only a single future is possible
    B. Information about the past can be used to predict the future
    C. There is no such thing as a truly free action
    D. Determinism is often viewed as incompatible with free will

43. Based on the final paragraph, with which statement would the author most likely agree?
    A. No one should be held responsible for their decisions
    B. True moral responsibility is meaningless
    C. The consequences of an action is always the fault of the decision maker
    D. We should all try to make our own decisions, even though it is unclear if we have free will
    E. We should all adopt an apathetic attitude towards our decisions

44. What does the Garden of Forking Paths describe?
    A. The existence of multiple "paths" of possibility required for free will
    B. The quantized nature of decisions
    C. The field of philosophy branching into the three camps of free will
    D. The external influence of our environment
    E. The burden of moral responsibility

45. What is the overall tone of this passage?
    A. Argumentative
    B. Critical
    C. Impartial
    D. Defensive
    E. Enthusiastic

46. According to the author, which of the following has a long history?
    A. Morality
    B. Free will
    C. Ethics
    D. Freedom
    E. Philosophy

47. In the context of the second paragraph, what best describes the author's meaning of "unconscious"?
    A. The state of being asleep
    B. Unable to respond to external stimuli
    C. A process that occurs automatically, without introspection
    D. A reservoir of all thoughts, feelings, and urges of the mind
    E. The reservoir of all repressed thoughts

48. What is the free agent?
    A. The ultimate source of our actions
    B. An individual with free will
    C. An important component of easy freedom
    D. The illusion of freedom
    E. The sum of internal and external influences

49. What is the purpose of the last sentence of the passage?
    A. To summarize the arguments presented
    B. To undermine the passage's main point
    C. To evoke thought and discussion among readers
    D. To end the passage on a humorous note
    E. To stress the urgency of this issue

50. What is the relationship between the first and second paragraph?
    A. To lead the reader down a train of thought, and then to disrupt it with a contrasting idea
    B. To present a problem, followed by a possible solution
    C. To present an argument about an issue, and then to undermine it
    D. To present an argument about an issue, and then to strengthen it
    E. To present a lengthy anecdote, and then to conclude it with a moral lesson

STOP

You have completed the RCT section of the DAT.
The exam is now over.

FULL-LENGTH 1 LOWER DIFFICULTY

SOLUTIONS

Survey of Natural Sciences

1. The RNA world hypothesis involves:
   A. Panspermia
   B. Ribozymes
   C. Metabolic pathways
   D. Centrioles
   E. Protocells

   A → Incorrect because panspermia is a different theory
   B → Correct answer
   C → Incorrect because the RNA world hypothesis states that self-replicating RNA molecules and ribozymes were the first to arise, not metabolic pathways
   D → Incorrect because centrioles are cell organelles, which arrive much later in evolutionary time
   E → Incorrect because cells evolve much later in time

2. Maltose is a ___ that is composed of ___
   A. Protein; amino acids
   B. Disaccharide; glucose and fructose
   C. Nucleic acid; nitrogenous bases
   D. Disaccharide; glucose
   E. Disaccharide; glucose and galactose

   A → Incorrect because maltose is a carbohydrate, not protein
   B → Incorrect because glucose + fructose is sucrose
   C → Incorrect because maltose is a carbohydrate, not a nucleic acid
   D → Correct answer
   E → Incorrect because glucose + galactose is lactose

3. Primary structure is best described as:
   A. The order of nucleic acids in DNA
   B. The order of amino acids in protein
   C. Hydrogen bonding between the polypeptide backbone of a protein
   D. Multiple polypeptide chains interacting together
   E. The high-level body plan of an organism

   A → Incorrect because the term "primary structure" most commonly refers to the order of amino acids in protein, not the sequence nucleic acids in DNA
   B → Correct answer
   C → Incorrect between hydrogen bonding between the polypeptide backbone is secondary structure
   D → Incorrect because interaction of multiple polypeptide chains is quaternary structure
   E → Incorrect because primary structure describes proteins, not organisms

4. Which of the following is NOT a special property of water:
   A. Solid form is less dense than liquid form
   B. High specific heat capacity
   C. Low specific heat of vaporization
   D. Cohesion
   E. Adhesion

   A → Incorrect because the statement is true. Ice floats on liquid water
   B → Incorrect because the statement is true
   C → Correct answer. Water has a high specific heat of vaporization. It takes a lot of energy to boil water, relative to other liquids
   D → Incorrect because the statement is true. Cohesion is the attraction between water molecules
   E → Incorrect because the statement is true. Adhesion is the attraction between water molecules and other polar or charged molecules

5. The most abundant substance in the extracellular matrix is:
   A. Proteoglycans
   B. Elastin
   C. Collagen
   D. Desmosomes
   E. Fibronectin

   A → Incorrect because although proteoglycans are part of the ECM, they are not nearly as abundant as collagen
   B → Incorrect because although elastin is part of the ECM, it is not nearly as abundant as collagen
   C → Correct answer
   D → Incorrect because desmosomes function for cell-to-cell attachment and are not part of the ECM
   E → Incorrect because although fibronectin functions for cell-to-ECM attachment, they are not as abundant as collagen

6. Which of the following would NOT occur if cholesterol was added to a lipid bilayer?
   A. Higher membrane fluidity at low temperatures
   B. Lower membrane fluidity at high temperatures
   C. Inversion of integral proteins
   D. Translation of integral proteins
   E. Atherosclerosis

   A → Incorrect because the statement is true. Cholesterol acts as a membrane fluidity buffer
   B → Incorrect because the statement is true. Cholesterol acts as a membrane fluidity buffer
   C → Correct answer. Integral proteins will almost never invert, since their polar regions would have to pass through the non-polar lipid tails of the bilayer
   D → Incorrect because the statement is true. Although integral proteins almost never invert, they are free to move side-to-side (translationally) in the lipid bilayer
   E → Incorrect because atherosclerosis involves cholesterol buildup within the lumen of arteries, not lipid bilayers

7. Animal cells are labelled with a fluorescent stain that visualizes nucleic acids. You observe the chromosomes moving to opposite ends of the cell. Which phase of the cell cycle is occurring?
   A. G1
   B. G2
   C. S
   D. Anaphase
   E. Metaphase

   A → Incorrect because the chromosomes are not condensed during G1 and thus would not be visible
   B → Incorrect because the chromosomes are not condensed during G2 and thus would not be visible
   C → Incorrect because the chromosomes are not condensed during S and thus would not be visible
   D → Correct answer. During anaphase of mitosis, the sister chromatids are pulled to opposite ends of the cell
   E → Incorrect because during metaphase, the chromosomes align at the metaphase plate but are not pulled yet

8. How do electric impulses move from cell to cell in cardiac tissue?
   A. Adherens junctions
   B. Tight junctions
   C. Gap junctions
   D. Hemidesmosomes
   E. Plasmodesmata

   A → Incorrect because adherens junctions do not allow the cytoplasm of neighbouring cells to be continuous
   B → Incorrect because tight junctions do not allow the cytoplasm of neighbouring cells to be continuous
   C → Correct answer. Gap junctions allow free flow of sodium and potassium ions to propagate an action potential
   D → Incorrect because hemidesmosomes function in cell-to-ECM attachment, not cell-to-cell
   E → Incorrect because although plasmodesmata allow free flow of ions, they are only found in plants

9. A large, positively charged molecule is most likely to cross a lipid bilayer via which process?
   A. Simple diffusion
   B. Osmosis
   C. Facilitated diffusion
   D. Complex diffusion
   E. Quorum sensing

   A → Incorrect because simple diffusion occurs with small, non-polar molecules
   B → Incorrect because osmosis is the movement of water across a membrane, not molecules
   C → Correct answer
   D → Incorrect because the term "complex diffusion" does not exist
   E → Incorrect because quorum sensing is a form of bacterial communication, not a cellular transport mechanism

10. Why does DNA migrate to the positive electrode during gel electrophoresis?
    A. The nitrogenous bases are negatively charged
    B. The nitrogenous bases are positively charged
    C. The phosphate groups are negatively charged
    D. The phosphate groups are positively charged
    E. The ribose sugars are negatively charged

    A → Incorrect because the nitrogenous bases are neutral
    B → Incorrect because the nitrogenous bases are neutral
    C → Correct answer
    D → Incorrect because each phosphate group has a −1 charge
    E → Incorrect because the ribose sugars are neutral

11. Which of the following DNA strands have the highest T_m:

    A. TAGATATA
    B. GCGGGTGC
    C. TGCTGCAC
    D. GTGACTTA
    E. GTATTTTG

    A → Incorrect because this strand only has 1/8 GC content
    B → Correct answer. This strand has the highest GC content (7/8), meaning it has the most number of hydrogen bonds between nitrogenous bases
    C → Incorrect because this strand only has 5/8 GC content
    D → Incorrect because this strand only has 3/8 GC content
    E → Incorrect because this strand only has 2/8 GC content

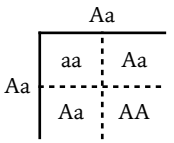
12. In mice, brown fur is recessive to black fur, and albinism is recessive to hair colour. A mouse that is recessive for both traits appears albino. What best describes this phenomenon?

    A. Pleiotropy
    B. Epistasis
    C. Polygenetic inheritance
    D. Expressivity
    E. Nondisjunction

    A → Incorrect because pleiotropy is when one gene influences multiple phenotypic traits
    B → Correct answer. Epistasis is when one gene affects the expression of a different gene
    C → Incorrect because polygenetic inheritance is when one trait is controlled by multiple genes
    D → Incorrect because expressivity is when the same genotype shows a varying spectrum of phenotypes
    E → Incorrect because nondisjunction is the failure of chromosomes to separate

13. If two heterozygous individuals mate, what is the percentage of offspring that will express the dominant trait?

    A. 0%
    B. 25%
    C. 50%
    D. 75%
    E. 100%



    The correct answer is 75% because 3/4 offspring have the dominant allele and thus will express the dominant trait

14. In photosystem II, chlorophyll serves as the:

    A. Prosthetic group
    B. Coenzyme
    C. Inhibitor
    D. Substrate
    E. Activator

    A → Correct answer. Prosthetic groups are non-organic cofactors that are covalently bound to an enzyme
    B → Incorrect because coenzymes are organic cofactors
    C → Incorrect because chlorophyll is a cofactor, which helps catalyze the enzyme reaction of photosystem II
    D → Incorrect because water is the substrate, not chlorophyll
    E → Incorrect because chlorophyll is a cofactor

15. How many ATP are produced by the glycolysis of two maltose molecules?

    A. 2
    B. 4
    C. 8
    D. 12
    E. 16

    Since each maltose is made up of two glucose molecules, we have $2 \times 2 = 4$ glucose in total. Each glucose that goes through glycolysis produces net 2 ATP. Therefore, we generate $4 \times 2 = 8$ ATP via the glycolysis of two maltose molecules

16. Which pair of anatomical traits is the best example of homologous structures?

    A. Human eye and squid eye
    B. Bat wing and insect wing
    C. Bat wing and whale fin
    D. Snake hindlimb bones and human appendix
    E. Dolphin dorsal fin and shark dorsal fin

    A → Incorrect because these structures are analogous. Although humans and squids both have eyes, they do not share a recent common ancestor
    B → Incorrect because these structures are analogous
    C → Correct answer. Bats and whales are both mammals. The appearance of a bat wing and a whale fin are dissimilar but closely related
    D → Incorrect because these are examples of vestigial structures, not homologous structures
    E → Incorrect because these structures are analogous

17. What must be true for a population to be in Hardy-Weinberg equilibrium?
    A. Immigration
    B. Non-random mating
    C. No genetic drift
    D. Sexual selection
    E. Artificial selection

    A → Incorrect because a Hardy-Weinberg equilibrium requires the absence of immigration or emigration
    B → Incorrect because a Hardy-Weinberg equilibrium requires random mating
    C → Correct answer
    D → Incorrect because sexual selection requires non-random mating
    E → Incorrect because a Hardy-Weinberg equilibrium requires the absence of natural or artificial selection

18. Which of the following is NOT a form of prezygotic isolation?
    A. Temporal isolation
    B. Ecological isolation
    C. Reproductive isolation
    D. Gamete isolation
    E. Behavioural isolation

    A → Incorrect because temporal isolation is when species have different breeding seasons
    B → Incorrect because ecological isolation is when species live in different habitats and don't meet
    C → Correct answer. The term "reproductive isolation" does not exist
    D → Incorrect because gamete isolation is when species produce gametes that don't recognize each other
    E → Incorrect because behavioural isolation is when species have different signals/rituals for mating

19. A forest ecosystem is rapidly destroyed after a small wildfire spreads, but begins to re-populate almost immediately after the fire is extinguished. This ecosystem has:
    A. High resistance and high resilience
    B. High resistance but low resilience
    C. Low resistance but high resilience
    D. Low resistance and low resilience
    E. Rapid primary succession

    A → Incorrect because resistance is the ability of an ecosystem to remain at equilibrium despite disruption. Since the forest is rapidly destroyed, it has low resistance
    B → Incorrect because the forest has low resistance
    C → Correct answer.
    D → Incorrect because resilience is how fast an ecosystem returns to equilibrium after disruption. Since the forest recovers quickly, it has high resilience
    E → Incorrect because primary succession is the colonization of land with previously no life. Since the forest had life prior to the fire, it is an example of secondary succession

20. Energy transfer between trophic levels in an ecosystem is inefficient mostly due to:
    A. Waste in the form of excrements
    B. Energy consumed by metabolism
    C. Waste in the form of heat
    D. Energy stored as biomass
    E. Waste in the form of kinetic energy

    A → Incorrect because although excretion does waste energy, it is not a major contributor to the inefficiency of energy transfer
    B → Incorrect because metabolism is not a major contributor to the inefficiency of energy transfer
    C → Correct answer. 90% of the energy transferred between trophic levels is wasted as heat. Only 10% is transferred to the next trophic level
    D → Incorrect because biomass is not a major contributor to the inefficiency of energy transfer
    E → Incorrect because kinetic energy is not a major contributor to the inefficiency of energy transfer

21. Ants feed on honeydew produced by aphids. In return, the ants protect aphids from predation by ladybugs. This relationship can be described as:
    A. Predation
    B. Herbivory
    C. Amensalism
    D. Commensalism
    E. Mutualism

    A → Incorrect because in predation, the predator benefits and the prey is harmed
    B → Incorrect because in herbivory, the herbivore benefits and the plant is harmed
    C → Incorrect because in amensalism, one species is harmed and the other is unaffected
    D → Incorrect because in commensalism, one species benefits and the other is unaffected
    E → Correct answer. In mutualism, both species benefit

22. You plate a colony of *E. coli* onto an agar plate and observe the bacteria growing slowly. What growth phase is this population in?
    A. Log phase
    B. Lag phase
    C. Exponential phase
    D. Stationary phase
    E. Death phase

    A → Incorrect because "log phase" is another term for "exponential phase", which is the fastest period of bacterial growth
    B → Correct answer. The lag phase is a period of slow growth as bacteria adapt to the new environment or growth medium
    C → Incorrect because the exponential phase is a period of fast growth as bacterial multiply via binary fission
    D → Incorrect because the stationary phase is a plateau in growth as the rate of death equals the rate of proliferation
    E → Incorrect because the death phase is a decline in population after the environment or growth medium is depleted and metabolic wastes accumulate

23. Which of the following is NOT a chordate:
    A. Shark
    B. Lobster
    C. Fish
    D. Crocodile
    E. Snake

    A → Incorrect because a sharks are chondrichthyes, which are chordates and vertebrates
    B → Correct answer. Lobsters are arthropods, which are not chordates
    C → Incorrect because fish are osteichthyes, which are chordates and vertebrates
    D → Incorrect because crocodiles are reptiles, which are chordates and vertebrates
    E → Incorrect because snakes are reptiles, which are chordates and vertebrates

24. During the double fertilization of angiosperms, why is the endosperm triploid?
    A. Because two sperm fuse with two polar bodies
    B. Because two sperm fuse with one polar body
    C. Because one sperm fuses with two polar bodies
    D. Because one sperm fuses with one polar body
    E. Because nondisjunction has occurred

    A → Incorrect because only one sperm is involved
    B → Incorrect because only one sperm is involved
    C → Correct answer
    D → Incorrect because two polar bodies are involved
    E → Incorrect because nondisjunction is the failure of chromosomes to separate. This is not the reason why double fertilization produces a triploid endosperm

25. Type ___ pneumocytes secrete surfactant, which _____ lung compliance.
    A. One; Increase
    B. One; Decrease
    C. Two; Increase
    D. Two; Decrease

    A → Incorrect because type two pneumocytes produce surfactant
    B → Incorrect because type two pneumocytes produce surfactant
    C → Correct answer
    D → Incorrect because surfactant increases lung compliance

26. What is the purpose of the papillary muscles?
    A. Pull on Bachmann's bundle to close the atrioventricular valves
    B. Conduct electrical signals to the Purkinje fibres
    C. Pull on chordae tendineae to close the atrioventricular valves
    D. Conduct electrical signals to the atrioventricular node
    E. Pump blood during systole

    A → Incorrect because Bachmann's bundle is a bundle of conductive cells that carries action potentials from the SA node to the left atrium
    B → Incorrect because the Purkinje fibres are conductive bundles that spread action potentials into the ventricles
    C → Correct answer
    D → Incorrect because electrical signals reach the AV node through the atria, not the papillary muscles of the ventricles
    E → Incorrect because the ventricles pump blood during systole, not the papillary muscles

27. Which of the following is NOT a function of the lymphatic system?
    A. Drain excess interstitial fluid
    B. Mature leukocytes
    C. Filter blood
    D. Fat absorption
    E. Prevent edema

    A → Incorrect because this statement is true. Lymph vessels drain interstitial fluid produced by blood pressure
    B → Incorrect because this statement is true. The thymus and bone marrow are primary lymphatic organs
    C → Correct answer. The renal system filters blood
    D → Incorrect because this statement is true. Lacteals are lymphatic vessels in the intestine that absorb digested fats
    E → Incorrect because this statement is true. A disruption in lymphatic drainage will cause edema

28. What is the most abundant leukocyte in the bloodstream?
    A. Mast cells
    B. Eosinophils
    C. Red blood cells
    D. Dendritic cells
    E. Neutrophils

    A → Incorrect
    B → Incorrect
    C → Incorrect because blood cells are not leukocytes
    D → Incorrect
    E → Correct answer. Neutrophils constitute 60-70% of circulating leukocytes

29. What occurs during the repolarization phase of an action potential?
    A. Sodium channels open and potassium channels close, allowing an inflow of Na^+
    B. Sodium channels close and potassium channels open, allowing an outflow of K^+
    C. Sodium channels close and potassium channels open, allowing an inflow of K^+
    D. Sodium channels open and potassium channels close, allowing an outflow of Na^+
    E. Sodium and potassium channels close

    A → Incorrect because sodium channels are inactivated
    B → Correct answer
    C → Incorrect because potassium flows out of the cell
    D → Incorrect because sodium channels are inactivated
    E → Incorrect because potassium channels open

30. Tadpoles will die when placed in salt water, because their cells are _____ to the surroundings, causing _____.
    A. Hypertonic; Plasmolysis
    B. Hypotonic; Plasmolysis
    C. Isotonic; Apoptosis
    D. Hypertonic; Cytolysis
    E. Hypotonic; Cytolysis

    A → Incorrect because the tadpole would be hypotonic to the surrounding water
    B → Correct answer. Plasmolysis occurs when too much water leaves the cell
    C → Incorrect because the tadpole would be hypotonic to the surrounding water
    D → Incorrect because the tadpole would be hypotonic to the surrounding water
    E → Incorrect because cytolysis occurs when too much water enters the cell

31. Which of the following strata is NOT a layer of the epidermis?
    A. Corneum
    B. Granulosum
    C. Basale
    D. Reticular
    E. Lucidum

    A → Incorrect because the stratum corneum is part of the epidermis
    B → Incorrect because the stratum granulosum is part of the epidermis
    C → Incorrect because the stratum basale is part of the epidermis
    D → Correct because the reticular region is part of the dermis, not epidermis
    E → Incorrect because the stratum lucidum is part of the epidermis

32. In the male reproductive system, which structure is responsible for secreting alkaline fluid that helps neutralize the acidity of the vaginal tract?
    A. Bulbourethral glands
    B. Seminiferous tubules
    C. Prostate
    D. Testes
    E. Spermatogonium

    A → Incorrect because the bulbourethral glands secrete a viscous, mucus-rich fluid called pre-ejaculate
    B → Incorrect because the seminiferous tubule produce sperm
    C → Correct answer
    D → Incorrect because the testes produce sperm
    E → Incorrect because the spermatogonium is a diploid stem cell that undergoes mitosis to produce primary spermatocytes

33. What mechanism is responsible for preventing polyspermy in humans?
    A. Acrosome reaction
    B. Electrical block
    C. Determinate cleavage
    D. Cortical reaction
    E. Medullary reaction

    A → Incorrect because the acrosome reaction allows the sperm to penetrate the zona pellucida
    B → Incorrect because the fast electrical block occurs in non-mammals
    C → Incorrect because determinate cleavage is a step in embryonic development
    D → Correct answer
    E → Incorrect answer because the term "medullary reaction" does not exist

34. Which of the following structures is NOT derived from the mesoderm?
    A. Heart
    B. Trachea
    C. Testes
    D. Dermis
    E. Tonsils

    A → Incorrect because the circulatory system is mesoderm-derived
    B → Correct answer. The respiratory system is endoderm-derived
    C → Incorrect because the genitourinary system is mesoderm-derived
    D → Incorrect because the dermis is mesoderm-derived
    E → Incorrect because the lymphatic system is mesoderm-derived. Tonsils are lymphoid organs

35. What extraembryonic membrane is responsible for waste management in egg-laying amniotes?
    A. Chorion
    B. Yolk sac
    C. Allantois
    D. Amnion
    E. Corona radiata

    A → Incorrect because the chorion functions for gas exchange
    B → Incorrect because the yolk sac functions as a nutrient reservoir
    C → Correct answer
    D → Incorrect because the amnion contains the embryo and functions as a protective layer
    E → Incorrect because the corona radiata is a layer of cells that surrounds the zona pellucida

36. A dog can be trained to salivate in response to hearing a bell. It can also be trained to navigate a maze to retrieve a treat. These are examples of _____ and _____ learning, respectively.
    A. Habituation; Observational
    B. Sensitization; Insight
    C. Operant; Classical
    D. Observational; Operant
    E. Classical; Operant

    A → Incorrect because habituation is when an animal becomes decreasingly sensitive to repeated stimuli
    B → Incorrect because sensitization is when an animal becomes increasingly sensitive to repeated stimuli
    C → Incorrect because the first example is classical conditioning. The bell is a conditioned stimulus
    D → Incorrect because observational learning occurs when an animal observes the behaviour of another and copies it, without the need for conditioning or reinforcement
    E → Correct answer. The first example is classical conditioning because the bell is a conditioned stimulus. The second example is operant conditioning because the treat is positive reinforcement

37. What is the function of guard cells?

A. Defence against herbivory
B. Secrete wax, which waterproofs the cuticle
C. Control airflow in leaves
D. Carbohydrate storage
E. C4 photosynthesis

A → Incorrect because guard cells do not prevent herbivory
B → Incorrect because epidermal cells secrete wax
C → Correct answer. Bundle sheath cells surround stomata
D → Incorrect because carbohydrate storage occurs predominantly in the roots
E → Incorrect because bundle sheath cells are the site of C4 photosynthesis, not guard cells

38. Which of the following characteristics are unique to angiosperms?

A. Cones, double fertilization, and pollination
B. Pollination, flowers, and gametophytes
C. Vasculature, flowers, and double fertilization
D. Fruit, double fertilization, and flowers
E. Vasculature, fruit, and flowers

A → Incorrect because cones are unique to gymnosperms
B → Incorrect because all plants have a gametophyte phase
C → Incorrect because gymnosperms, lycophytes, and pterophytes also have vasculature
D → Correct answer. These are the "three Fs"
E → Incorrect because gymnosperms, lycophytes, and pterophytes also have vasculature

39. During angiosperm fertilization, how does the pollen reach the embryo sac?

A. Travels through the micropyle
B. Initiates an acrosome reaction
C. Travels through the pollen tube
D. Initiates a cortical reaction
E. Travels via flagellar motion

A → Correct answer
B → Incorrect because the acrosome reaction occurs in animal fertilization only
C → Incorrect because the pollen tube travels from the stigma to the ovary. It needs to go through the micropyle to enter the embryo sac, therefore option A is a better answer
D → Incorrect because the cortical reaction occurs in animal fertilization only
E → Incorrect because pollen does not have a flagella

40. A population consisting of which of the following species would most likely exhibit a uniform distribution?

A. Dandelions
B. Honey bees
C. Humans
D. Conifers
E. Termites

A → Incorrect because dandelions are randomly distributed by the wind
B → Incorrect because the social structure of honey bee populations results in a clumped distribution
C → Incorrect because the social structure of human populations results in cities, following a clumped distribution
D → Correct answer. A uniform population distribution occurs when the distance between individuals are maximized, often due to competitive interactions between them
E → Incorrect because the social structure of termite populations results in a clumped distribution

41. Which of the following is NOT a diatomic gas?

A. Fluorine
B. Nitrogen
C. Oxygen
D. Neon
E. Iodine

Neon is not a member of the seven diatomic gasses: H, N, O, F, Cl, Br, I

42. List the following elements in order of increasing atomic radius: Ag, Na, Rb, Li, O.

A. O < Li < Na < Rb < Ag
B. O < Li < Na < Ag < Rb
C. O < Na < Li < Ag < Rb
D. O < Na < Li < Rb < Ag
E. Na < O < Li < Rb < Ag

Atomic radius increases with each row and decreases with each column. Therefore, the element with the larger atomic radius is closer to the bottom left corner of the periodic table, and vice versa.

43. What is the maximum number of electrons that the p subshell can hold?

A. 2
B. 4
C. 6
D. 8
E. 10

The maximum electron capacity of any subshell can be calculated with $4l + 2$. Since the p subshell corresponds with an l of 1, then the maximum number of electrons it can hold is $4(1) + 2 = 6$

44. If the pressure of a gas is tripled while holding temperature constant, the volume is:

A. Reduced to 1/2
B. Reduced to 1/3
C. Doubled
D. Tripled
E. Unchanged

According to Boyle's law, $PV = k$. This means the pressure and volume are inversely proportional. Thus, if P is multiplied by 3, the V must be multiplied by 1/3

45. If an orbital's principle quantum number is 3, then which of the following can NOT be its angular quantum number?

A. 1
B. 0
C. 2
D. 3

An orbital's angular quantum number (l) ranges from 0 to $(n-1)$. The principle quantum number is 3, thus l ranges from 0 to 2. Therefore 3 cannot be a valid angular quantum number

46. What is the correct electron configuration for sodium?

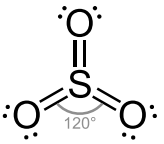
A. $1s^2 2s^2 2p^6 3s^2$
B. $1s^2 2s^2 2p^6 3s^1$
C. $1s^2 2s^2 2p^6$
D. $1s^2 2s^2 2p^5$
E. $1s^1 2s^1 2p^6 3s^1$

We start in the first row of the s-block and fill the first subshell ($1s^2$). Then we move to the next row and fill the next subshell ($2s^2$). Next we fill the first row of the p-block ($2p^6$). Finally, we add one electron to the third row of the s-block ($3s^1$). Review chapter 6 to learn how to write electron configurations

47. What bond angle does SO_3 have?

A. 104.5
B. 90
C. 120
D. 105
E. 109.5

SO_3 has $6 + (3)(6) = 24$ valence electrons. S is the least electronegative atom so we place it in the centre. Finally, we draw the appropriate number of bonds to satisfy the octet rule and formal charges. S can have an expanded octet, since it is a third row element. We arrive at the following structure:



Since the three S-O bonds are spread equally apart, the bond angle is 360/3 = 120. Review chapter 7 to learn how to draw lewis structures

48. Which set of coefficients would balance the following reaction?

$$\_\ NaBr + \_\ Cl_2 \rightarrow \_\ NaCl + \_\ Br_2$$

A. 2, 1, 2, 1
B. 2, 2, 2, 1
C. 1, 1, 1, 1
D. 1, 2, 1, 2

We begin by balancing the Cl atoms. There are 2 on the left and 1 on the right, so multiply NaCl by 2:

$\_\ NaBr + 1\ Cl_2 \rightarrow \mathbf{2}\ NaCl + \_\ Br_2$

Next we balance the Na atoms. There are 2 on the right and 1 on the left, so multiply NaBr by 2:

$\mathbf{2}\ NaBr + 1\ Cl_2 \rightarrow 2\ NaCl + \_\ Br_2$

Finally we balance the Br atoms. There are 2 on the left and 2 on the right, so multiply Br_2 by 1:

$2\ NaBr + 1\ Cl_2 \rightarrow 2\ NaCl + \mathbf{1}\ Br_2$

49. An alkaline buffer solution may consist of which of the following?

A. A strong acid and its conjugate base
B. A weak acid and its conjugate acid
C. A strong base and its conjugate acid
D. A weak base and its conjugate acid

A buffer solution always consists of a *weak* acid or base in equilibrium with its conjugate. Therefore option A and C are incorrect. Additionally, conjugate pairs always consist of an acid and a base. Therefore option B is incorrect

50. According to the following equation, how many grams of H_2O will be produced when 10 g of CH_4 is combusted?

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

A. $\dfrac{(10)(2)(18)}{(16)}$

B. $\dfrac{(10)(18)}{(16)}$

C. $\dfrac{(10)(18)}{(16)(2)}$

D. $\dfrac{(16)}{(10)(2)(18)}$

E. $\dfrac{(12)(2)(18)}{(16)}$

Divide mass of CH_4 by molar mass to find number of moles:

$$\text{Moles } CH_4 = \frac{10 \text{ g}}{12 + 4(1) \text{ mol/g}} = \frac{10}{16}$$

Then, multiply by the molar ratio of H_2O to CH_4:

$$\text{Moles } H_2O = \frac{(10)(2)}{16}$$

Finally, multiply by the molar mass of water:

$$\text{Mass } H_2O = \frac{(10)(2)(16 + 2 \text{ g/mol})}{16} = \frac{(10)(2)(18)}{16}$$

51. Under standard conditions, which of the following is true for a reaction that has a positive enthalpy change (ΔH)?

A. The reaction will be non-spontaneous for any value of ΔS
B. The reaction will be spontaneous for any value of ΔS
C. The reaction will be spontaneous if $\Delta S < \Delta H$
D. The reaction will be spontaneous if $\Delta H < \Delta S$
E. The reaction will be spontaneous if $\Delta S = \Delta H$

The equation for Gibbs free energy is $\Delta G = \Delta H - T\Delta S$. Therefore, if ΔS is greater than ΔH, then we can be sure that ΔG will be negative. There the reaction is spontaneous

52. A 100 g sample of aluminum was heated from 20°C to 50°C with 1 kJ of energy. What is the specific heat of aluminum in J/g°C?

A. $\dfrac{(100)(30)}{(1000)}$

B. $\dfrac{(1000)(30)}{(100)}$

C. $\dfrac{(1000)}{(100)(30)}$

D. $\dfrac{(100)}{(1000)(30)}$

E. $\dfrac{(1)}{(100)(30)}$

Use the heat transfer formula $q = mc\Delta T$. We can rearrange for the specific heat capacity:

$$c = \frac{q}{m\,\Delta t}$$

Finally, substitute the values into the formula. Remember to convert kJ to J:

$$c = \frac{1000 \text{ J}}{(100 \text{ g})(30)}$$

53. Sublimation is a ____ process describing a transformation from ____ to ____.

A. Chemical, Reducing Agent, Oxidizing Agent
B. Chemical, Reactant, Product
C. Physical, Gas, Solid
D. Physical, Gas, Liquid
E. Physical, Solid, Gas

Sublimation is a physical process because it involves intermolecular forces, not intermolecular forces. Sublimation occurs when a solid undergoes a phase change directly to the gaseous state without a liquid intermediate

54. Which of the following is NOT an intermolecular force?

A. Ion-dipole interactions
B. Hydrogen bonding
C. Ionic bonding
D. London dispersion forces
E. Dipole-induced dipole

Ionic bonding is an intramolecular force, which is responsible for holding ionic molecules together

55. How many molecules of aluminum are in two moles of Al_2O_3?

A. $(6.02 \times 10^{23})(2)(3)$
B. $(6.02 \times 10^{22})(2)(2)$
C. $(6.02 \times 10^{23})(2)$
D. $(2.06 \times 10^{23})(2)(2)$
E. $\boldsymbol{(6.02 \times 10^{23})(2)(2)}$

Since we have 2 moles of Al for every 1 mole of Al_2O_3, then we have 2×2 moles of Al. We can multiply this by Avogadro's constant to find the number of molecules of Al, since there are 6.02×10^{23} molecules per mole

56. Assuming the following reaction is at equilibrium, what will occur if the volume of the system is increased?

$$2SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$$

A. $[SO_2]$ increases
B. $[SO_3]$ increases
C. $[O_2]$ increases
D. $[SO_2]$ decreases
E. $[SO_3]$ decreases

If volume increases or pressure decreases, an equilibrium will shift to the side with fewer total moles of gas. In this equation, the reactant side has 3 moles while the product side has 2 moles. Therefore the equilibrium shifts to the right and $[SO_3]$ increases

57. What form of radioactive decay involves the production of a high-energy photon?

A. Alpha decay
B. Beta positive decay
C. Gamma decay
D. Beta negative decay

Gamma decay is the only form of radioactive decay that emits a high-energy photon (gamma particle). Alpha decay emits a helium nucleus, while beta decay emits an electron/positron

58. A sealed cylinder contains 1 mol of N_2, 3 mol of O_2, and 2 mol of Cl_2. If the total pressure is 350 kPa, what is the partial pressure of Cl_2 in kilopascals?

A. $\boldsymbol{\left(\frac{2}{6}\right)(350)}$
B. $\left(\frac{2}{4}\right)(350)$
C. $\left(\frac{6}{2}\right)(350)$
D. $\left(\frac{4}{6}\right)(350)$
E. $\left(\frac{2}{6}\right)(350000)$

Dalton's law states that the partial pressure of an individual gas is equal to the total pressure of the gas mixture multiplied by the mole fraction of the individual gas:

$P_{partial} = P_{total} \times X_{gas}$

After substituting the known values, we get:

$$P_{partial} = 350 \text{ kPa} \times \frac{2 \text{ mol}}{1 + 3 + 2 \text{ mol}}$$

$$P_{partial} = 350 \times \frac{2}{6}$$

59. Which of the following best describes a Lewis base?

A. Proton acceptor
B. Electron acceptor
C. Proton donor
D. Electron donor
E. Hydroxyl group donor

A Lewis base is defined as an electron donor, while a lewis acid is an electron acceptor. A Brønsted-Lowry base is defined as a proton acceptor, while a Brønsted-Lowry acid is a proton donor

60. Given the experimentally determined initial rates, what is the rate law for the following reaction?

$$A + B \rightarrow C$$

Trial	[A]	[B]	Initial Rate
1	0.5 M	0.3 M	2.0×10^{-2} M/s
2	2 M	0.3 M	8.0×10^{-2} M/s
3	0.5 M	0.6 M	8.0×10^{-2} M/s

A. $r = k[A][B]$
B. $r = k[A]^2[B]$
C. $r = k[A]^2[B]^2$
D. $r = k[A][B]^2$
E. $r = k[A]^3[B]^2$

Comparing trial 1 and 2, [A] is quadrupled:

$$\frac{2\text{ M}}{0.5\text{ M}} = 4$$

The initial rate is also quadrupled:

$$\frac{8.0\times10^{-2}\text{ M/s}}{2.0\times10^{-2}\text{ M/s}} = 4$$

Since $4^1 = 4$, therefore the reaction is first order with respect to reactant A

Comparing trial 1 and 3, [B] is doubled:

$$\frac{0.6\text{ M}}{0.3\text{ M}} = 2$$

The initial rate is quadrupled:

$$\frac{8.0\times10^{-2}\text{ M/s}}{2.0\times10^{-2}\text{ M/s}} = 4$$

Since $2^2 = 4$, therefore the reaction is second order with respect to reactant B

61. Which of the following is a colligative property?

A. Specific heat capacity
B. Color
C. Viscosity
D. Surface tension
E. Osmotic pressure

Colligative properties depend on the ratio of solute to solvent particles, but not the type of particle. Osmotic pressure is a colligative property because it is defined by $\Pi = TRiM$, where M represents concentration in molarity

62. What is the oxidation state of Ag_2S in the following redox reaction?

$$Ag + H_2S \rightarrow Ag_2S + H_2$$

A. 0
B. +1
C. −2
D. +2
E. −1

Ag and H_2 are in their elemental states, so they have an oxidation state of 0. The H in H_2S have an oxidation state of +1, so S must have an oxidation state of −2 if the overall molecule is neutral. The S in Ag_2S has an oxidation state of −2, so each Ag has an oxidation state of +1. Review chapter 14 to learn about redox reactions

$$\overset{0}{Ag} + \overset{+1\ -2}{H_2S} \rightarrow \overset{+1\ -2}{Ag_2S} + \overset{0}{H_2}$$

63. When homogenized cow liver is added to hydrogen peroxide, oxygen gas and water is produced. Cow liver contains the catalase enzyme. What is the function of catalase?

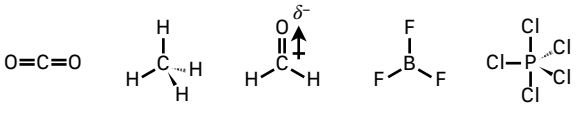
A. Decreases the reaction's rate constant
B. Increases the reaction's rate constant
C. Shifts the reaction equilibrium
D. Decreases activation energy
E. Increases activation energy

Catalase is an enzyme, which is a biological catalyst. Catalysts increase the speed (kinetics) of a reaction by decreasing activation energy. Catalysts do not effect the reaction equilibrium (thermodynamics) or rate constant

64. Which of the following compounds is polar?

A. CO_2
B. CH_4
C. CH_2O
D. BF_3
E. PCl_5

A polar molecule must contain a polar bond *and* be non-symmetrical. We must draw out the lewis structures of each answer option and use VSEPR theory to predict geometries:

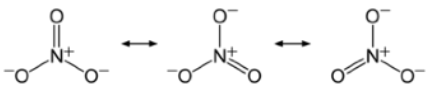


Note that CH_4 does not have any polar bonds because the difference in electronegativity of C and H is too low. CH_2O is the only molecule with a net dipole. Therefore it is polar

65. How many resonance structures can be drawn for the compound NO^{3-}?

A. 0
B. 1
C. 2
D. 3
E. 4

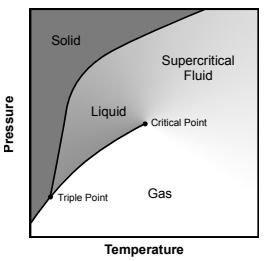
To minimize formal charges, NO^{3-} has one double bond. Notice how the sum of formal charges equals the overall charge of the molecule. This double bond can be arranged to generate the following three equivalent resonance structures:



66. When a gas is exposed to a temperature and pressure beyond the _, the gas turns into a _.

A. Equivalence Point; Subcritical Fluid
B. Triple Point; Supercritical Fluid
C. Critical Point; Subcritical Fluid
D. Half-Equivalence Point; Supercritical Fluid
E. Critical Point; Supercritical Fluid

The critical point of a phase diagram represents an equilibrium between the gaseous phase and supercritical fluid



67. In the following nuclear reaction, what is the identity of the second product?

$$^{238}_{92}\text{U} \rightarrow {}^{4}_{2}\text{He}^{2+} + \_$$

A. $^{238}_{90}$Th
B. $^{234}_{90}Th$
C. $^{234}_{92}$Th
D. $^{234}_{94}$Pu
E. $^{234}_{91}$Pa

Since a helium nucleus was released during the reaction, we know that this is alpha decay. The product of alpha decay has a mass number of $A - 4$ and an atomic number of $Z - 2$:

$$^{238-4}_{92-2} = {}^{234}_{90}$$

The atomic number of 90 corresponds to Th on the periodic table, so the product is $^{234}_{90}$Th

68. The equivalence point is defined as:

A. Equal moles of the acid and its conjugate
B. Equal moles of the titrate and its conjugate
C. Equal moles of the acid and base
D. pH of 7
E. Equal volumes of the titrant and titrate

The equivalence point is defined as equal moles of the acid and base. Option A is incorrect because this is the definition for the half-equivalence point. Options B and E are incorrect because the moles of the titrate/titrant are not necessarily equal to the moles of acid or base. Option D is incorrect because the equivalence point does not necessarily have to occur at a neutral pH

69. Which of the following compounds is NOT ionic?

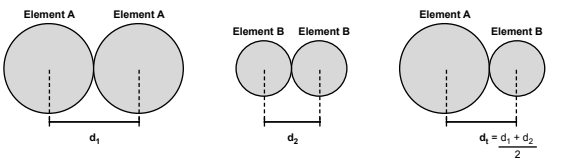
A. NaCl
B. HBr
C. K_2S
D. NH_3
E. KOH

Ammonia (NH_3) is not ionic because the difference in electronegativity is not high enough. All other option choices involve a metal and non-metal or polyatomic ion

70. If the bond length of H_2 is 74 pm and the bond length of Cl_2 is 199 pm, what is the bond length of HCl?

A. $\dfrac{74 + 74}{199}$
B. $\dfrac{74 + 199}{199}$
C. $74 + 199$
D. $\dfrac{74 + 199}{2}$
E. $\dfrac{74 + 199}{4}$

The bond length of between two elements is equal to the average bond length of the two pure elements:



Solutions – Perceptual Ability Test

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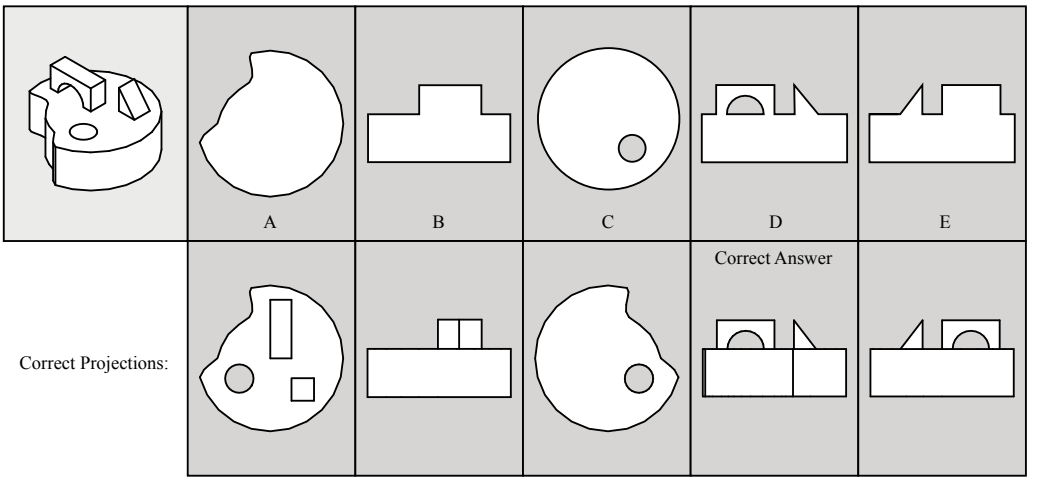

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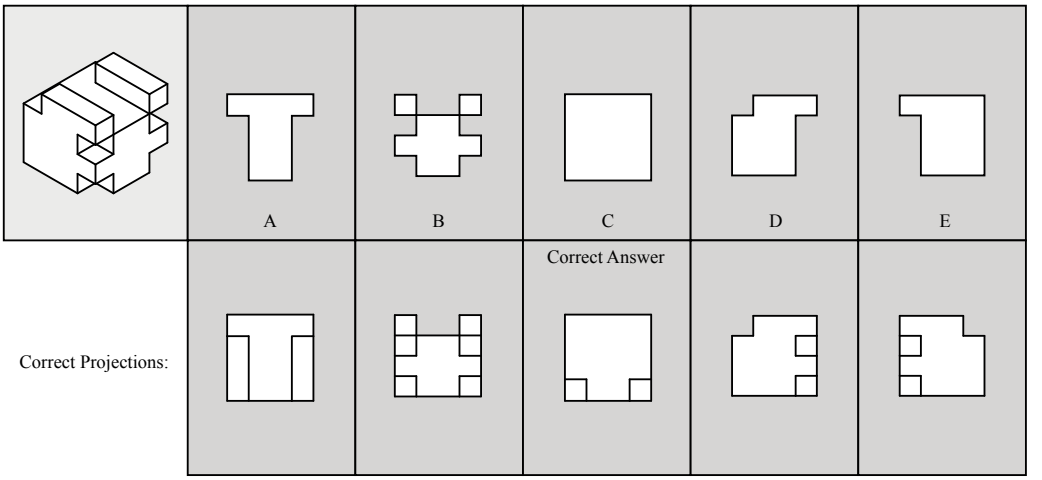

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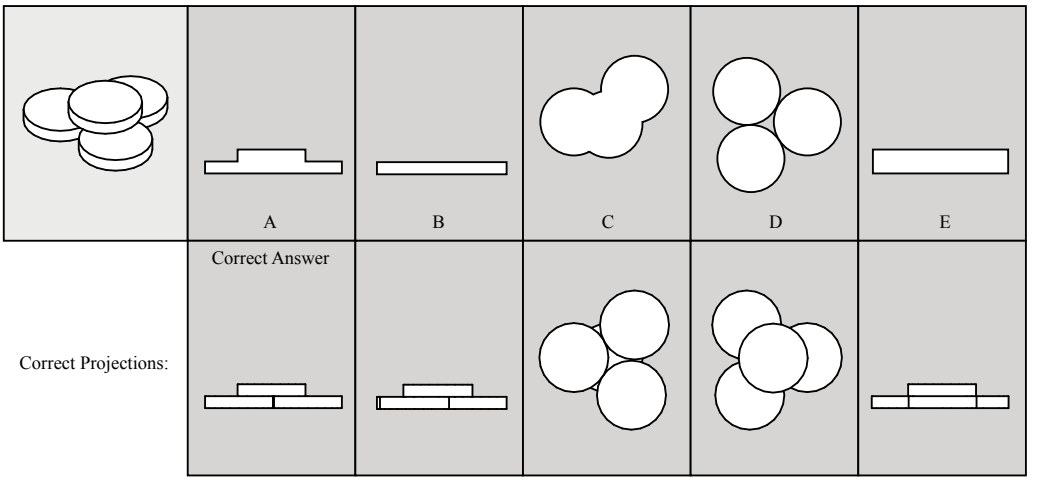

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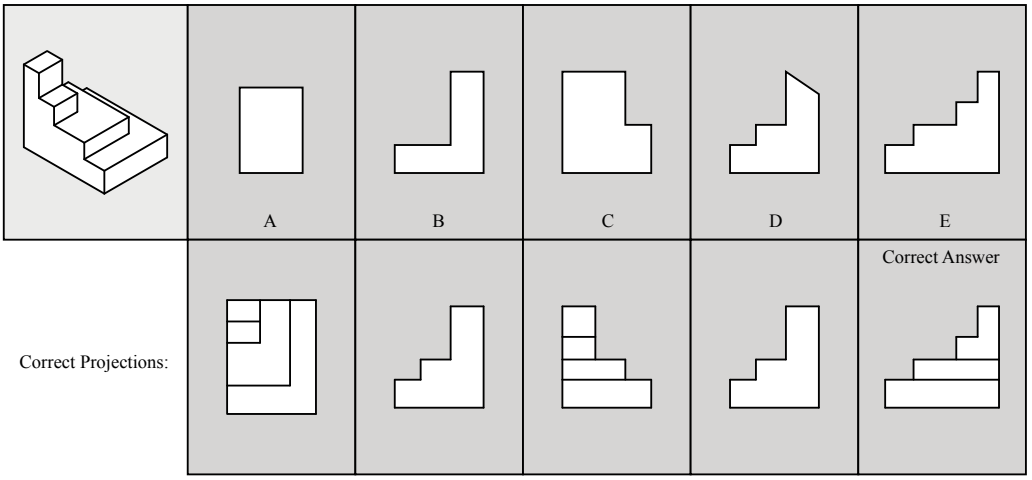
A
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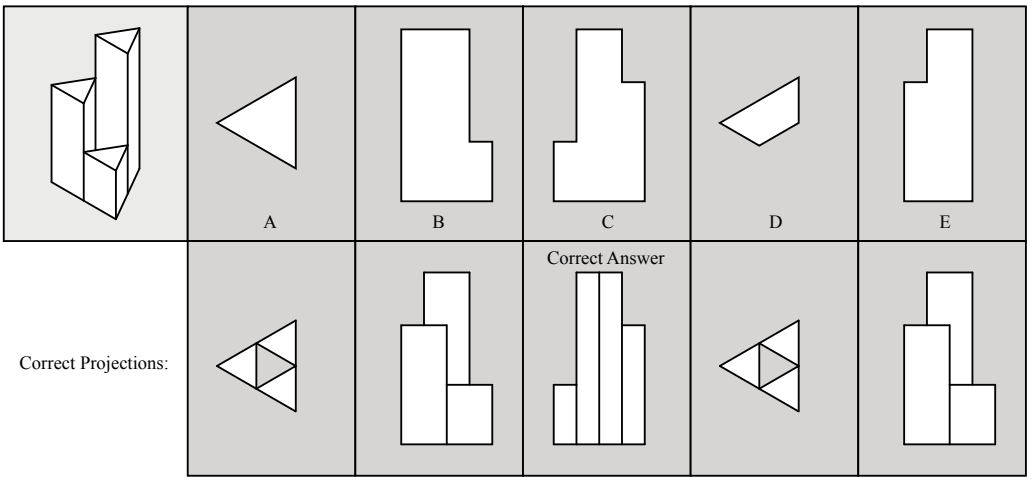
E
Correct Answer
Correct Projections:

5.


A
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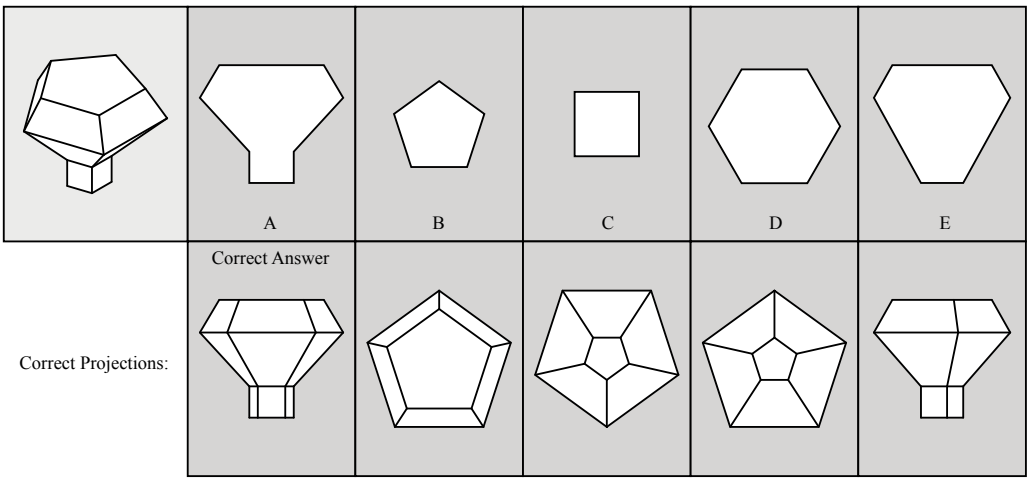
Correct Answer
Correct Projections:

6.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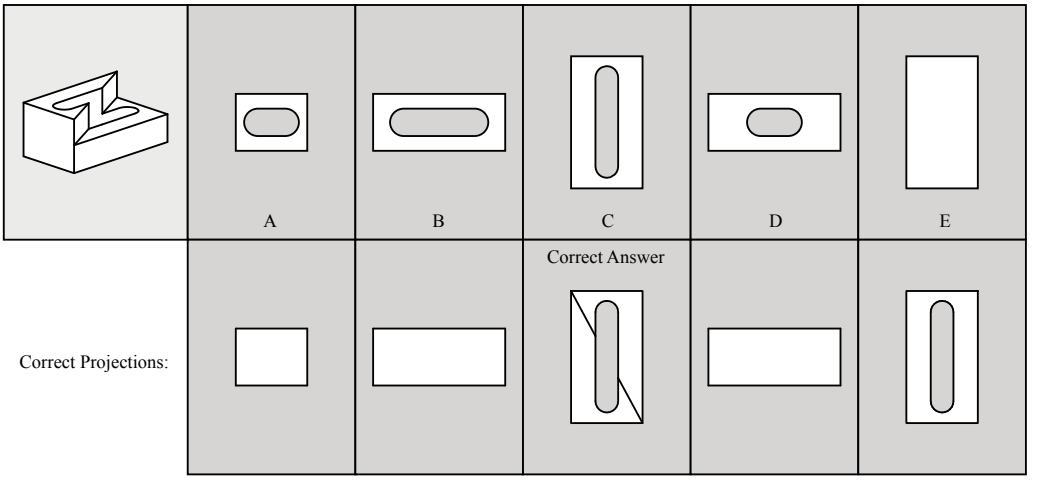
Correct Answer
Correct Projections:

7.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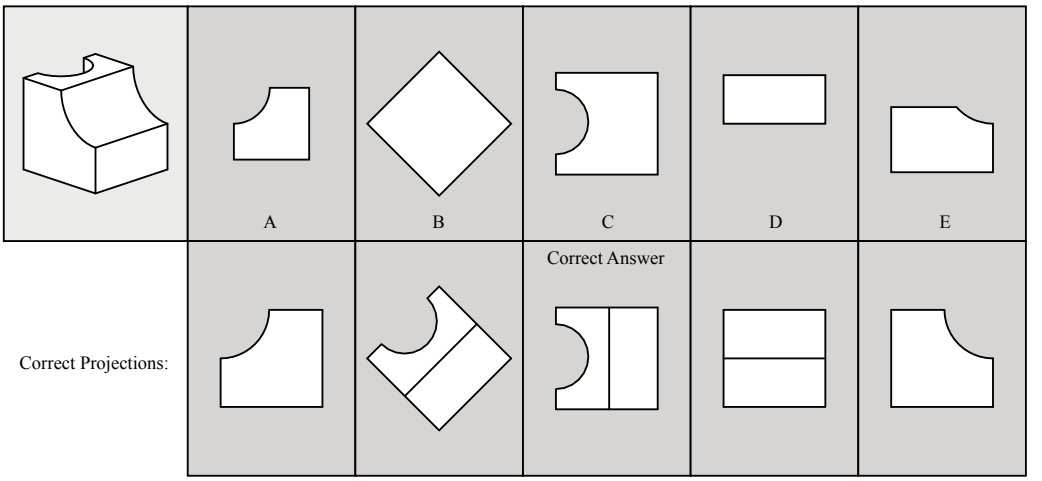
Correct Answer
Correct Projections:

8.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Correct Answer
Correct Projections:

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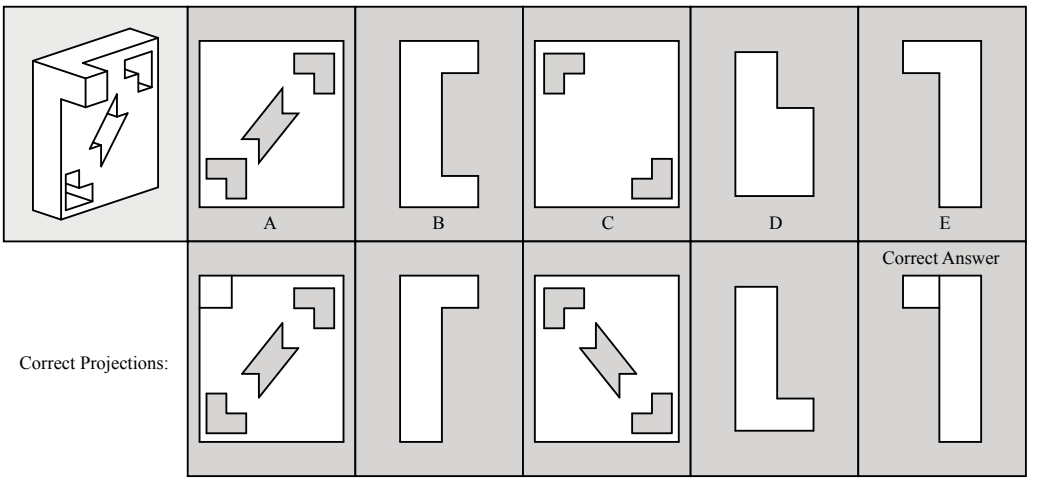
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Correct Answer
Correct Projections:

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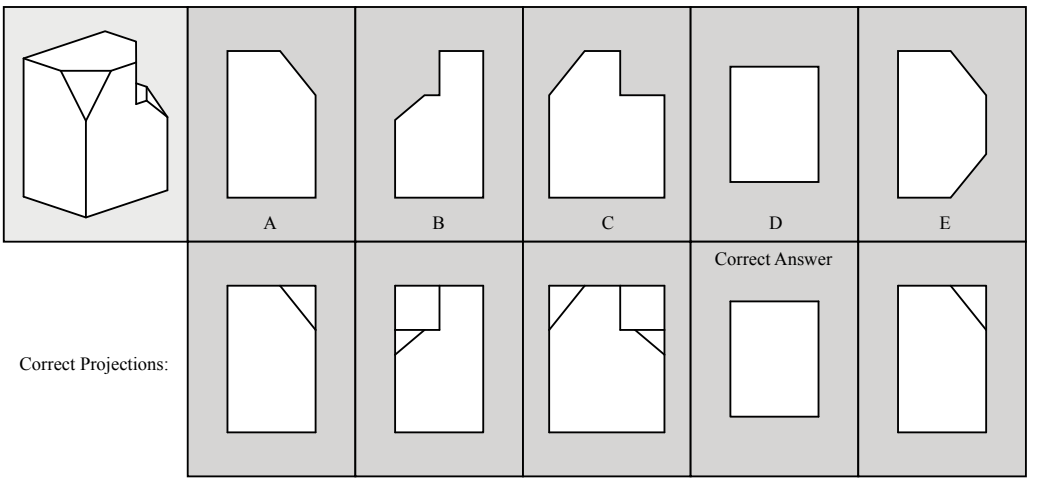
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Correct Answer
Correct Projections:

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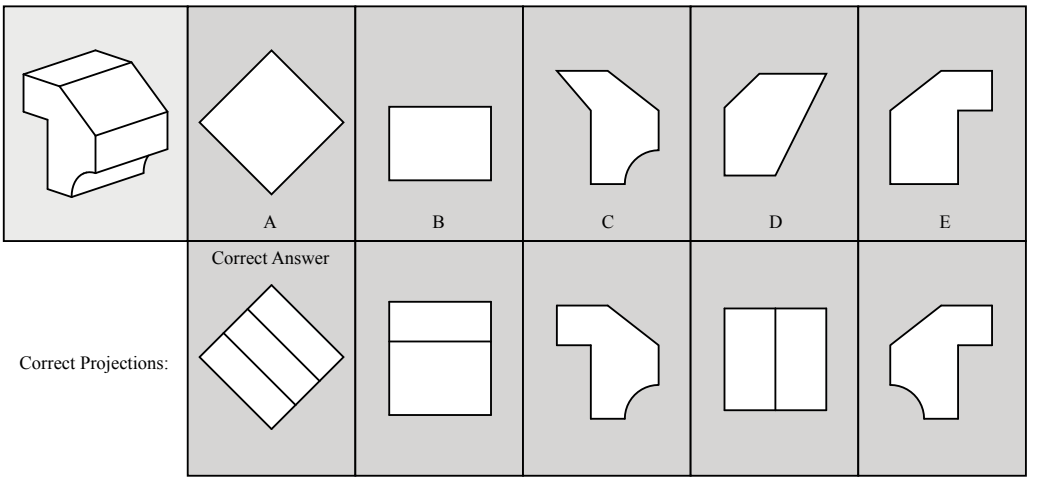
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Correct Answer
Correct Projections:

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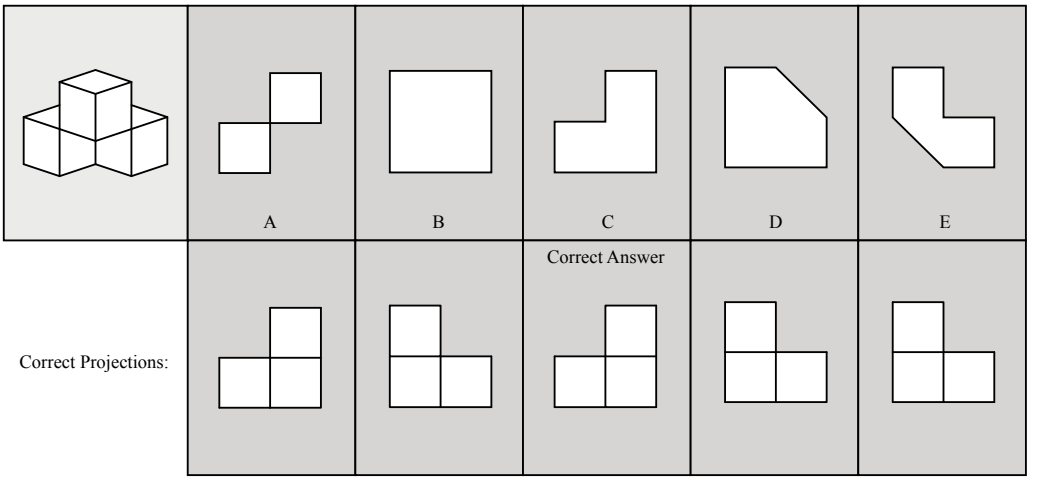
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Correct Answer
Correct Projections:

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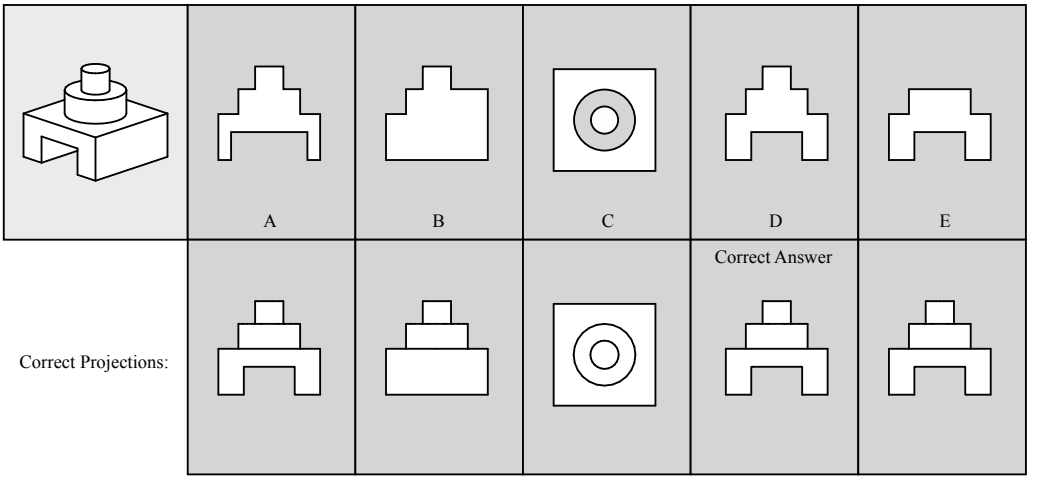
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Correct Answer
Correct Projections:

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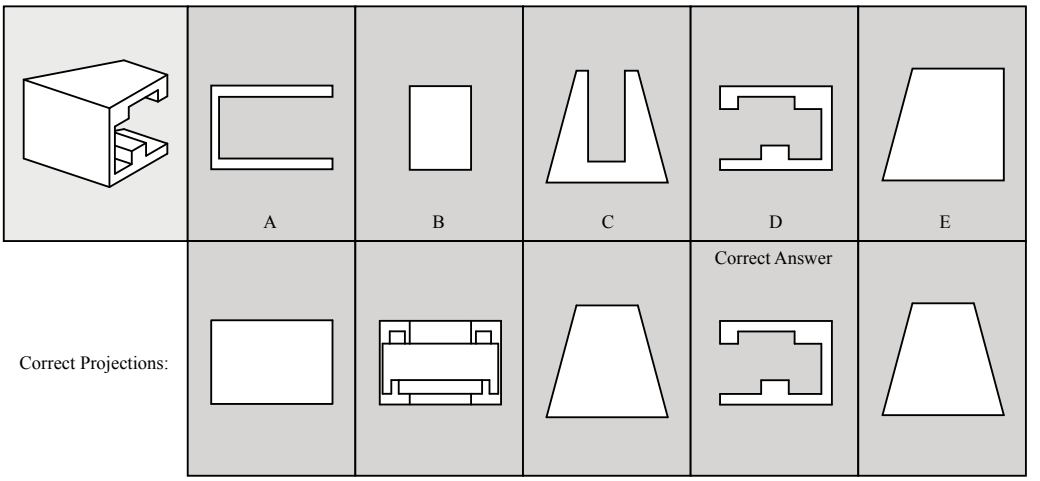
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Correct Answer
Correct Projections:

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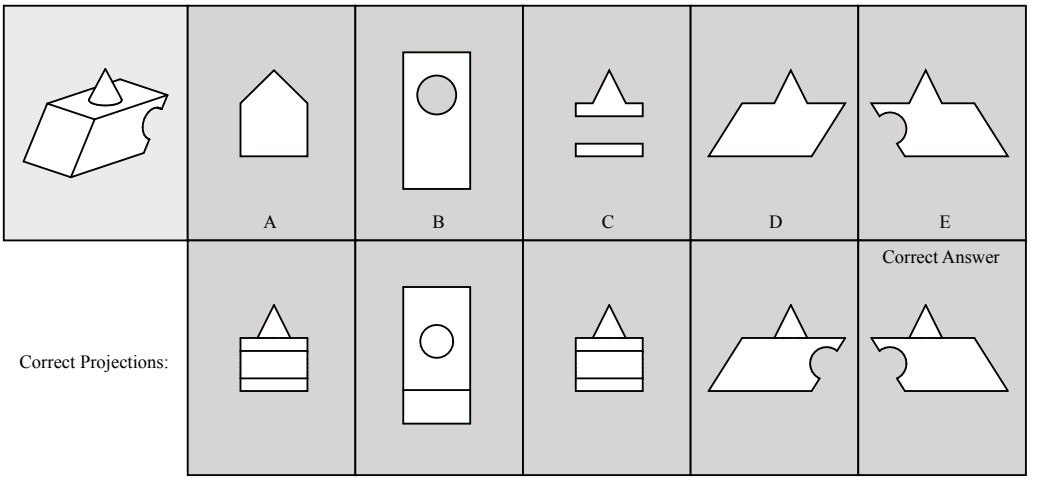
A
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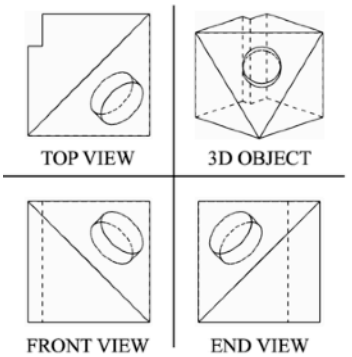
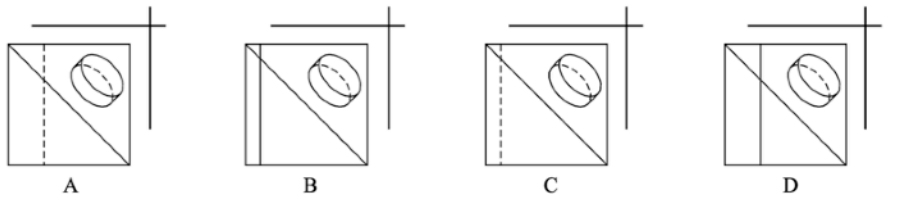
Correct Answer
Correct Projections:

16. Choose the correct FRONT VIEW





Correct Answer

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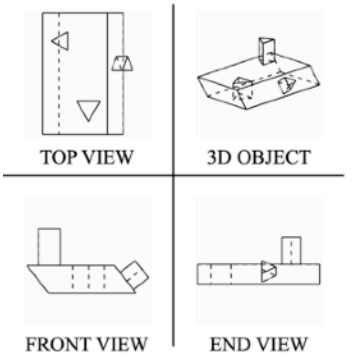

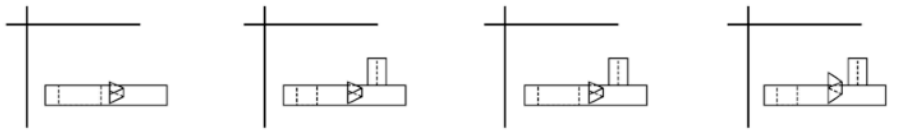

Correct Answer

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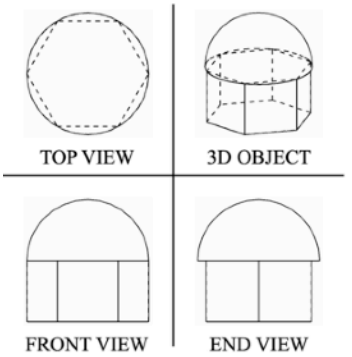

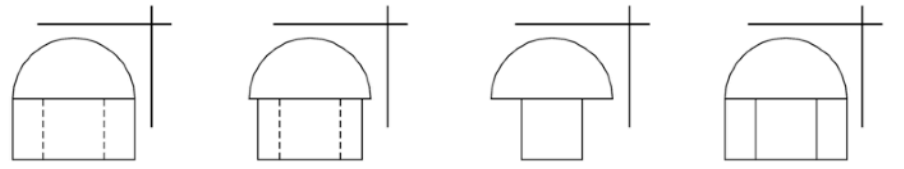

Correct Answer

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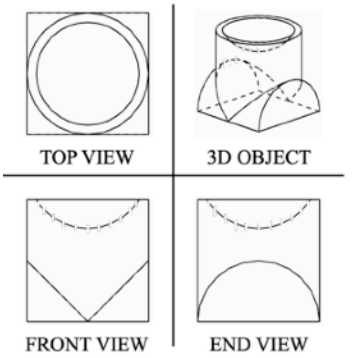

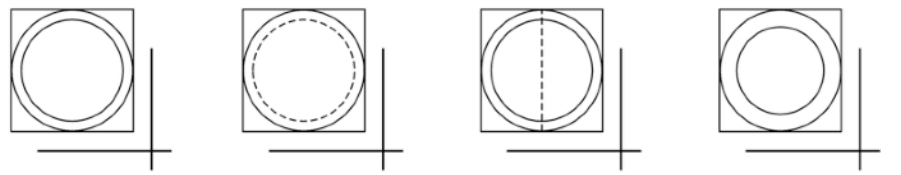

Correct Answer

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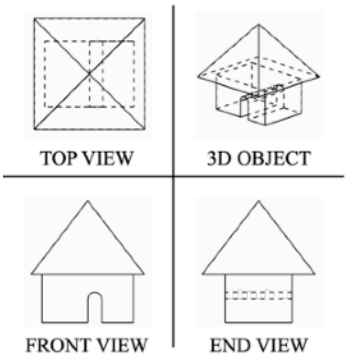

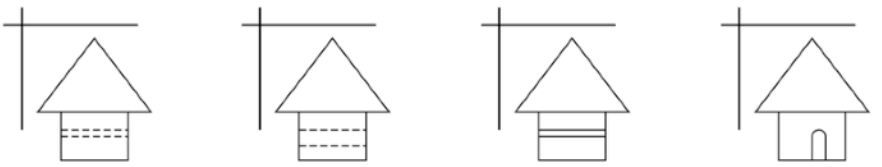

Correct Answer

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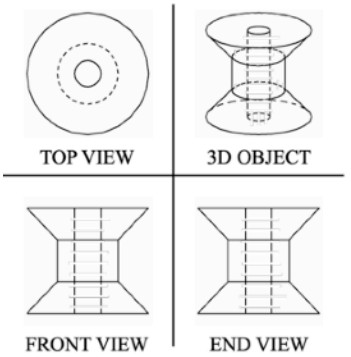

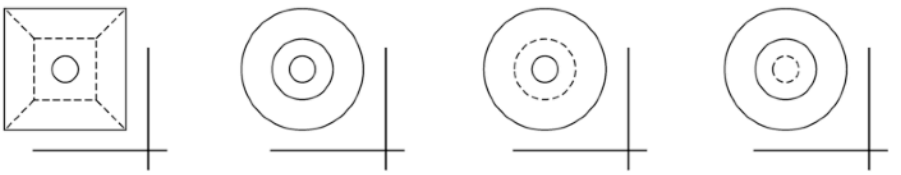

Correct Answer

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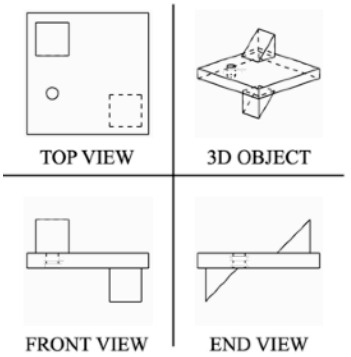

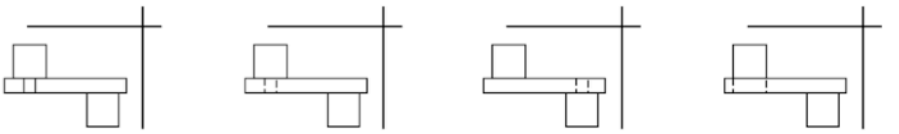

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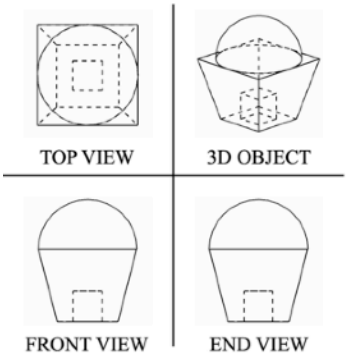

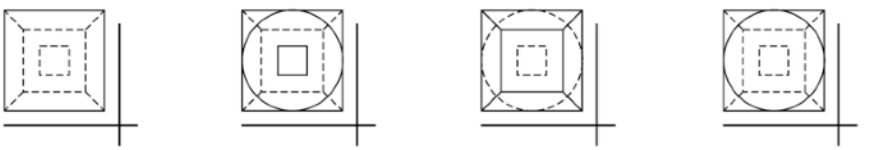

Correct Answer

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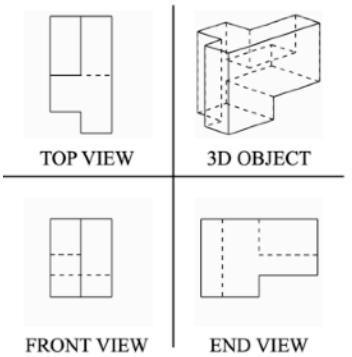

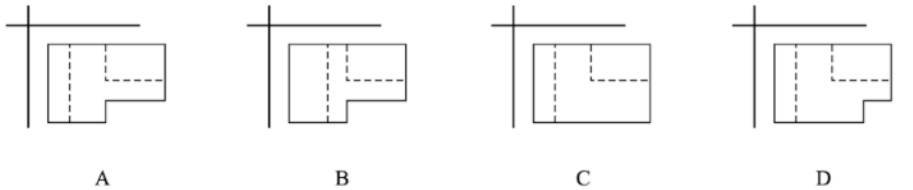

Correct Answer

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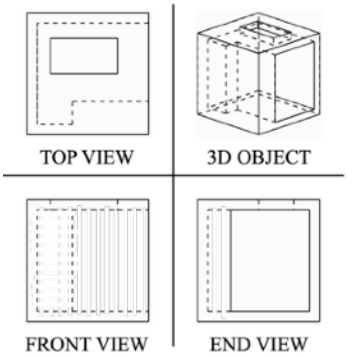

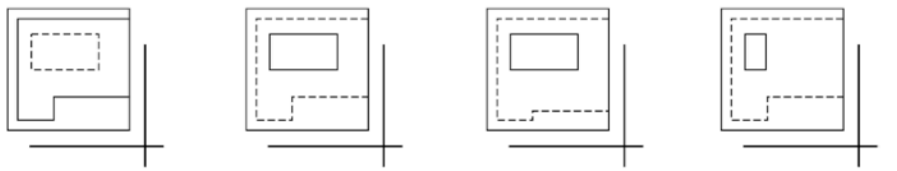

Correct Answer

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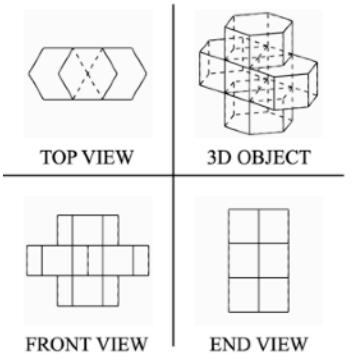

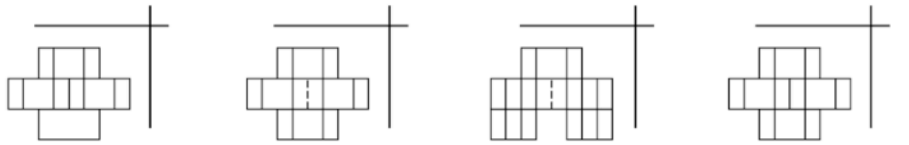

Correct Answer

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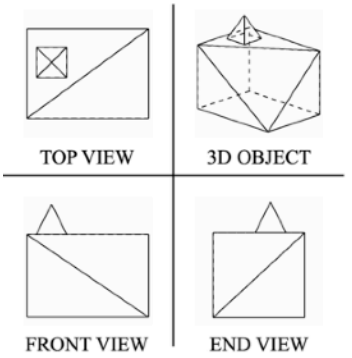
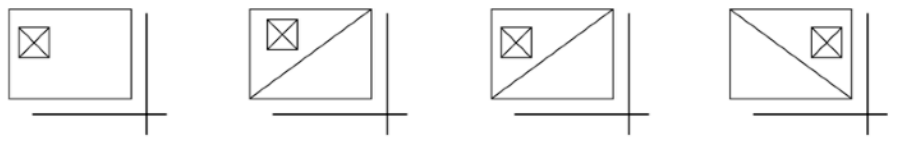
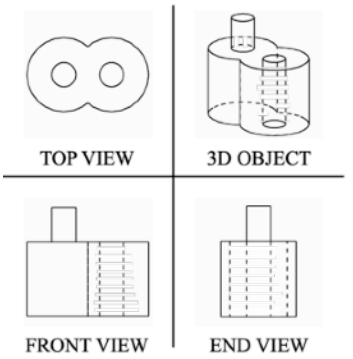
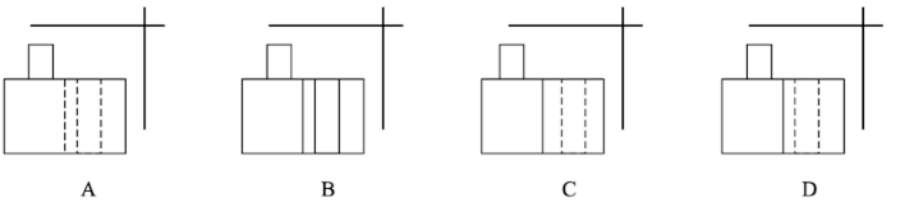




Correct Answer

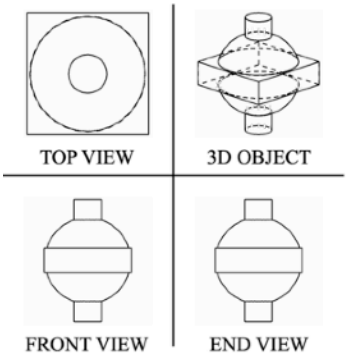
28. Choose the correct FRONT VIEW

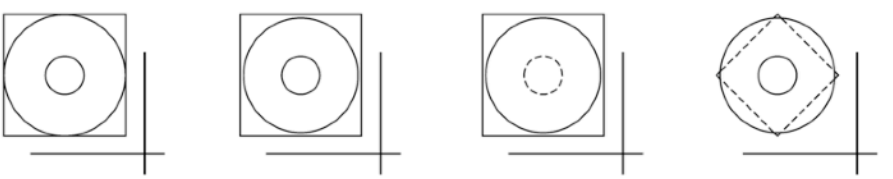




Correct Answer

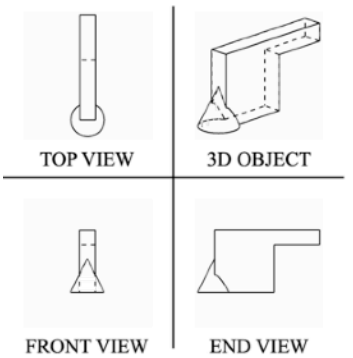
29. Choose the correct TOP VIEW

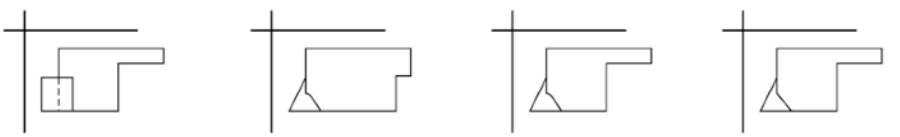




Correct Answer

30. Choose the correct END VIEW





Correct Answer

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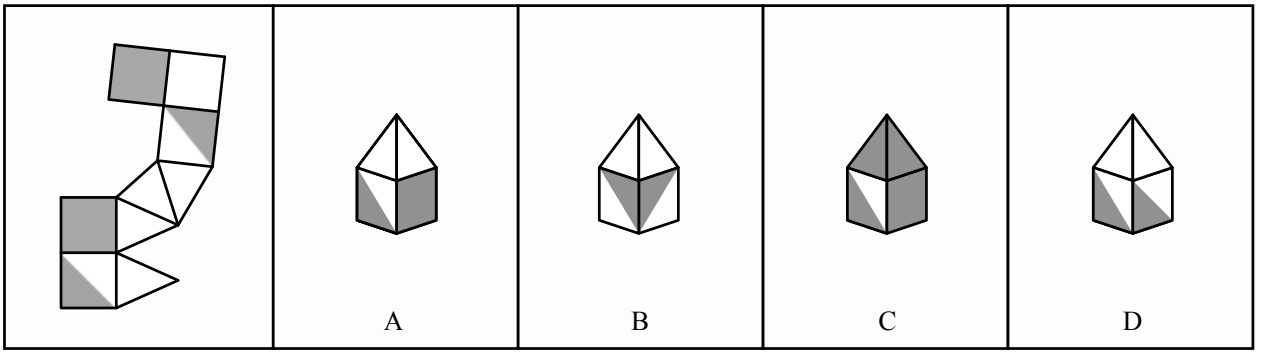

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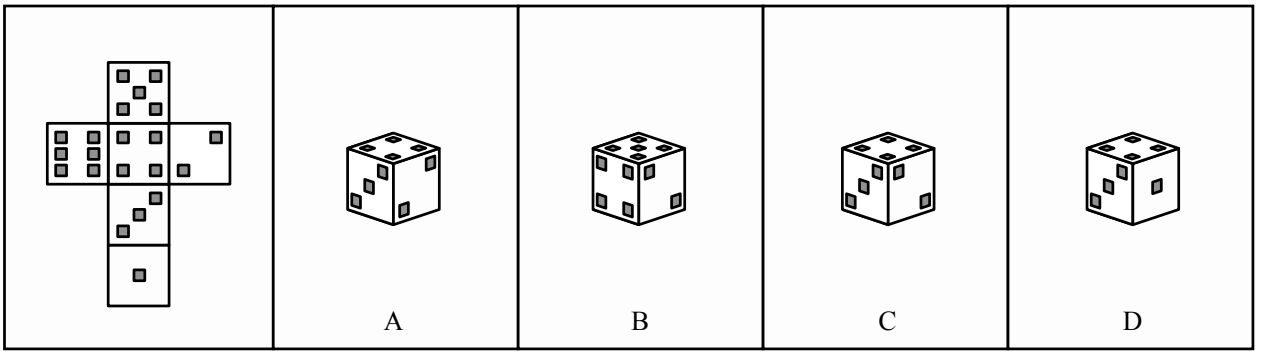

Correct Answer

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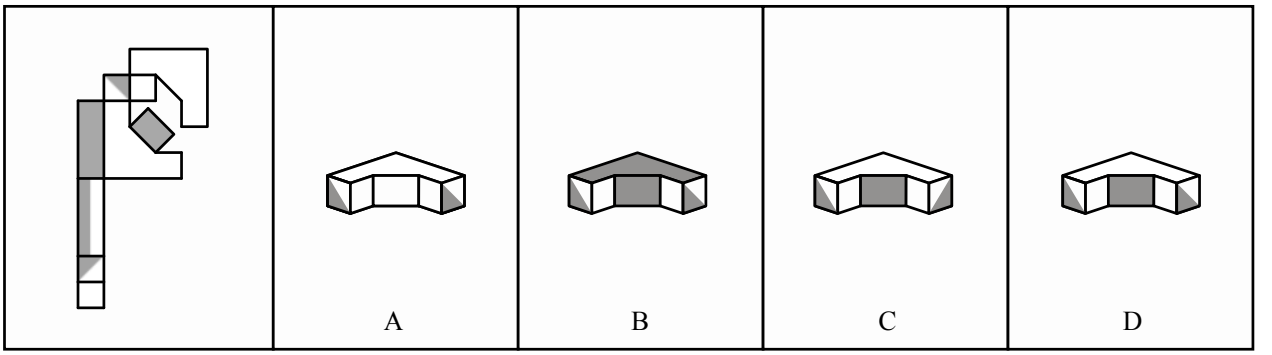

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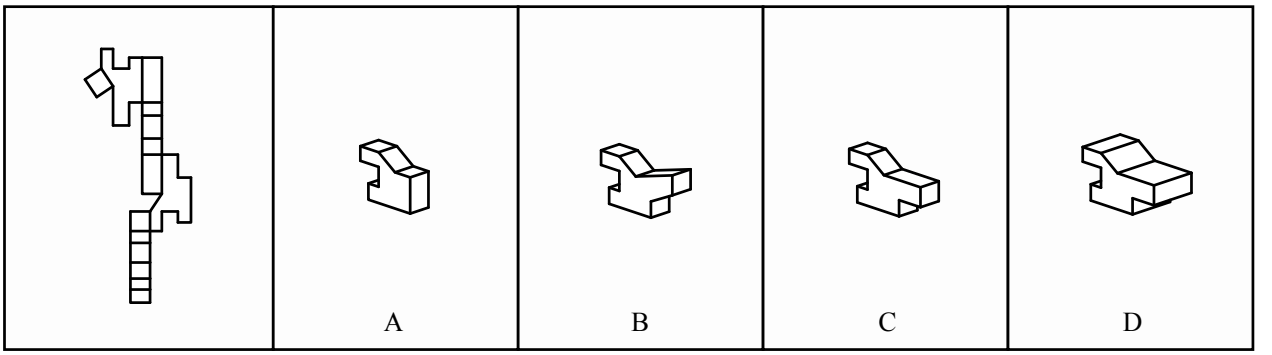

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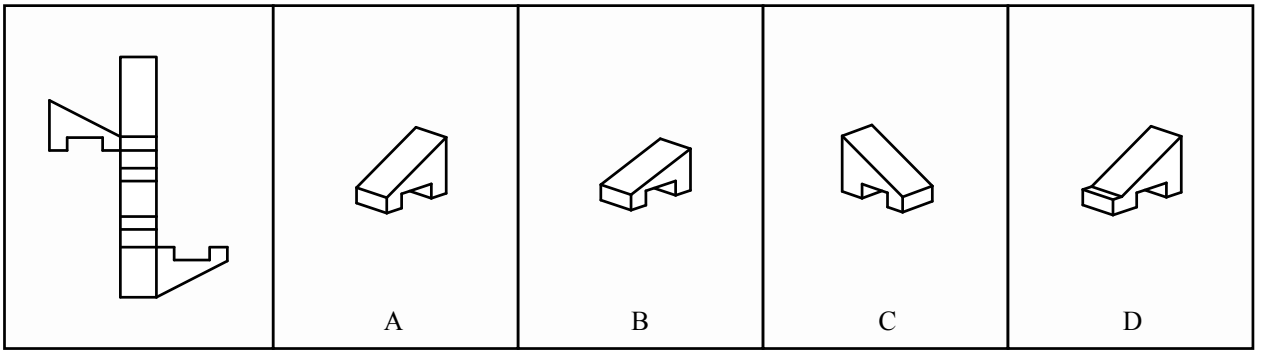

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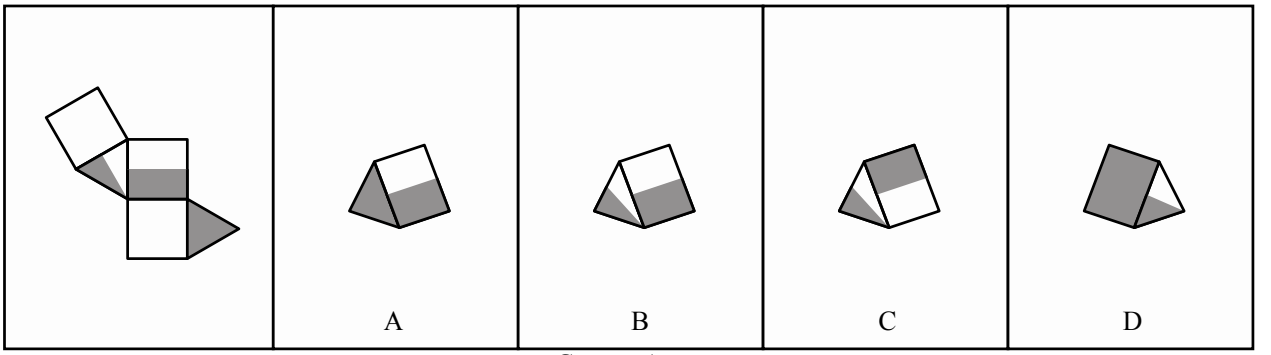

Correct Answer

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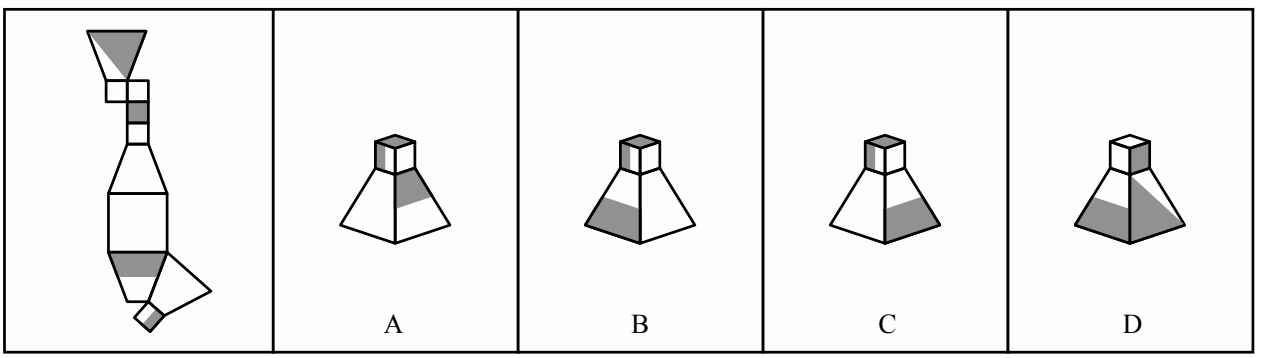

Correct Answer

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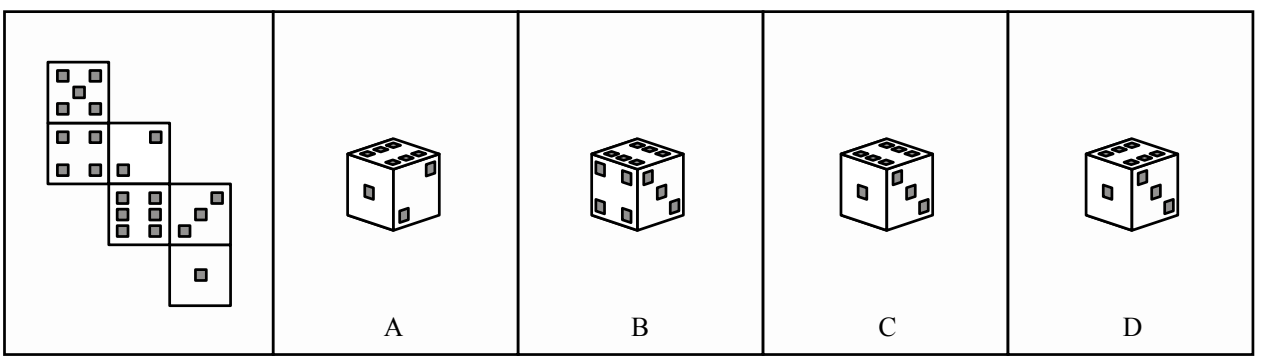

Correct Answer

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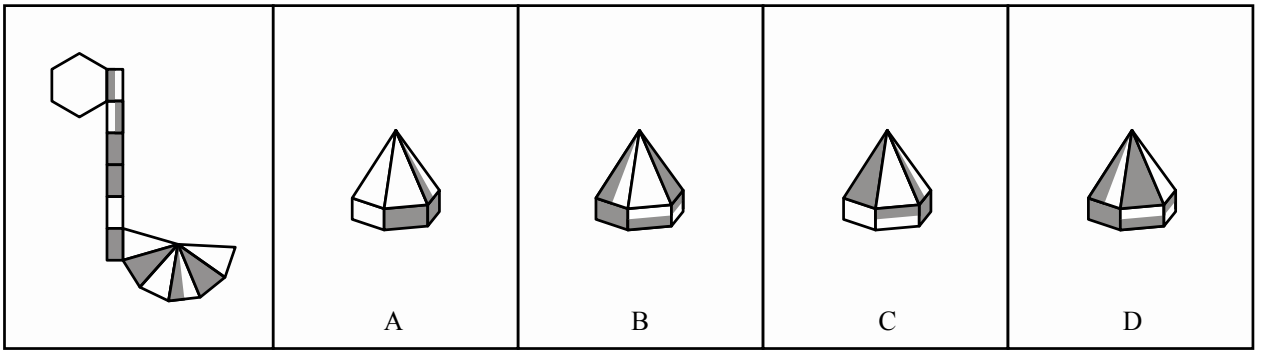

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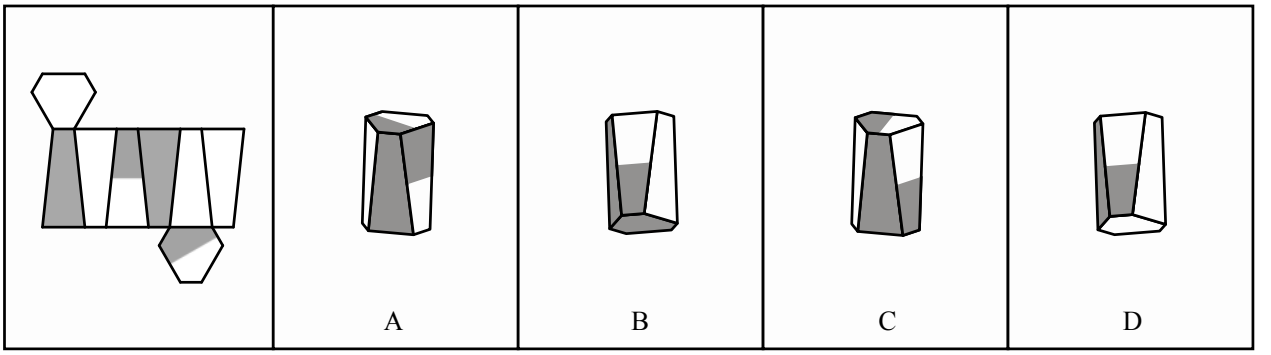

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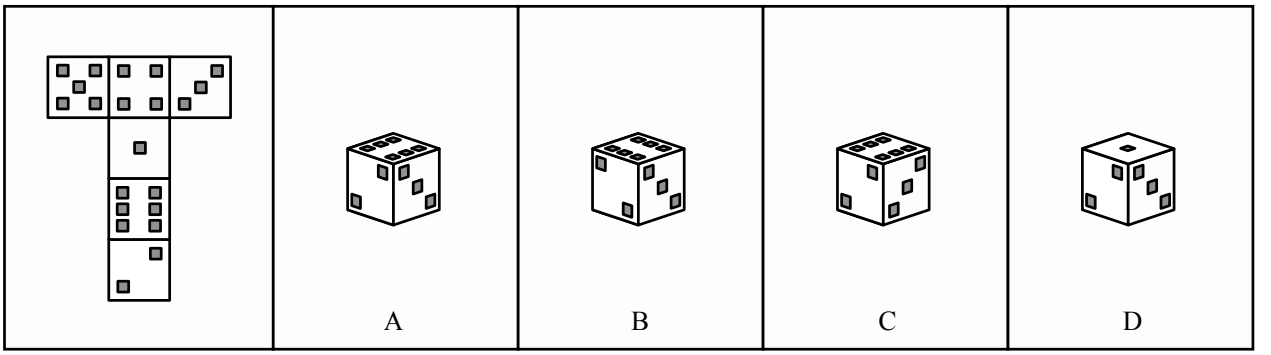

Correct Answer

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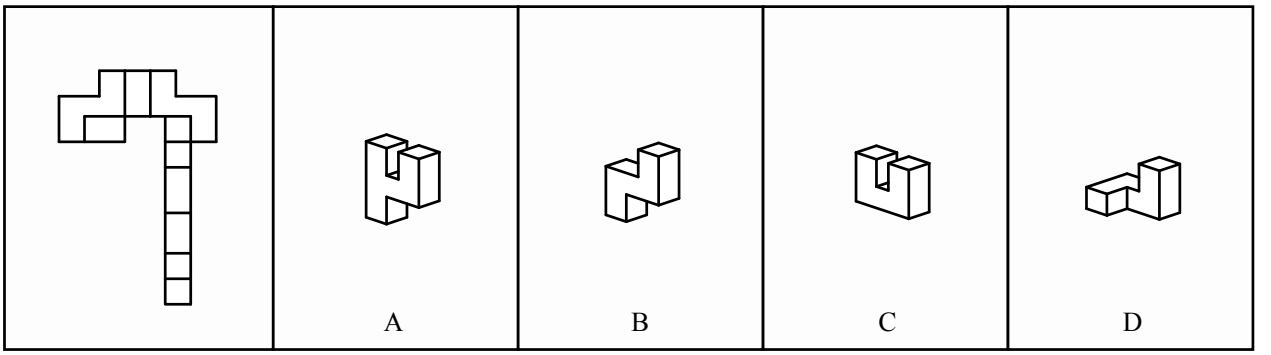

Correct Answer

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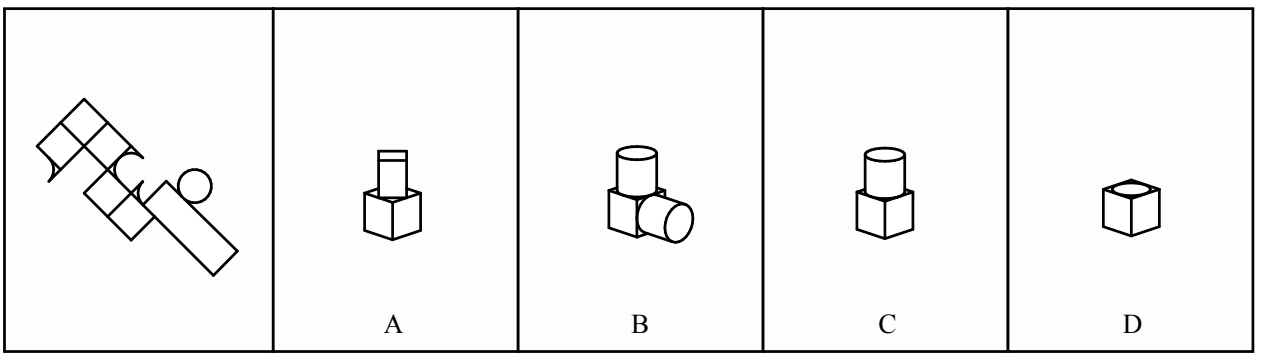

Correct Answer

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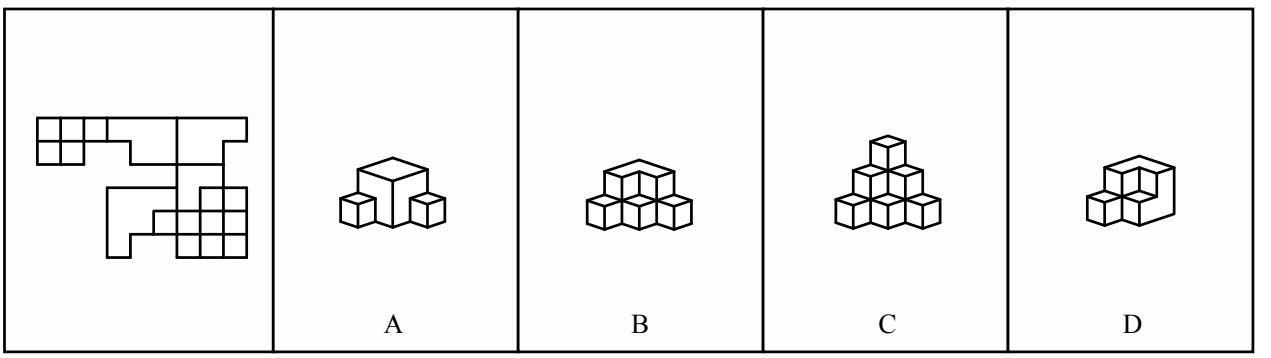

Correct Answer

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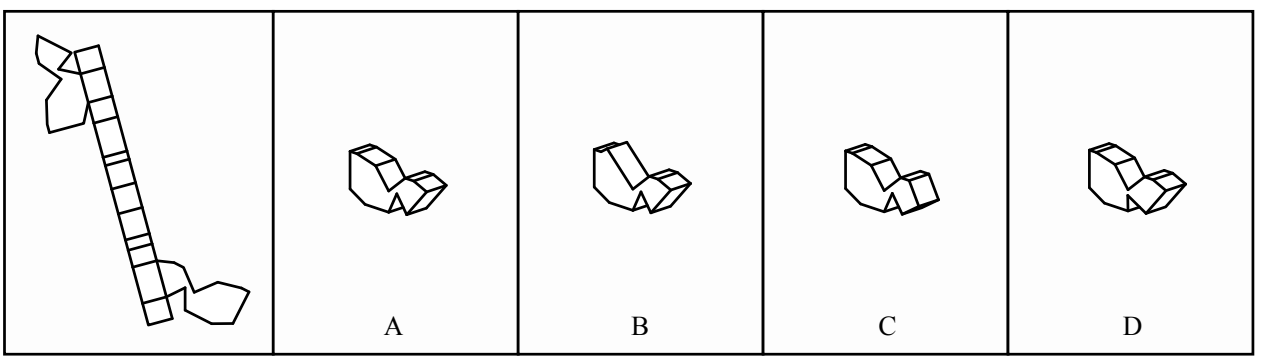


Correct Answer

Solutions – Reading Comprehension Test

1. Which of the following is NOT a reef structure?
   A. Fore reef
   B. Outer reef
   C. Reef crest
   D. Inner reef
   E. Reef floor

   According to the second paragraph, "Three distinct zones are recognized: the fore reef, reef crest, and inner reef". Therefore "outer reef" is not a reef structure

2. Coral reef systems are unique because:
   A. They are composed of calcium carbonate
   B. They are composed of multiple zones
   C. They are one of humankind's greatest conservation challenges
   D. They are composed of both biotic and abiotic structures
   E. They are composed of individual polyps

   According to the first paragraph, "Coral reefs are unique because they consist of both biotic and abiotic structures …"

3. What allows multiple coral polyps to attach to each other?
   A. Protein-based glue
   B. Desmosomes
   C. Calcium carbonate
   D. Calcified hydroxyapatite
   E. Tentacles

   According to the first paragraph, "The polyps feature a prominent exoskeleton, composed of secreted calcium carbonate. Many polyps can also coalesce, held together by the same substance."

4. Which of the following most accurately describes the scale of the Great Barrier Reef?
   A. Larger than Japan
   B. Larger than the United Kingdom, Switzerland, and Netherlands
   C. Larger than the United States, Switzerland, and the Netherlands
   D. As large as the United Kingdom, Switzerland, and Netherlands
   E. As large as the United States, Switzerland, and the Netherlands

   According to the first paragraph, "[the] Great Barrier Reef is the largest living structure on Earth. It is as big in size as Japan, and bigger than the United Kingdom, Switzerland and the Netherlands put together". Option A is incorrect as the passage implies that the reef is equal in size to Japan. Option D is incorrect as the passage implies the reef is larger in size than all three countries combined

5. If you were a coral farmer, where would you choose to grow coral to maximize production?
   A. Reef crest
   B. Fore reef
   C. Reef floor
   D. Inner reef

   According to the second paragraph, "The inner reef is the shallowest zone, which experiences surges and tides. It is also the zone where corals grow the fastest, due to the abundance of sunlight, plankton, and turbulent water …" Therefore a coral farmer would choose the inner reef to maximize production

6. Which of the following is NOT a similarity between a fringing reef and a platform reef?
   A. Both may have a lagoon
   B. Both are attached to the mainland
   C. Both are aquatic ecosystems
   D. Both may host invertebrate animals
   E. Both have multiple zones

   According to paragraph three, "Platform reefs are completely separate from any mainland, forming anywhere on the continental shelf or open ocean." Option A, C, D, and E are incorrect because they are true

7. What is responsible for the coloration of coral?
   A. Coral polyps
   B. Calcium carbonate exoskeleton
   C. Amino acids
   D. Metal-based chromophores
   E. Symbiotic algae

   According to paragraph four, "… the vibrant colours of coral reef systems come from these symbiotic algae, and not from the coral polyps themselves."

8. The Crown-of-Thorns starfish is an invasive species that feed on coral

   The Great Barrier Reef Marine Park authority allows fishing and removal of artefacts

   A. Both statements are TRUE
   B. Both statements are FALSE
   C. The first statement is TRUE, the second is FALSE
   D. The first statement is FALSE, the second is TRUE

   According to paragraph six, "Crown-of-Thorns Starfish (COTS) … are an invasive species that feed on coral." Therefore the first statement is true.

   According to paragraph eight, "[The Marine Park Authority] place strict regulations on fishing, removal of artefacts or wildlife, and set defined routes for commercial shipping." Therefore the second statement is false

9. When was the first documented mass coral bleaching event of the Great Barrier Reef?

   A. 1999
   B. 2002
   C. 2016
   D. 1998
   E. 2017

   According to paragraph five, "Four major events of mass coral bleaching in the Great Barrier Reef have been documented. The first was in 1998, where the majority of corals bleached were mostly along the coast …"

10. The third documented mass bleaching event was the most extensive and severe because it coincided with a decrease in ocean temperatures due to El Nino

    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

    According to paragraph five, "The third [bleaching event] was in 2016, where the increase in ocean temperatures due to El Nino led to the most extensive and severe levels of coral bleaching". Therefore, the statement is true but the reason is false, because El Nino caused an increase (not decrease) in ocean temperatures

11. Which of the following will NOT lead to coral bleaching, either directly or indirectly?

    A. Global warming
    B. Invasive species
    C. Tropical cyclones
    D. Industrial farming
    E. Interspecific competition

    A → Incorrect because according to paragraph five, "One of the primary global stressors is climate change …"
    B → Incorrect because paragraph six talks about the Crown-of-Thorns starfish (COTS), which is an invasive species
    C → Incorrect because according to paragraph six, "Tropical cyclones … can damage coral reefs through the breakage of coral tips and branches …"
    D → Incorrect because according to paragraph six, "Nitrogen run-offs from farm pollution can contribute to the survival and outbreak of COTS by promoting algae blooms …"
    E → Correct answer. Interspecific competition is not mentioned anywhere and is out of the passage's scope

12. How do fish contribute to a positive feedback cycle that speeds up reef degradation?

    A. Bleached coral poison nearby fish, which contribute to algae blooms
    B. Bleached coral cause fish to migrate to unaffected reefs, hindering coral recovery
    C. Bleached coral become dominated by non-symbiotic algae, which attract grazing fish
    D. Fish form a symbiotic relationship with COTS larvae, which colonize the reef
    E. Fish farming leads to algae blooms, which COTS larvae feed on

    A → Incorrect because the passage does not suggest that bleached coral is somehow toxic to fish, nor that fish contribute to algae blooms. In fact, paragraph six states the nitrogen run-off contributes to algae blooms
    B → Correct answer. According to paragraph seven, "Some fish may disperse to unaffected reefs, which have negative consequences on the recovery of damaged reefs."
    C → Incorrect because the passage does not suggest that non symbiotic algae attract grazing fish. In fact, paragraph seven states that fish may disperse to unaffected reefs, implying that they are repelled by bleached coral
    D → Incorrect because the passage does not suggest a symbiotic relationship between fish and the invasive COTS
    E → Although this is possible, it is not explicitly mentioned in the passage. Therefore option B is a better answer

13. The Great Barrier Reef Marine Park authority is responsible for:
    - ***A. Conservation, care, and protection***
    - B. Protection, legislation, and conservation
    - C. Conservation, care, and reclamation
    - D. Conversion, maintenance, and tourism
    - E. Protection, regulation, and reclamation

    According to paragraph eight, "The Great Barrier Reef Marine Park Authority … is responsible for the protection, conservation, and care of the reef."

14. What is not included in the Reef 2050 plan?
    - A. Monitoring of environmental changes
    - B. Reporting of environmental threats
    - C. Report cards
    - ***D. Press releases***
    - E. Strategic investments

    According to paragraph eight, "the Reef 2050 Plan … includes an integrated monitoring and reporting program aimed to detect environmental changes, threats, and future risks to the reefs. As well, report cards are released annually outlining these changes in the reef and its management. The program also helps focus investments on effective strategies that can deliver measurable results". Therefore, the only answer option that is not mentioned is "press releases"

15. Which of the following is the most likely goal of the Sea-quence project?
    - A. Create man-made reef structures
    - ***B. Create transgenic coral that can tolerate increasing sea temperatures***
    - C. Create transgenic coral that can tolerate increasing sea levels
    - D. Create transgenic microbes to augment coral growth
    - E. Create a genetic repository of all reef-building coral species

    According to paragraph nine, "Researchers investigate genetic differences between nine reef-building corals … on the Great Barrier Reef and the same coral species in the Red Sea that allow these corals to survive at higher temperatures." Therefore, the author implies that the purpose of the project is to find and take advantage of genes that allow corals to tolerate higher sea temperatures

16. The author of this passage is most likely to recommend which of the following reef restoration strategies?
    - A. Coral transplantation
    - B. Genetic engineering
    - ***C. Voltage-mediated reef regrowth***
    - D. Increased government legislation
    - E. Population control of invasive species

    Based on the author's enthusiastic tone in paragraph eleven, it is implied that voltage-mediated reef regrowth (Biorock) is the recommended reef restoration strategy: "Of greatest interest is an incredibly novel field restoration effort … This new technology, safe to both animals and humans, is known as Biorock." Options A, B, and D are incorrect as the author presents these strategies in an informative and unbiased tone. Option E is incorrect because the passage never mentions population control of invasive species

17. What is the correct order of structures, from smallest to largest?
    - A. Cluster < polyp < zone < reef
    - B. Reef < polyp < zone < cluster
    - C. Polyp < zone < reef < cluster
    - ***D. Polyp < cluster < zone < reef***
    - E. Polyp < cluster < reef < zone

    We know that a polyp must be smaller than a cluster because according to the first paragraph, "Each visible coral "cluster" is actually composed of many individual polyps.

    We also know that zones must be smaller than reefs because according to the second paragraph, "Coral reef formations are complex ecosystems that are composed of multiple zones"

18. A study on coral transplantation showed a:
    - A. 25% 28-month survivorship of 530 subjects
    - ***B. 51% 28-month survivorship of 530 subjects***
    - C. 25% 7-month survivorship of 530 subjects
    - D. 51% 28-month survivorship of 350 subjects
    - E. 25% 7-month survivorship of 350 subjects

    According to paragraph ten, "… one case study following 530 transplants over 28 months [found] a survivorship of only 51%, with 25% mortality occurring in the first 7 months as a result of wave action."

19. Which of the following best describes the author's tone?
    A. Sombre
    B. Casual
    C. Informative
    D. Skeptical
    E. Satirical

    A → Incorrect because "sombre" would refer to a dark and serious mood throughout the passage
    B → Incorrect because "casual" would mean the author sounds relaxed and unconcerned about the topic
    C → Correct answer. The author is seeking to inform the reader in an objective, nonjudgemental manner
    D → Incorrect because "skeptical" would mean the author expresses disapproving comments throughout, seeking to undermine the opposing viewpoint
    E → Incorrect because "satirical" would involve the use of irony to ridicule or mock an entity

20. This passage is best suited for which of the following contexts?
    A. Tourism pamphlet
    B. Government website
    C. Investor annual report
    D. Magazine article
    E. Debate script

    A → Incorrect because the passage is too academic to be suitable for a tourism pamphlet
    B → Correct answer. The passage's informative tone suggests that it could be found on a government website
    C → Incorrect because the passage's main point does not focus on topics that would be of interest to investors
    D → Incorrect because the passage is too academic to be suitable for a magazine article
    E → Incorrect because the passage does not seek to convince the reader or refute opposing arguments

21. Which scientist first demonstrated that DNA was the carrier of hereditary information?
    A. Francis Crick
    B. James Watson
    C. Alexander Todd
    D. Oswald Avery
    E. Jerry Donohue

    According to the second paragraph, "… Oswald Avery had shown that DNA was the 'transforming principle,' the carrier of hereditary information, in pneumococcal bacteria."

22. Which of the following technologies was NOT enabled by the discovery of the double helix?
    A. Monoclonal antibodies
    B. Gene sequencing
    C. Western blotting
    D. Genetic engineering
    E. Recombinant DNA

    According to the first paragraph, "[the discovery] helped to produce new and powerful scientific techniques, specifically recombinant DNA research, genetic engineering, rapid gene sequencing, and monoclonal antibodies …"

23. Which of the following partially explains why Crick attempted to prevent the publication of Watson's book?
    A. The book was scientifically unsound
    B. The book invaded Crick's privacy
    C. The book portrayed Watson in a poor light
    D. The title was understated
    E. Crick was listed as second author

    According to paragraph ten, "Crick was incensed at Watson's depiction of their collaboration in The Double Helix (1968), castigating the book as a betrayal of their friendship, an intrusion into his privacy, and a distortion of his motives"

24. Watson and Crick first met each other in:
    A. 1944
    B. 1950
    C. 1953
    D. 1951
    E. 1968

    According to paragraph three, "They seized on this problem during their very first encounter, in the summer of 1951"

25. According to the author, which of the follow was responsible for Watson and Crick's success?
    A. Their extensive DNA experimentation
    B. Their identical scientific backgrounds
    C. Their ambition, intelligence, and bravery
    D. Their tenacity, collaborative spirit, and charisma
    E. Their persistence, luck, and intuition

    According to paragraph three, "… and relying on their brilliant intuition, persistence, and luck, the two showed that DNA had a structure sufficiently complex and yet elegantly simple enough to be the master molecule of life."

26. Which of the following correctly pairs the scientist with their contribution?
    A. Pauling; X-ray images of DNA
    B. Wilkins; Purine/pyrimidine ratios
    C. Pauling; Discovery of alpha helix
    D. Wilkins; Model building technique
    E. Donohue; Composition of DNA backbone

    According to paragraph four, "Linus Pauling, then the world's leading physical chemist, had recently discovered the single-stranded alpha helix …"

27. At what angle do nitrogenous bases connect with the DNA backbone in a double helix?
    A. 30°
    B. 45°
    C. 60°
    D. 90°
    E. 120°

    According to paragraph five, "The bases connected to the two backbones at right angles …"

28. The author views Watson and Crick's use of Franklin's data as controversial because:
    A. No consent was provided
    B. The evidence was used inappropriately
    C. Little acknowledgement was given
    D. It was an intrusion into her privacy
    E. Franklin's cancer was likely due to the X-rays

    According to paragraph eleven, "Franklin's superb experimental work thus proved crucial in Watson and Crick's discovery. Yet, they gave her scant acknowledgment."

29. Watson and Crick first published their findings in Nature on May 30

    The original Nature article was immediately met with great enthusiasm and praise
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

    According to paragraph six, "Watson and Crick published their findings in a one-page paper … in the British scientific weekly Nature on April 25, 1953 …" Therefore the first statement is false.

    According to paragraph eight, "Although recognized today as one of the seminal scientific papers of the twentieth century, Watson and Crick's original article in Nature was not frequently cited at first." Therefore the second statement is also false

30. Prior to 1953, most scientists believed:
    A. DNA had a heterogenous structure
    B. DNA is a complex molecule
    C. DNA was a double helix
    D. Hereditary material is carbohydrate-based
    E. Hereditary material is protein-based

    According to the second paragraph, "… many scientists continued to believe that DNA had a structure too uniform and simple to store genetic information for making complex living organisms. The genetic material, they reasoned, must consist of proteins, much more diverse and intricate molecules known to perform a multitude of biological functions in the cell."

31. What eventually solidified Watson and Crick's theory as correct?
    A. Crystallography by Franklin
    B. Laboratory experiments by Meselson and Kornberg
    C. Elucidation of a replication mechanism
    D. Laboratory experiments by Wilkins
    E. Discovery of base pair hydrogen bonding

    According to paragraph eight, "towards the end of the 1950s … their conclusions were confirmed in the laboratory by Matthew Meselson, Arthur Kornberg, and others."

32. According to Watson and Crick, what was essential for understanding heredity?
    A. Understanding gene sequences
    B. Understanding DNA composition
    C. Understanding gene structure
    D. Understanding the central dogma
    E. Understanding DNA replication

    According to paragraph three, "Crick and Watson recognized, at an early stage in their careers, that gaining a detailed knowledge of the three-dimensional configuration of the gene was the central problem in molecular biology."

33. Chargaff discovered that complementary bases always appeared in a ratio of two-to-one

    Pauling proposed a model of DNA months before Watson and Crick published

    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

    According to paragraph four, "Chargaff had found that while the amount of DNA and of its four types of bases – the purine bases adenine (A) and guanine (G), and the pyrimidine bases cytosine (C) and thymine (T) – varied widely from species to species, A and T always appeared in ratios of one-to-one, as did G and C." Therefore the first statement is false.

    According to paragraph four, "… Crick and Watson feared that they would be upstaged by Pauling, who proposed his own model of DNA in February 1953 …". Since this date is before Watson and Crick's paper in April 25, 1953, the second statement is true

34. Crick used cardboard models to arrive at the proper base pairing structure because Donohue pointed out that the textbook configuration for the rings of bases were incorrect

    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

    According to paragraph five, "On February 28, 1953, Watson, acting on Donohue's advice, put the two bases into their correct form in cardboard models …" Therefore the statement is incorrect.

    According to paragraph five, "Jerry Donohue … pointed out that the configuration for the rings of carbon, nitrogen, hydrogen, and oxygen (the elements of all four bases) in thymine and guanine given in most textbooks of chemistry was incorrect." Therefore the reason is correct

35. The X-ray diffraction pattern of DNA showed that the backbone:

    A. Ran in the same direction
    B. Ran in opposite directions
    C. Was arranged as a triple helix
    D. Was arranged as a beta helix
    E. Was arranged as a single-stranded helix

    According to paragraph five, "… the complementary pairing of the bases was compatible with the fact, also established by the X-ray diffraction pattern, that the backbones ran in opposite direction to each other, one up, the other down."

36. Which of the following is NOT one of the widely accepted definitions of free will?

    A. The ability to do what you want
    B. A relationship between the sources of our actions and the actions themselves
    C. The ability to evoke alternative possibilities to reality
    D. A relationship between morality and reality

    A → Incorrect because this is the definition of "easy freedom" discussed in paragraph four
    B → Incorrect because this is the "source view of freedom" discussed in paragraph six
    C → Incorrect because this is the "Garden of Forking Paths" model discussed in paragraph five
    D → Correct answer. Morality is never discussed as a definition for free will

37. What is the purpose of the first paragraph?

    A. To suggest that Quinn did not consciously decide not to study
    B. To introduce the idea of free will
    C. To provide an example of determinism
    D. To introduce a counterargument against a widely accepted view
    E. To present a definition for free will

    A → Incorrect because the first paragraph suggests that Quinn did have the capacity to decide whether to study or not
    B → Correct answer. The question "How much control do people exercise over who they are and what they do?" Introduces the idea of free will
    C → Incorrect because determinism is not mentioned
    D → Incorrect because the paragraph does not argue a point
    E → Incorrect because free will is not defined until paragraph four

38. Which of the following is necessary in order to understand why humans act freely?
    A. Understand the concept of determinism
    B. Define moral responsibility
    C. Understand the difference between internal and external factors
    D. Define free will
    E. Understand the physiology of unconscious brain processes

According to paragraph three, "To investigate whether or not humans sometimes act freely, we need to first clarify what is meant by free will."

39. According to most philosophers, free will enables humans to:
    A. Have direct control over reality
    B. Choose between right and wrong
    C. React to blame or praise
    D. Always make the responsible decision
    E. Anticipate the consequences of their actions

According to paragraph three, "… most philosophers today who write on free will have in mind the kind of control required for morally responsible action. That is, to ask whether or not someone is free is to ask whether or not they have control over their actions such that they are deserving of blame or praise for what they do (or fail to do)."

40. What does the author refer to as "easy freedom"?
    A. Situations in which our decisions have no moral and ethical implications
    B. A simplified definition of free will
    C. Situations in which the free agent is the source of our actions
    D. The Garden of Forking Paths
    E. The theory of determinism

According to paragraph four, "Most accounts of freedom fall into one of three camps. Some people take freedom to require merely the ability to 'do what you want to do.' … We will call this easy freedom." Therefore the author uses the term "easy freedom" to refer to one of the three definitions of free will

41. Free-will skeptics suggest that:
    A. Internal factors are a major influence over our thoughts and actions
    B. Determinism is incompatible with free will
    C. Our thoughts and actions are mainly the result of external factors
    D. The Garden of Forking Paths model is incompatible with free will
    E. People should not be held accountable for their actions

According to paragraph two, the author asks "Are we really in control of who we are and what we do? Or are free will skeptics correct to claim that the things we do and the way that we are is ultimately the consequent of external factors beyond our control?"

A → Incorrect because skeptics suggest that external factors are a major influence, not internal factors
B → Incorrect because this idea is neither presented or argued
C → Correct answer
D → Incorrect because this idea is neither presented or argued
E → Incorrect because this idea is too extreme and beyond the scope of the passage

42. Which of the following statements regarding determinism is INCORRECT?
    A. Only a single future is possible
    B. Information about the past can be used to predict the future
    C. There is no such thing as a truly free action
    D. Determinism is often viewed as incompatible with free will

A → Incorrect because this statement is true. Paragraph seven states "determinism is the view that at any one time, only one future is physically possible"
B → Incorrect because the statement is true: "determinism is the view that a complete description of the past along with a complete account of the relevant laws of nature logically entails all future events."
C → Correct answer. This idea is never stated
D → Incorrect because the statement is true: "Determinism and free will are often thought to be in deep conflict"

43. Based on the final paragraph, with which statement would the author most likely agree?
    A. No one should be held responsible for their decisions
    B. True moral responsibility is meaningless
    C. The consequences of an action is always the fault of the decision maker
    D. We should all try to make our own decisions, even though it is unclear if we have free will
    E. We should all adopt an apathetic attitude towards our decisions

    A → Incorrect because the author does not advocate this viewpoint at all. The tone is informative and unbiased
    B → Incorrect because the author does not advocate this
    C → Incorrect because this answer is too extreme
    D → Correct answer. The author is unbiased towards both free-will advocates and skeptics. However, the author states that being "influenced by the world is different from being determined by it" and suggests that we should exercise some control over our actions, even if nobody knows whether true free will exists
    E → Incorrect because the author advocates the exact opposite of this

44. What does the Garden of Forking Paths describe?
    A. The existence of multiple "paths" of possibility required for free will
    B. The quantized nature of decisions
    C. The field of philosophy branching into the three camps of free will
    D. The external influence of our environment
    E. The burden of moral responsibility

    According to paragraph five, the Garden of Forking Paths model states "The key to freedom, then, is alternative possibilities …" In the garden analogy, these alternative probabilities are the multiple "paths" that are required for true free will

45. What is the overall tone of this passage?
    A. Argumentative
    B. Critical
    C. Impartial
    D. Defensive
    E. Enthusiastic

    A → Incorrect because the author does not argue for one side or the other. Rather, the passage is objective and unbiased
    B → Incorrect because the author does not critique any of the definitions or concepts presented
    C → Correct answer. The author remains objective throughout the passage
    D → Incorrect because the author does not present nor defend their own ideas or arguments
    E → Incorrect because the author does not use any explicit words that convey enthusiasm such as incredible, interesting, thought-provoking, novel, engaging, amazing, etc

46. According to the author, which of the following has a long history?
    A. Morality
    B. Free will
    C. Ethics
    D. Freedom
    E. Philosophy

    According to paragraph three, "The discussion of freedom has a long history and free will has been used to apply to a multitude of, often radically different, abilities and capacities that people may, or may not, have."

47. In the context of the second paragraph, what best describes the author's meaning of "unconscious"?
    A. The state of being asleep
    B. Unable to respond to external stimuli
    C. A process that occurs automatically, without introspection
    D. A reservoir of all thoughts, feelings, and urges of the mind
    E. The reservoir of all repressed thoughts

    In the context of this paragraph, the word "unconscious" is used to describe the state of not being "in control". The other answer choices describe different connotations of the word

48. What is the free agent?

A. The ultimate source of our actions
B. An individual with free will
C. An important component of easy freedom
D. The illusion of freedom
E. The sum of internal and external influences

According to paragraph six, "Sometimes [freedom] is explained by saying that the free agent is the source, perhaps even the ultimate source of her action."

49. What is the purpose of the last sentence of the passage?

A. To summarize the arguments presented
B. To undermine the passage's main point
C. To evoke thought and discussion among readers
D. To end the passage on a humorous note
E. To stress the urgency of this issue

A → Incorrect because the passage does not present arguments, but rather simply informs the reader
B → Incorrect because the author does not attempt to summarize any of the three definitions of freedom presented
C → Correct answer. The rhetorical questions presented in this paragraph suggest the author is trying to provoke thought and discussion
D → Incorrect because there is no attempt at humour
E → Incorrect because the author does not convey that the topics presented in the passage are urgent or require action

50. What is the relationship between the first and second paragraph?

A. To lead the reader down a train of thought, and then to disrupt it with a contrasting idea
B. To present a problem, followed by a possible solution
C. To present an argument about an issue, and then to undermine it
D. To present an argument about an issue, and then to strengthen it
E. To present a lengthy anecdote, and then to conclude it with a moral lesson

A → Correct answer. The first paragraph suggests to the reader that Quinn had full autonomy over her decision. The second paragraph questions her autonomy
B → Incorrect because no problem or solution is presented
C → Incorrect because no arguments are presented
D → Incorrect because no arguments are presented
E → Incorrect because morality is not discussed until paragraph three

FULL-LENGTH 1 LOWER DIFFICULTY

SCORE CONVERSION SCALE

Biology		Chemistry		PAT		RCT	
Percent →	DAT Score	Percent →	DAT Score	Percent →	DAT Score	Percent →	DAT Score
1–5%	0	1–5%	0	1–5%	0	1–5%	0
5–10%	1–3	5–10%	1–3	5–10%	1–3	5–10%	1–3
10–15%	3–5	10–15%	3–5	10–15%	3–5	10–15%	3–5
15–20%	5–8	15–20%	5–8	15–20%	5–8	15–20%	5–8
20–25%	8–10	20–25%	8–10	20–25%	8–11	20–25%	9
25–30%	11	25–30%	11	25–30%	11–13	25–30%	10
30–35%	12	30–35%	12	30–35%	14	30–35%	11
35–40%	13	35–40%	13	35–40%	15	35–40%	12
40–45%	14	40–45%	14	40–45%	16	40–45%	13
45–50%	15	45–50%	15	45–50%	17	45–50%	14
50–55%	16	50–55%	16	50–55%	18	50–55%	15
55–60%	17	55–60%	17	55–60%	19	55–60%	16
60–65%	18	60–65%	18	60–65%	20	60–65%	17
65–70%	20	65–70%	20	65–70%	22	65–70%	18
70–75%	22	70–75%	22	70–75%	23	70–75%	19
75–80%	23	75–80%	23	75–80%	25	75–80%	20
80–85%	24	80–85%	24	80–85%	27	80–85%	22
85–90%	26	85–90%	26	85–90%	28	85–90%	24
90–95%	28	90–95%	28	90–95%	29	90–95%	27
95–100%	30	95–100%	30	95–100%	30	95–100%	30

FULL-LENGTH 2 MEDIUM DIFFICULTY

SURVEY OF THE NATURAL SCIENCES

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Survey of Natural Sciences:

1. Each item is a question and/or incomplete statement followed by possible answers or completions. Read the item, decide which answer choice is the best, and bubble in the corresponding circle on the answer sheet
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 60 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. **DO NOT TURN PAST THE STOP PAGE AND ON TO THE NEXT SECTION UNTIL INSTRUCTED**
6. At the end of this section, the answer sheet is collected. The booklet remains at your table for use during the next section

TIME LIMIT:
60 minutes

TEST NAME:
SNS

TEST NUMBER:
02

This is a DAT simulation.

This section is composed of 70 questions:
Biology (1-40) and General Chemistry (41-70)

1. Which embryonic germ tissue develops into the musculoskeletal system?
   A. Ectoderm
   B. Epiderm
   C. Mesoderm
   D. Endoderm
   E. Neural crest

2. Which structure stores chromosomal DNA within bacteria?
   A. Capsule
   B. Nucleus
   C. Plasmid
   D. Nucleolus
   E. Nucleoid

3. Which of the following animals is an acoelomate?
   A. Starfish
   B. Snail
   C. Earthworm
   D. Nematode
   E. Lobster

4. If a male with type B^+ blood and a female with type AB^- blood have children, which of the following would NOT be a possible blood type for their progeny?
   A. AB^+
   B. B^+
   C. AB^-
   D. O^+
   E. B^-

5. In a sample of dysfunctional tissue, the epithelium no longer adheres to the basement membrane. Which of the following components is most likely damaged?
   A. Desmosome
   B. Tight junction
   C. Gap junction
   D. Adherens junction
   E. Hemidesmosome

6. Which of the following ocular structures contains the highest density of cone cells?
   A. Retina
   B. Sclera
   C. Fovea
   D. Iris
   E. Cornea

7. A rodent runs away from a lightbulb as soon as it is turned on. What is this an example of?
   A. Chemotaxis
   B. Photokinesis
   C. Chemokinesis
   D. Phototaxis
   E. Fixed action pattern

8. A male mates with a female who's father was colour-blind. If the couple has three children, what is the probability that all three will be both male and colour-blind?
   A. $\frac{1}{16}$
   B. $\frac{1}{64}$
   C. $\frac{1}{256}$
   D. $\frac{1}{4}$
   E. $\frac{1}{2}$

9. During which phase of meiosis does synapsis or crossing-over occur?
   A. Anaphase I
   B. Telophase I
   C. Prophase I
   D. Metaphase II
   E. Prophase II

10. Top-level predators (such as humans) are at greatest risk for ingesting relatively high levels of heavy metals in fish. Which of the following phenomena is most responsible for this?
    A. Parasitism
    B. Bioaccumulation
    C. Bottom-up model
    D. Biological magnification
    E. Top-down model

11. Which of the following lists is sorted in the correct order of taxonomic hierarchy?
    A. Class, Domain, Phylum, Family, Genus
    B. Domain, Phylum, Class, Family, Genus
    C. Family, Genus, Class, Domain Phylum
    D. Genus, Family, Class, Phylum, Domain
    E. Class, Phylum, Domain, Family, Genus

12. What is the role of the ascending loop of Henle in the urinary system?
    A. Resorb sodium from the filtrate
    B. Resorb water from the filtrate
    C. Filter blood plasma via hydrostatic pressure
    D. Resorb glucose and amino acids
    E. Secrete sodium into the filtrate

13. A population of wolves are in Hardy-Weinberg equilibrium. The allele for grey fur (F) has a frequency of 0.11, and the allele for white fur (f) has a frequency of 0.89. What is the percentage of heterozygotes in the population?
    A. 0.18
    B. 0.82
    C. 0.81
    D. 0.01
    E. 0.5

14. Which of the following cells are involved in both innate and adaptive immunity?
    A. Plasma cells
    B. Neutrophils
    C. Natural killer cells
    D. Macrophages
    E. Regulatory T cells

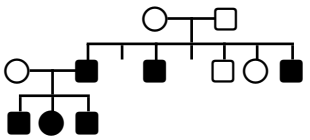
15. Two psychiatric patients both have a NCID1 gene deletion. One develops bipolar disorder, while the other develops intellectual disability. Which of the following best describes this phenomenon?
    A. Epistasis
    B. Pleiotropy
    C. Polygenetic inheritance
    D. Low penetrance
    E. X inactivation

16. Which of the following biomes have the highest level of biodiversity?
    A. Boreal forest
    B. Tropical forest
    C. Marine
    D. Savanna
    E. Temperate forest

17. After intense exercise, levels of ___ are low and levels of ___ are high in the blood
    A. CO_2; ethanol
    B. O_2; ethanol
    C. CO_2; lactate
    D. O_2; lactate
    E. O_2; insulin

18. Which of the following describes the proliferative phase of the menstrual cycle?
    A. Endometrium thickens in preparation for implantation of the blastocyst
    B. Endometrium is shed in the form of a period
    C. Endometrium thickens in preparation for implantation of the zygote
    D. Implantation occurs and estrogen is produced by the corpus luteum
    E. Granulosa cells of the corpus luteum begin to produce progesterone and inhibin

19. A genetic disease is identified to have the following pedigree within a family of dogs. What is the most likely inheritance pattern?



    A. Autosomal recessive
    B. Autosomal dominant
    C. X-linked recessive
    D. X-linked dominant
    E. Y-linked

20. At which stage during embryonic development does the three germ layers form?
    A. Neurulation
    B. Blastulation
    C. Cleavage
    D. Organogenesis
    E. Gastrulation

21. Which of the following series of events occurs during anaphase?
    A. Spindle fibres attach to chromatids via the kinetochore; formation of the metaphase plate
    B. Chromosomes condense; centrioles move to poles; mitotic spindle forms; nuclear membrane dissolves
    C. Centrosomes split and chromatids get pulled towards the poles
    D. Spindle dissolves; nuclear membrane reforms; chromosomes uncoil
    E. A cleavage furrow forms in animal cells and a cell plate forms in plant cells to divide the organelles and cytoplasm into two daughter cells

22. Which of the following cells actively engage in bone formation?
    A. Osteocytes
    B. Osteoblasts
    C. Chondrocytes
    D. Osteoclasts
    E. Chondroblasts

23. Which of the following factors are NOT required for evolution to occur?
    A. Variation
    B. Overpopulation
    C. Inheritance
    D. Non-random mating
    E. Natural selection

24. Which of the following plant structures is involved in the mass transport of sugar?
    A. Stomata
    B. Plasmodesmata
    C. Vessel elements
    D. Sieve tube elements
    E. Tracheids

25. Which of the following extraembryonic membranes is the umbilical chord derived from in placental animals?
    A. Yolk sac and allantois
    B. Chorion and amnion
    C. Allantois and chorion
    D. Yolk sac and amnion
    E. Chorion and yolk sac

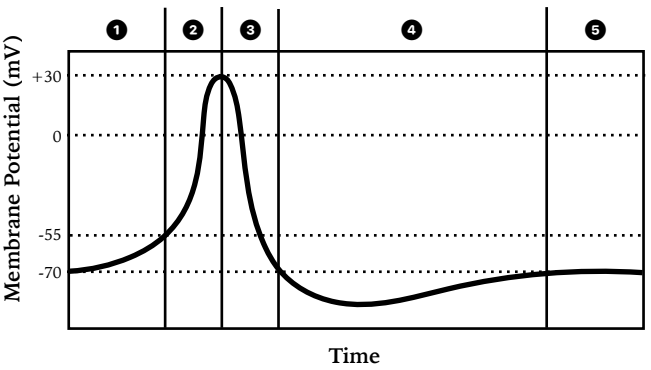
26. Which of the following cells is NOT found in the small intestine?
    A. Enterocytes
    B. Mucus neck cells
    C. Paneth cells
    D. Goblet cells
    E. S cells

27. Which of the following is the correct order of muscle organization, from largest to smallest?
    A. Fascicle, muscle, fiber, myofibril, sarcomere
    B. Muscle, fiber, fascicle, myofibril, sarcomere
    C. Muscle, fascicle, fiber, myofibril, sarcomere
    D. Myofibril, sarcomere, muscle, fascicle, fiber
    E. Sarcomere, myofibril, fiber, fascicle, muscle

28. Which of the following is NOT a property of gram negative bacteria?
    A. Appears pink under Gram stain
    B. Has a thin peptidoglycan layer
    C. Contains teichoic acid in the cell wall
    D. Secretes exotoxin
    E. Secretes endotoxin (lipopolysaccharides)

29. Which of the following statements regarding the heart is INCORRECT?
    A. Oxygenated blood flows into the left atrium from the pulmonary veins
    B. Blood flows from the right atrium into the right ventricle via the bicuspid valve
    C. Oxygenated blood leaves the left ventricle through the aortic valve
    D. The left ventricle contains the thickest walls
    E. The systemic circuit extends from the left ventricle to the right atrium

30. Which of the following numbers corresponds to the relative and absolute refractory periods of an action potential, respectively?



    A. Relative – 4 and 5; Absolute – 3
    B. Relative – 2 and 3; Absolute – 4
    C. Relative – 4; Absolute – 2
    D. Relative – 4; Absolute – 2 and 3
    E. Relative – 5; Absolute – 1 and 2

31. Which of the following is NOT a sporophyte-dominant plant species?
    A. Lycophytes
    B. Angiosperms
    C. Pterophytes
    D. Hornworts
    E. Gymnosperms

32. Which of the following biomes is characterized by low rainfall, variable extreme temperatures, and C4/CAM plants?
    A. Savanna
    B. Tropical forest
    C. Alpine tundra
    D. Desert
    E. Chaparral

33. A strand of DNA is composed of 20% guanine. What is the percentage of thymine?
    A. 30%
    B. 60%
    C. 40%
    D. 20%
    E. 15%

34. During DNA electrophoresis, what property of the samples determines their pattern of separation within the gel?
    A. Isoelectric point
    B. Overall charge
    C. Number of base pairs
    D. Genetic sequence
    E. Temperature

35. Which of the following embryonic structures develops into the root of a plant?
    A. Epicotyl
    B. Cotyledon
    C. Hypocotyl
    D. Plumule
    E. Radicle

36. Which blood types are known as the "universal donor" and "universal acceptor", respectively?
    A. Type A; type O
    B. Type O; type AB
    C. Type B; type AB
    D. Type AB; type O

37. Which of the following statements regarding menstruation is CORRECT?
    A. Progesterone levels are at their highest during the proliferative phase
    B. If implantation occurs, the endometrium is maintained by estrogen from the corpus luteum
    C. If implantation does not occur, the corpus luteum is resorbed by polar bodies
    D. Menstruation occurs from birth to menopause
    E. The menstrual cycle lasts around 14 days

38. A population of 60 European colonialists settle an uninhabited island in the Pacific. Years later, the resulting population has an abnormally high incidence of cystic fibrosis. Which of the following best explains this phenomenon?
    A. Bottleneck effect
    B. Genetic drift
    C. Artificial selection
    D. Founder effect
    E. Random outbreeding

39. Which of the following substances is NOT filtered into the Bowman's capsule of the nephron?
    A. Na^+
    B. K^+
    C. Glucose
    D. Amino acids
    E. Polypeptides

40. Which of the following best describes the citric acid cycle?
    A. Glucose is broken down into two molecules of pyruvate, generating ATP through substrate-level phosphorylation
    B. Acetyl-CoA is broken down into carbon dioxide, generating ATP through substrate-level phosphorylation
    C. Pyruvate is reduced into lactic acid, regenerating NAD^+
    D. Electrons undergo a series of redox reactions, generating ATP through oxidative phosphorylation
    E. Pyruvate is oxidized into acetyl-CoA, producing carbon dioxide

41. Exactly 300 g of mercury is required to fill an unknown container at 20°C. If this mercury has a density of 14 g/cm^3, what mass of water is required to fill the container at the same temperature?
    A. 0.05 g
    B. 1 g
    C. 10 g
    D. 20 g
    E. 40 g

42. Which of the following interactions is strongest?
    A. London dispersion
    B. Dipole-dipole
    C. Hydrogen bond
    D. Covalent bond
    E. Induced dipole

43. Which of the following measurements contains the least number of significant digits?
    A. 401 cm
    B. 23,000 mL
    C. 3.20×10^{24}
    D. 0.00430 g
    E. 0.500 m^3

44. NaCl is added to an aqueous solution until it cannot dissolve any more solute. Which of the following terms best describes the resulting solution?
    A. Supersaturated
    B. Hyposaturated
    C. Hypersaturated
    D. Saturated
    E. Unsaturated

45. If the concentration of iron in a solution of Fe_2S_3 is 3 M, what is the concentration of sulphur?
    A. 2 M
    B. 3 M
    C. 3.5 M
    D. 4 M
    E. 4.5 M

46. What is the maximum number of electrons that the d subshell can hold?
    A. 14
    B. 10
    C. 6
    D. 5
    E. 2

47. If the K_{sp} of AgBr is 5×10^{-13}, then what is its molar solubility?
    A. $x = 5 \times 10^{-11}$
    B. $x = 5 \times 10^{-15}$
    C. $x = \sqrt{5 \times 10^{-15}}$
    D. $x = \sqrt{5 \times 10^{-13}}$
    E. $x = 5 \times 10^{-13}$

48. An electrochemical cell consists of half-reactions with the following standard reduction potentials:

$$E_r^\circ(F_2) = 2.87\ V$$
$$E_r^\circ(Ca^{2+}) = -2.87\ V$$

Which of the following best describes the cell?

A. Voltaic cell with $E_{cell}^\circ = (2)(2.87)\ V$
B. Galvanic cell with $E_{cell}^\circ = (2)(2.87)\ V$
C. Voltaic cell with $E_{cell}^\circ = -(2)(2.87)\ V$
D. Galvanic cell with $E_{cell}^\circ = -(2)(2.87)\ V$
E. Voltaic cell with $E_{cell}^\circ = 0\ V$

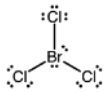
49. In the following nuclear reaction, what is the identity of element "X"?

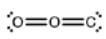
$$^{239}_{94}Pu \rightarrow {}^{4}_{2}He^{2+} + X$$

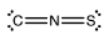
A. $^{239}_{92}U$
B. $^{235}_{94}Pu$
C. $^{238}_{92}U$
D. $^{243}_{96}Cm$
E. $^{235}_{92}U$

50. Which of the following molecules has a +2 formal charge on the central atom?

A. 

B. 

C. 

D. 

E. 

51. If the temperature of a gas is doubled while holding pressure constant, the volume is:

A. Reduced to 1/2
B. Reduced to 1/3
C. Doubled
D. Tripled
E. Unchanged

52. How much energy does it take to raise the temperature of 10 grams of water from 25 to 50 °C? The specific heat capacity of liquid water is 4.18 J/g°C

A. (10)(4.18)(25)
B. $\dfrac{(10)(4.18)(25)}{18.02}$
C. (10)(18.02)(4.18)(25)
D. $\dfrac{(18.02)(4.18)(25)}{10}$
E. (10)(18.02)(4.18)(50)

53. If a weak acid is titrated with a strong base, at which point is the concentrations of the acid and its conjugate equal?

A. Equivalence point
B. Triple point
C. Half-equivalence point
D. Critical point
E. Neutralization

54. What mass of butane (C_4H_{10}) must be burned in excess oxygen to produce 44.8 L of carbon dioxide? Assume standard temperature and pressure (STP) conditions.

A. 29 g
B. 58 g
C. 2 g
D. 0.5 g
E. 116 g

55. What is the molecular geometry of SO_3?

A. Tetrahedral
B. Linear
C. Trigonal pyramidal
D. Trigonal planar
E. Square planar

56. Which of the following pieces of laboratory glassware is LEAST appropriate for the precise measurement of liquids?

A. Buret
B. Volumetric pipette
C. Graduated pipette
D. Transfer pipette
E. Volumetric flask

57. Which of the following changes will shift the equilibrium shown below to the reactants side?

$$2NH_{3(g)} \rightleftharpoons N_{2(g)} + 3H_{2(g)}$$

A. Adding more $NH_{3(g)}$
B. Increasing pressure
C. Decreasing pressure
D. Removing $N_{2(g)}$
E. Increasing temperature

58. Which of the following compounds will produce an aqueous solution with a pH greater than 7?

A. CH_3COOH
B. KCl
C. $NaNO_3$
D. NH_4^+
E. $NaNO_2$

59. Which of the following is the correct electron configuration for Al^{1+}?

A. $1s^2 2s^2 2p^6 3s^2$
B. $1s^2 2s^6 2p^6 3s^2$
C. $1s^2 2s^2 3p^6 3s^2$
D. $1s^2 2s^2 2p^6 3s^2 3p^1$
E. $1s^2 2s^2 2p^6 3s^2 3p^6$

60. Which set of coefficients would balance the following reaction?

$$\_\ SnO_2 + \_\ H_2 \rightarrow \_\ Sn + \_\ H_2O$$

A. 2, 2, 2, 1
B. 1, 1, 1, 2
C. 2, 1, 2, 1
D. 1, 2, 1, 2
E. 1, 4, 1, 4

61. What is the oxidation state of sulphur in $S_2O_3^{2-}$?

A. +1
B. +2
C. −1
D. −2
E. 0

62. Which of the following elements has the lowest ionization energy?

A. F
B. Cl
C. B
D. N
E. Be

63. Given the redox equation shown below, which of the following statements is true?

$$Pb + PbO_2 + 2SO_4^{2-} + 4H^+ \rightarrow 2PbSO_4 + 2H_2O$$

A. Pb is the oxidizing agent
B. PbO_2 is the reducing agent
C. Pb is being reduced
D. This is a disproportionation reaction
E. PbO_2 is being oxidized

64. The half-life of a highly radioactive compound is 30 days. If 60 grams of this compound is stored in a closed container for three months, how much of it remains?

A. 3.5
B. 6
C. 7.5
D. 15
E. 30

65. The following table contains the empirical initial rates for the reaction:

$$2NO_{(g)} + O_{2(g)} \rightleftharpoons 2NO_{2(g)}$$

What is the correct rate law?

Trial	[NO]	$[O_2]$	Initial Rate
1	0.3 M	0.3 M	1.2×10^{-1} M/s
2	0.3 M	0.6 M	2.4×10^{-1} M/s
3	0.6 M	0.6 M	4.8×10^{-1} M/s

A. $r = k[NO][O_2]$
B. $r = k[NO][O_2]^2$
C. $r = k[NO]^2[O_2]$
D. $r = k[NO]^4[O_2]$
E. $r = k[NO][O_2]^4$

66. Considering the following reaction, how many grams of oxygen are required to produce 2 moles of carbon dioxide in excess carbon monoxide?

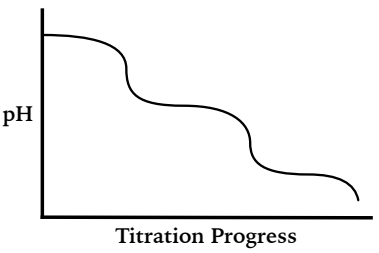
$$CO_{(g)} + O_{2(g)} \rightarrow CO_{2(g)}$$

A. 1 g
B. 2 g
C. 16 g
D. 32 g
E. 64 g

67. Which of the following describes the second law of thermodynamics?

A. Energy can neither be created nor destroyed
B. Spontaneous processes always increase the entropy of the system and surroundings
C. The total energy of the universe is constant
D. Spontaneous processes always increase the entropy of the system
E. Non-spontaneous processes always decrease the entropy of the system and surroundings

68. Which of the following compounds would lead to a titration curve similar to the one shown, when used as a titrant?



A. H_2SO_4
B. HCl
C. H_3PO_4
D. NH_4^+
E. H_3O^+

69. Which of the following elements is NOT a diatomic gas?

A. Oxygen
B. Hydrogen
C. Bromine
D. Iodine
E. Helium

70. Which of the following is NOT an example of a physical change?

A. Glass melting at 1600°C
B. Dissolving sugar into water
C. A steel wrench rusting over time
D. Mixing ethanol and methanol together
E. Making ice cubes

STOP

You have completed the SNS section of the DAT.
You will receive a 10 min break before the next section.

FULL-LENGTH 2 MEDIUM DIFFICULTY

PERCEPTUAL ABILITY TEST

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Perceptual Ability Test:

1. Each item is a question requiring perceptual skills. This section contains six sub-sections. Read the specific instructions before starting each sub-section. Decide which answer choice is correct and bubble in the corresponding circle on the answer sheet. **Do not stop after each subsection; continue to answer all 90 questions**
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 60 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. **DO NOT TURN PAST THE STOP PAGE AND ON TO THE NEXT SECTION UNTIL INSTRUCTED**
6. At the end of this section, the answer sheet is collected. The booklet remains at your table for use during the next section

TIME LIMIT:
60 minutes

TEST NAME:
PAT

TEST NUMBER:
02

This is a DAT simulation.

PART 1

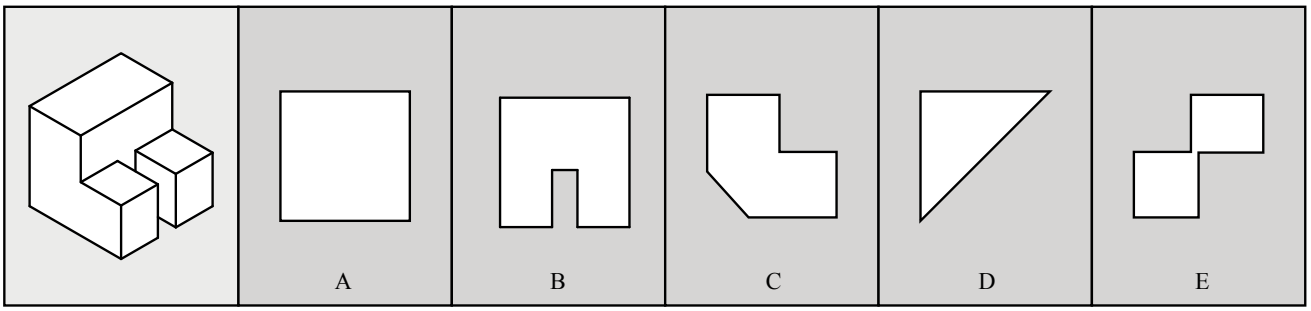
For questions 1 to 15, the test contains questions similar to the example shown below. A three-dimensional object is shown in the light-coloured box on the left. Various two-dimensional answer choices are shown on the right, in dark-coloured boxes.

In each question, your task is to visualize how the three-dimensional object would look from all sides. Then from the answer choices, you must choose a two-dimensional keyhole which would allow the three-dimensional object to pass through. Finally, bubble in the corresponding circle on your answer sheet.

The rules are as follows:

1. Before passing through the keyhole, the object may be rotated in any direction
2. Once the object starts passing through the keyhole, it cannot be rotated
3. Both the object and the keyhole are drawn to scale. They should have the same dimensions
4. There are no irregularities in the hidden parts of the objects

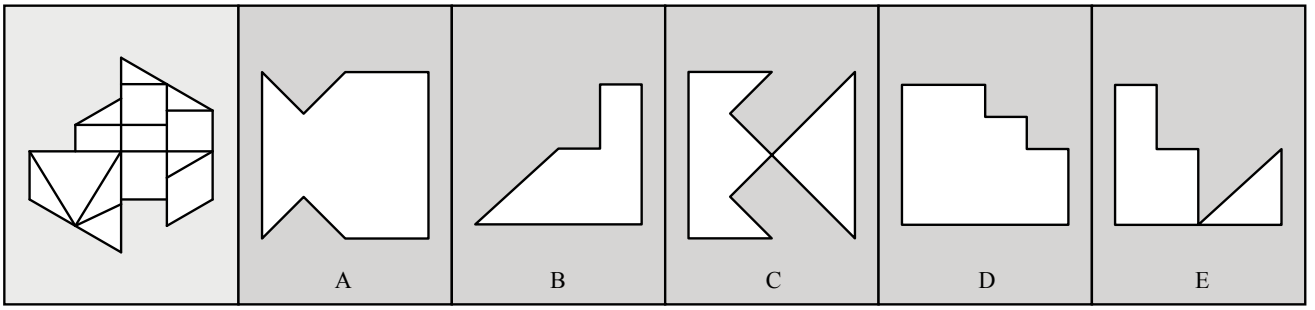
Example Question (Do NOT mark the answer to this example on your answer sheet)



The correct answer is B because the object would pass through this keyhole if the bottom or top side was rotated and inserted first

Please proceed to the questions

1.



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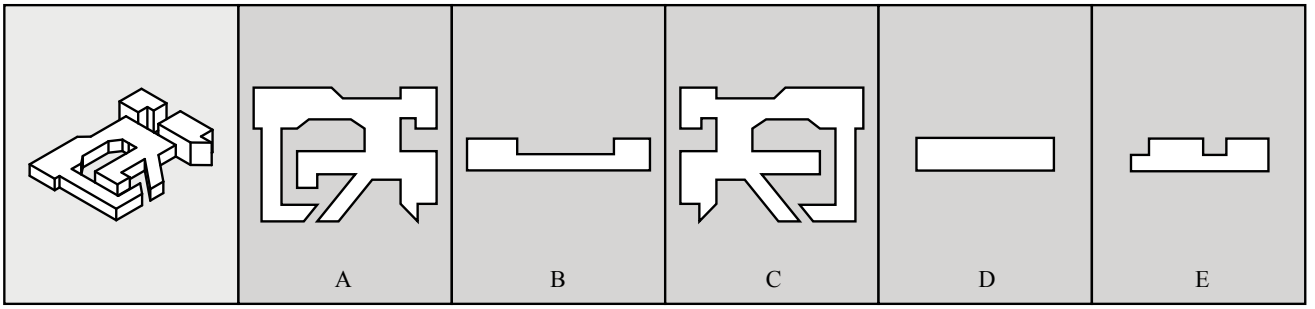

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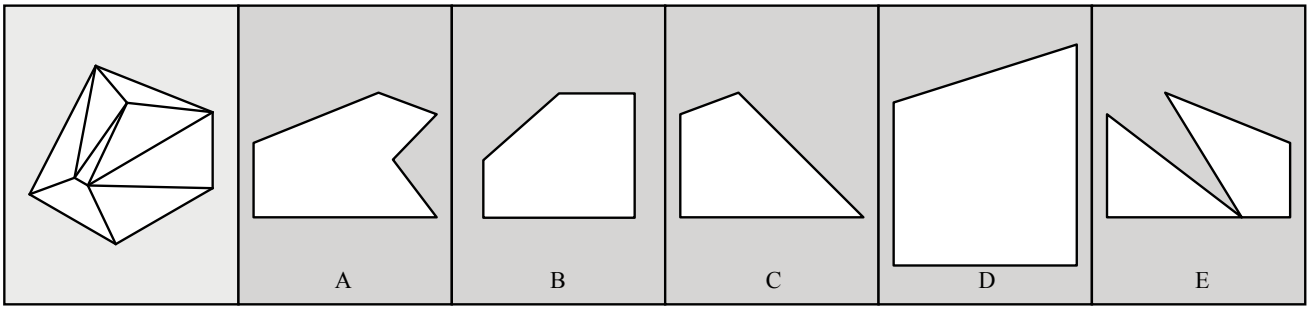

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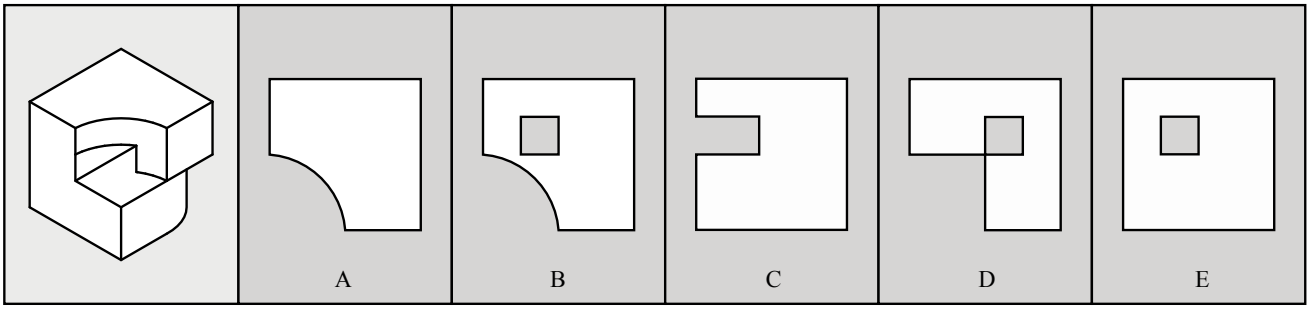

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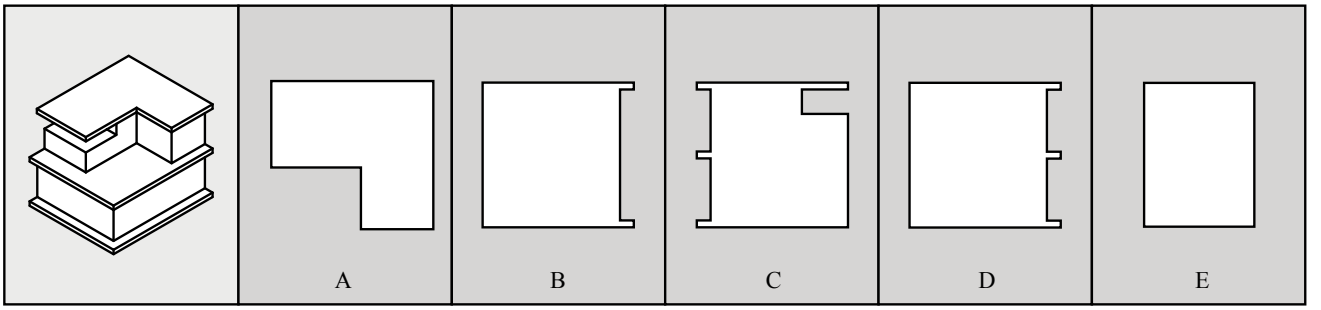

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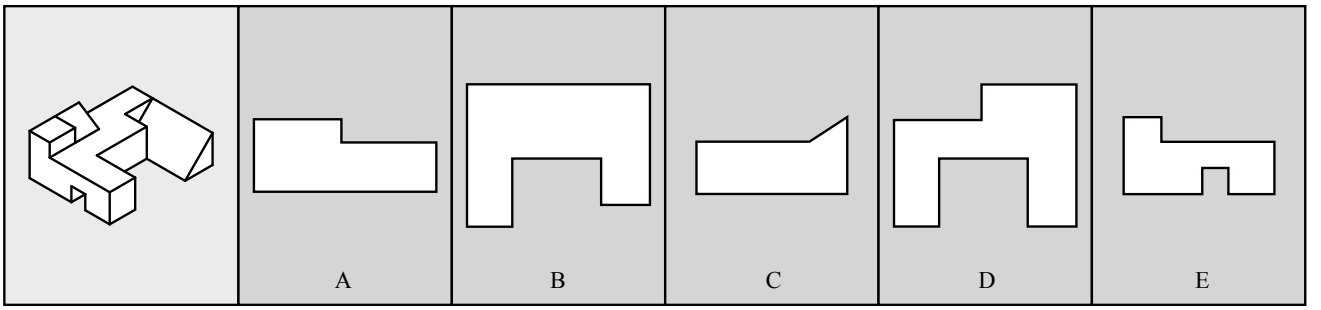

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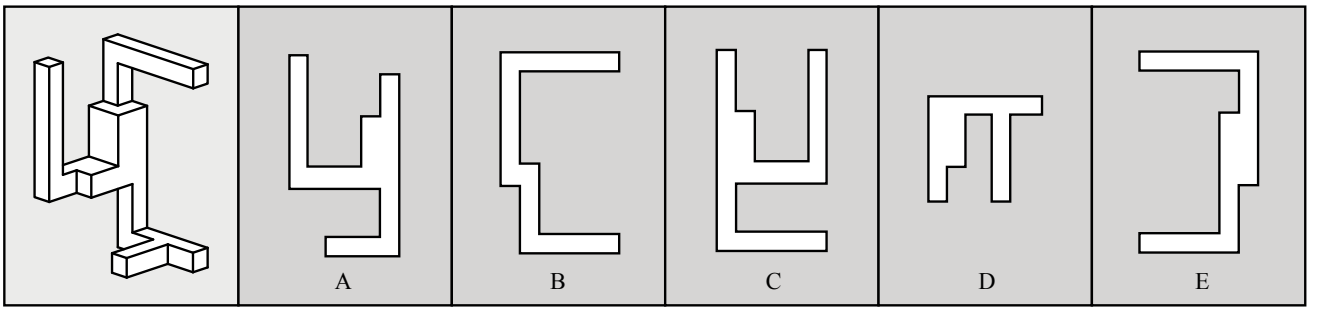

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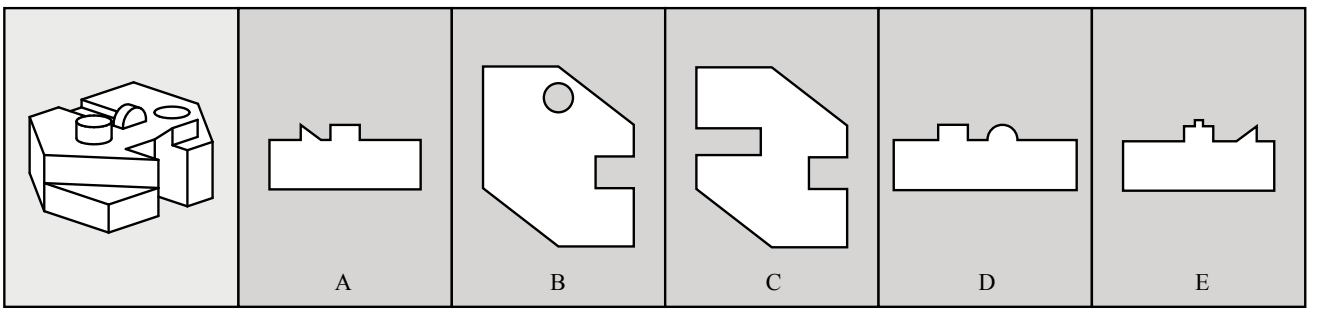

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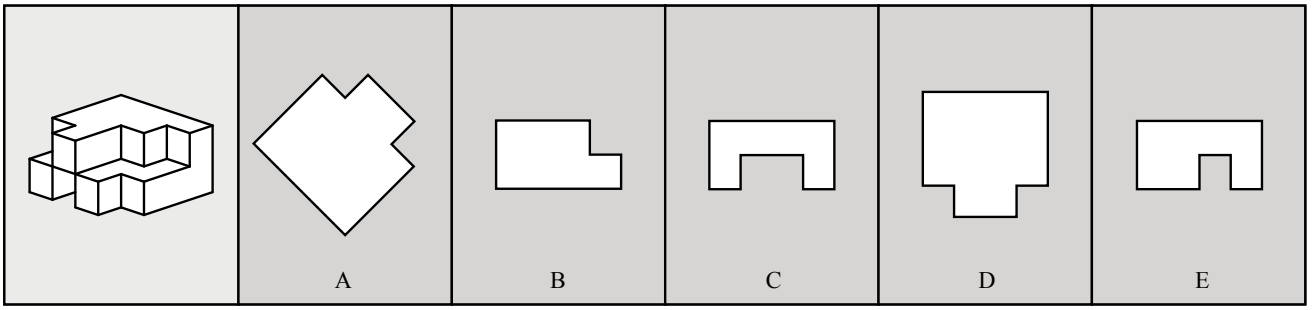

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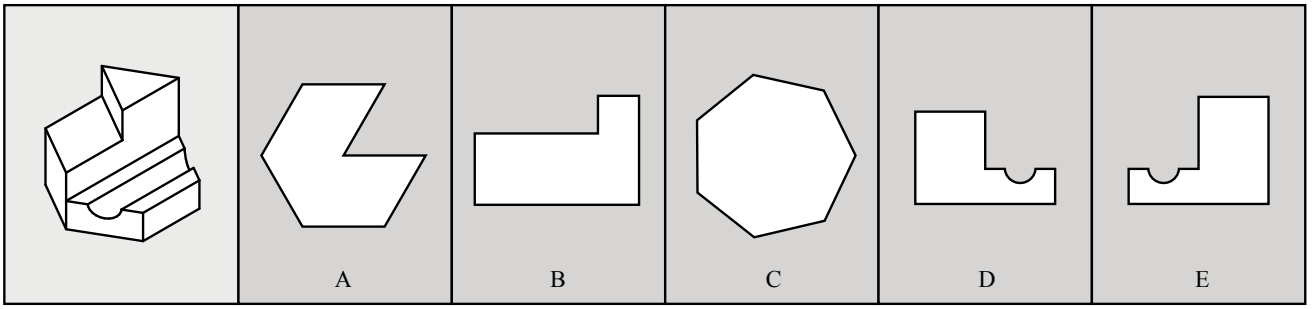

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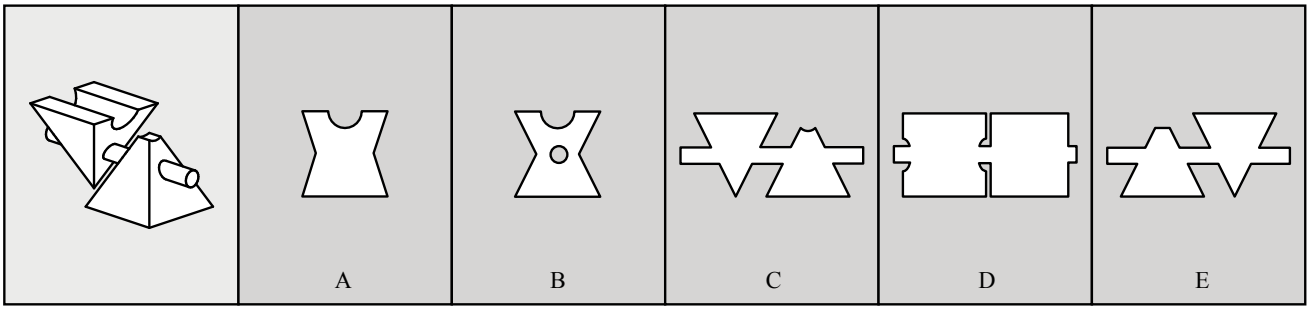

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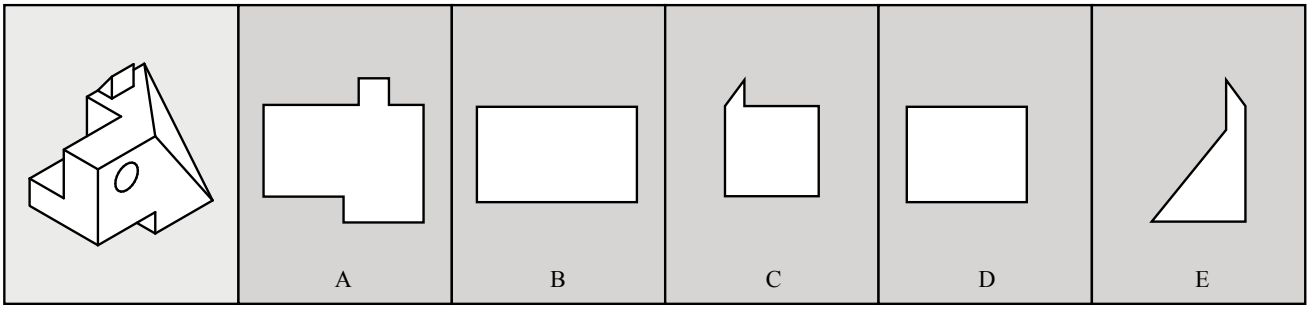

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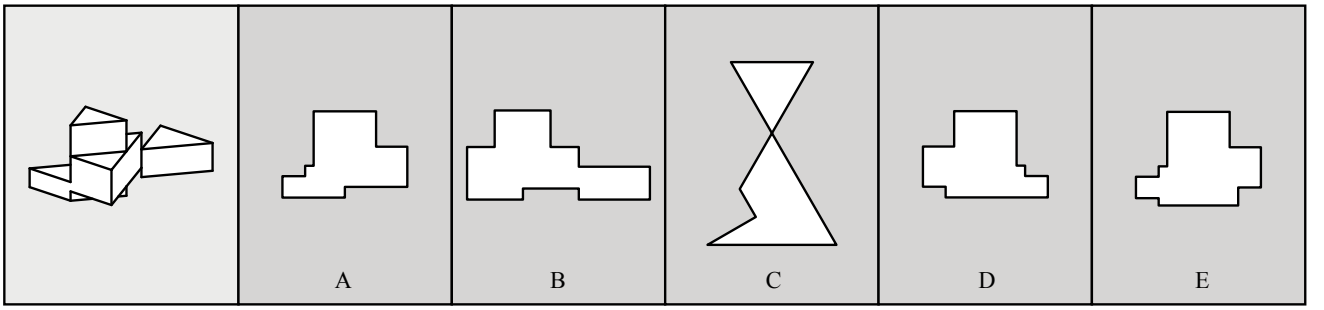

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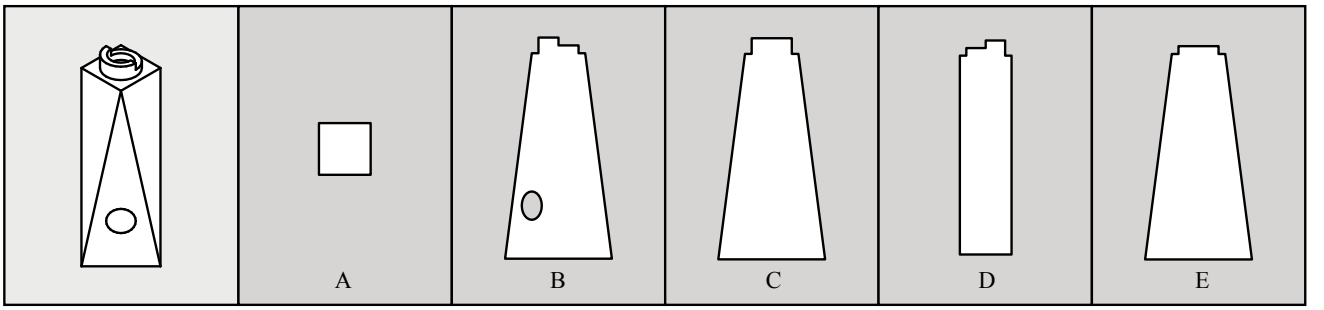

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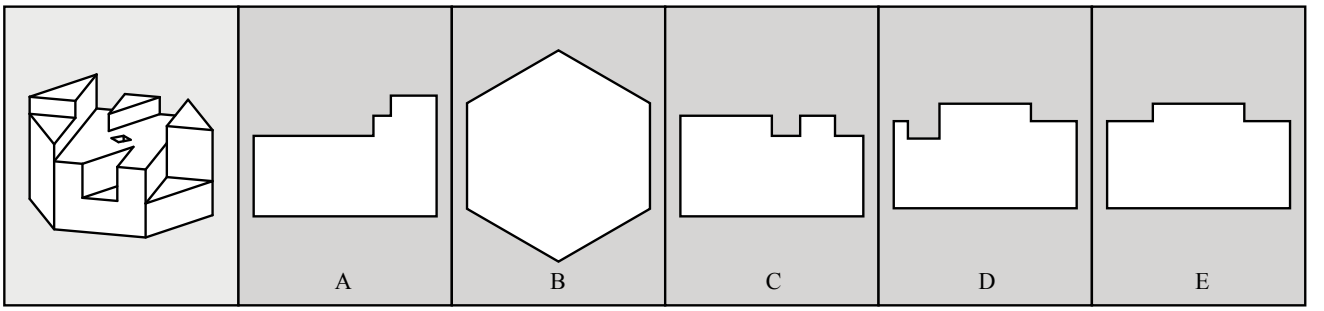
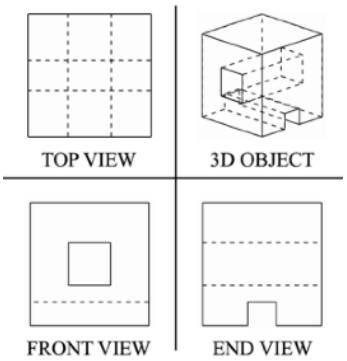


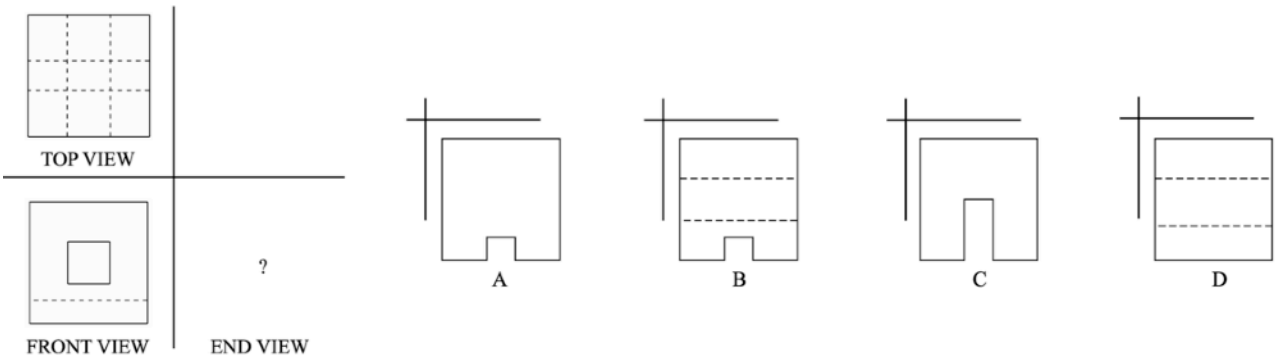
PART 2

For questions 16 to 30, the test contains questions similar to the example shown below. The top, front, and end projections of a three-dimensional object are shown. Edges that are obscured by parts of the object are shown as dotted lines, while edges that can be directly seen are shown as solid lines.



In each question, one of the three projections will be missing. Your task is to choose the projection that would complete the set of three projections in a manner consistent with the three-dimensional object (not shown).

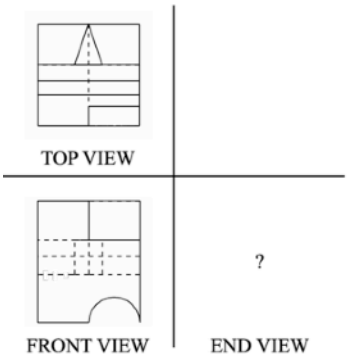
Example Question (Do NOT mark the answer to this example on your answer sheet)

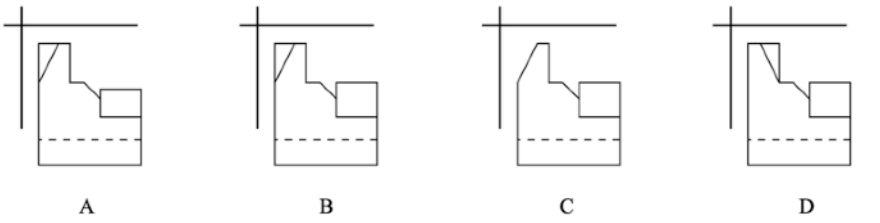


The correct answer is B because the object should have a rectangular tunnel at the bottom running left-to-right, and another square tunnel running front-to-back.

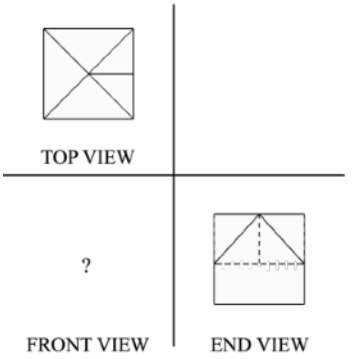
Please proceed to the questions

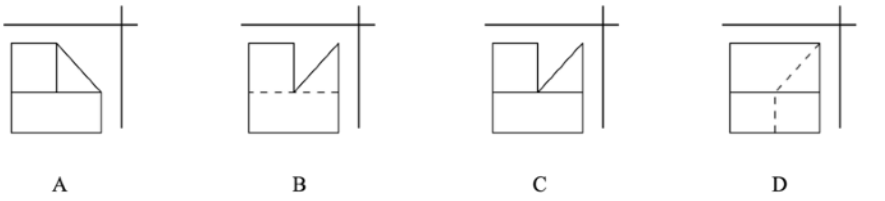
16. Choose the correct END VIEW



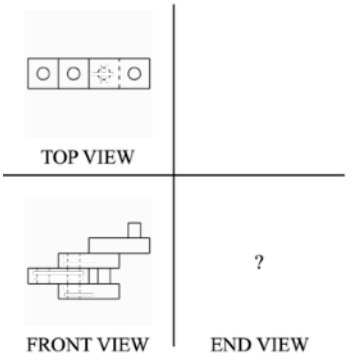


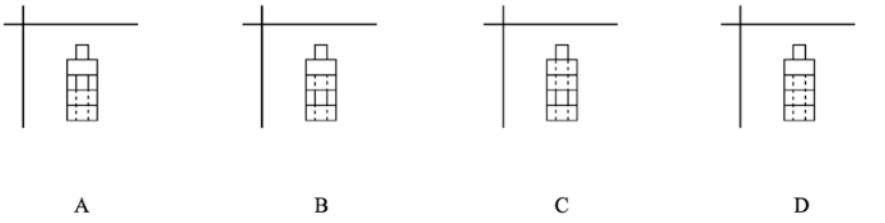
17. Choose the correct FRONT VIEW



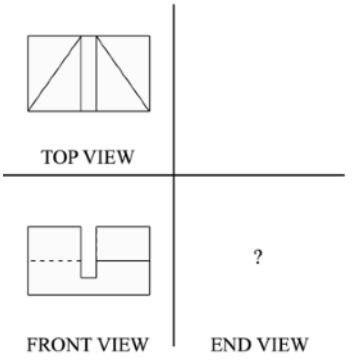


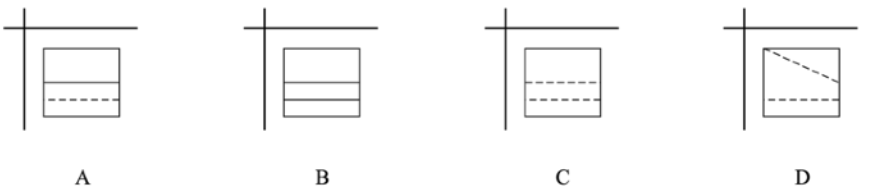
18. Choose the correct END VIEW



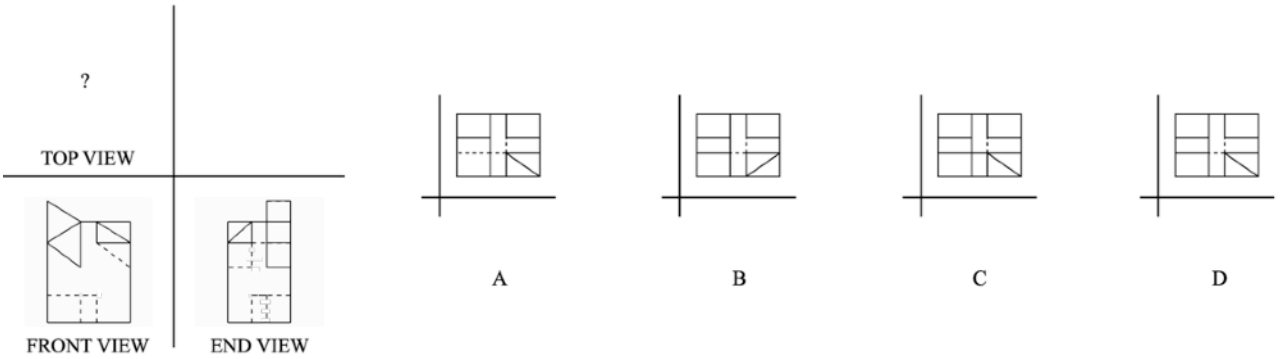


19. Choose the correct END VIEW

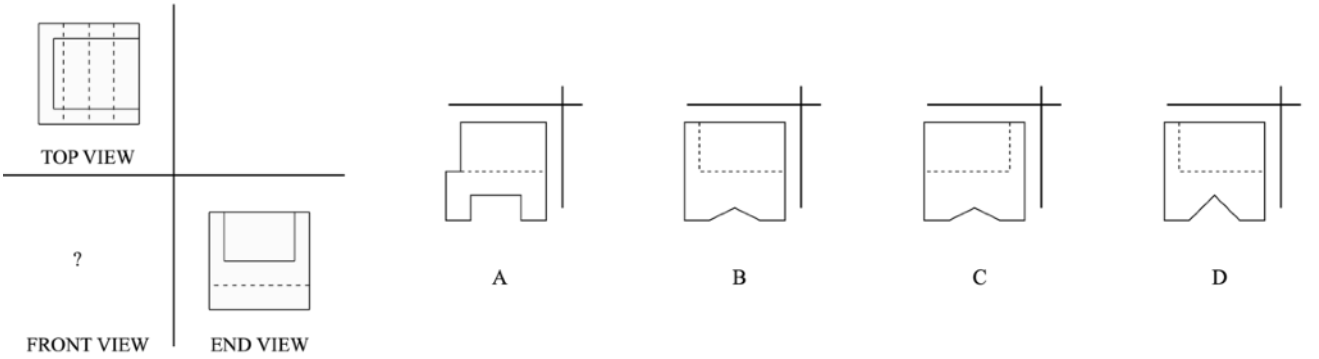




20. Choose the correct TOP VIEW



21. Choose the correct FRONT VIEW



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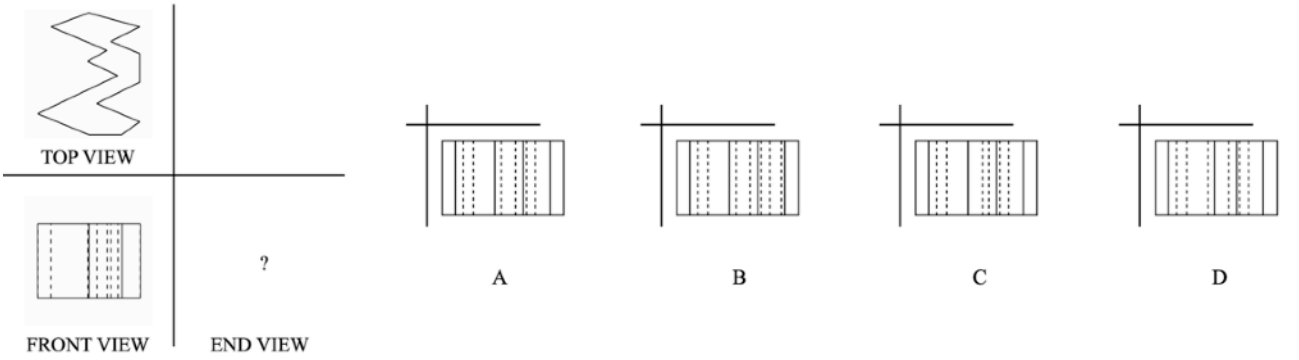

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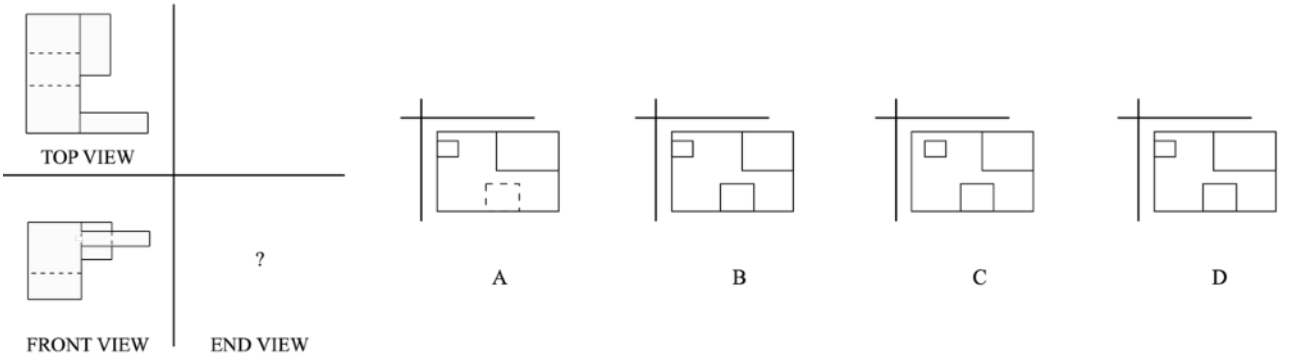
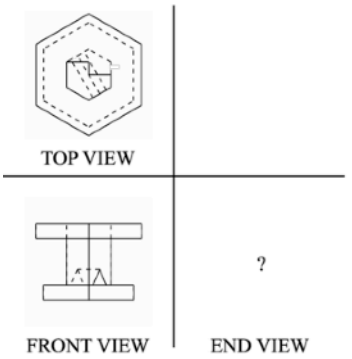
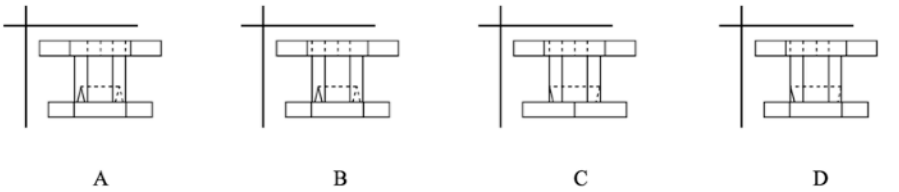
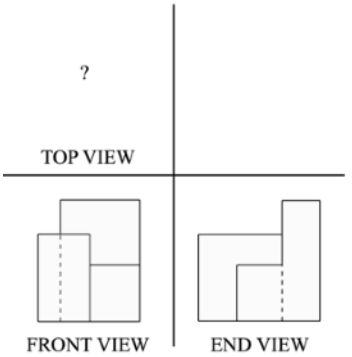


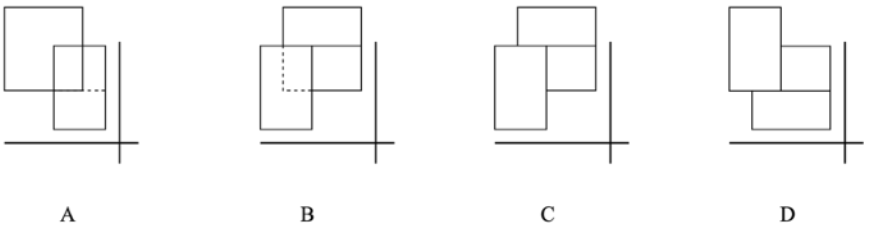
24. Choose the correct END VIEW



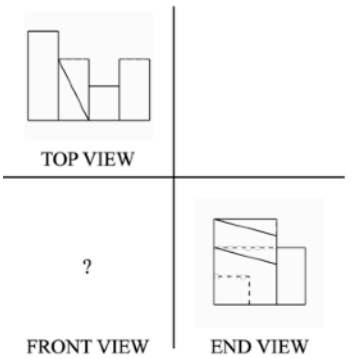


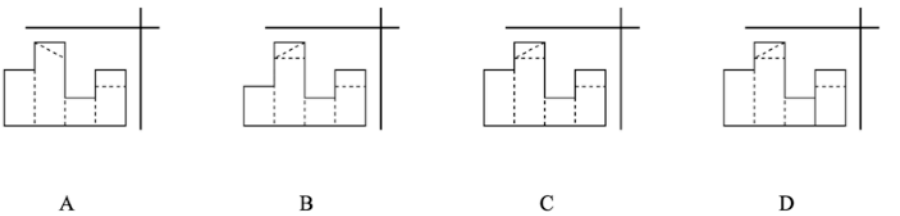
25. Choose the correct TOP VIEW



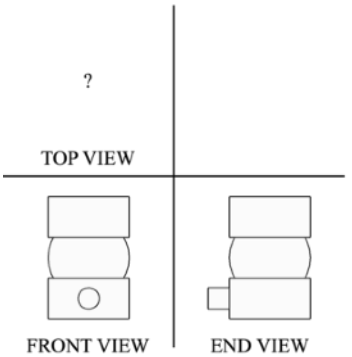


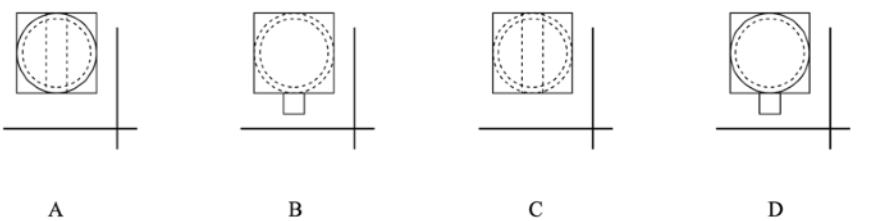
26. Choose the correct FRONT VIEW



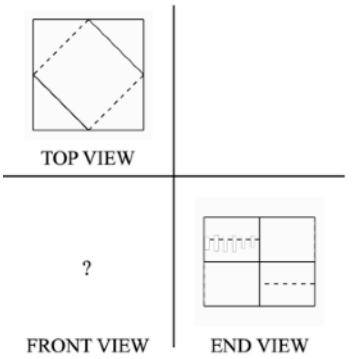


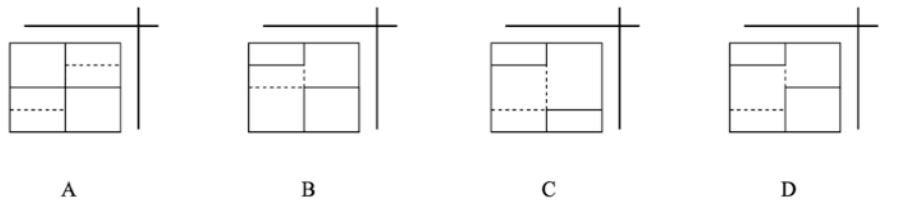
27. Choose the correct TOP VIEW



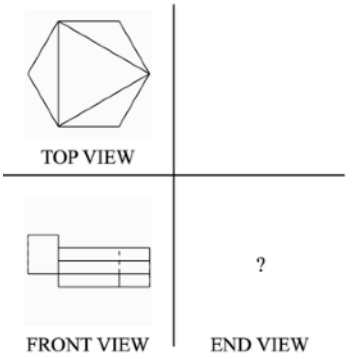


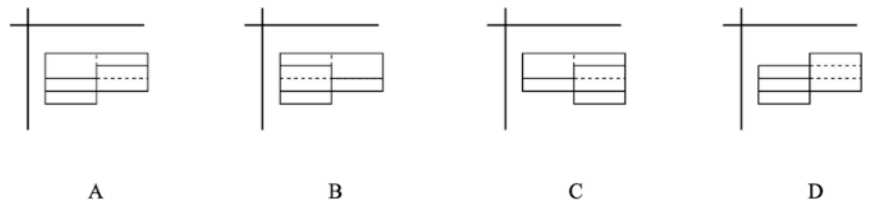
28. Choose the correct FRONT VIEW



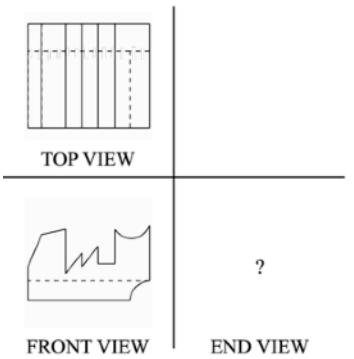


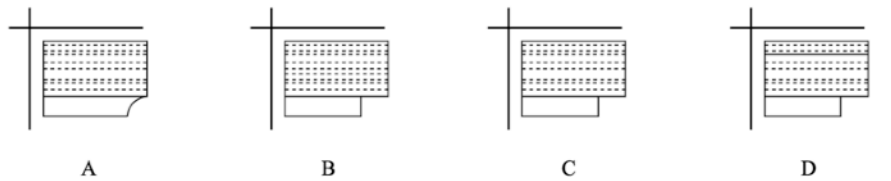
29. Choose the correct END VIEW





30. Choose the correct END VIEW

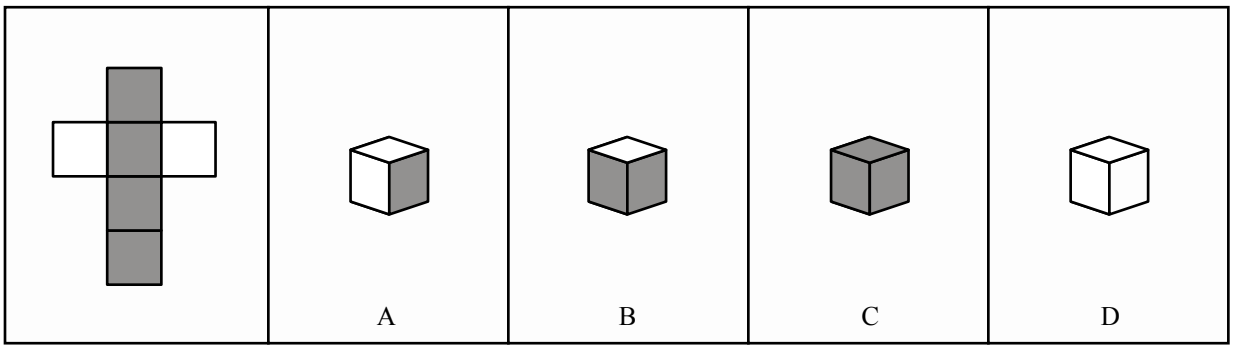




PART 6

For questions 76 to 90, the test contains two-dimensional patterns similar to the example shown below. This pattern is folded into the page, forming a three-dimensional figure. Your task is to mentally fold the two-dimensional patterns and select the correct three-dimensional figure out of the four presented.

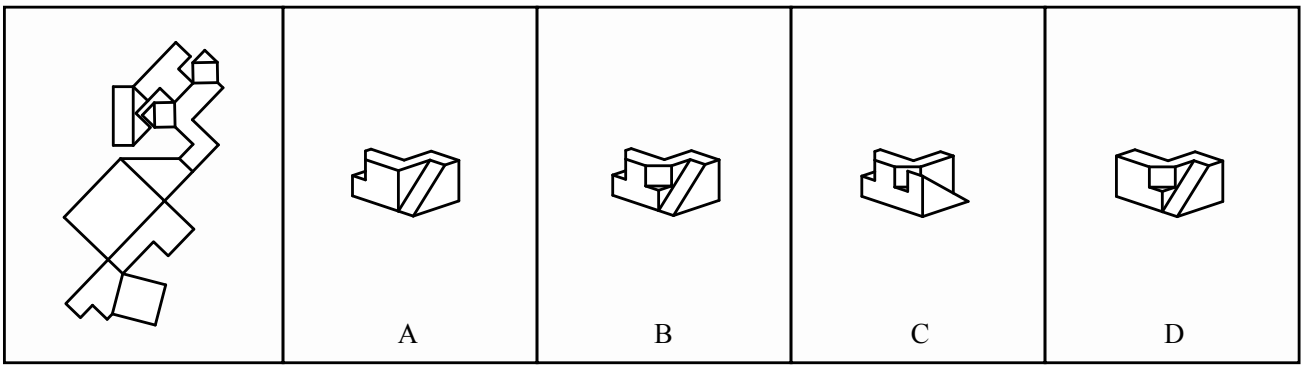
Example Question (Do NOT mark the answer to this example on your answer sheet)



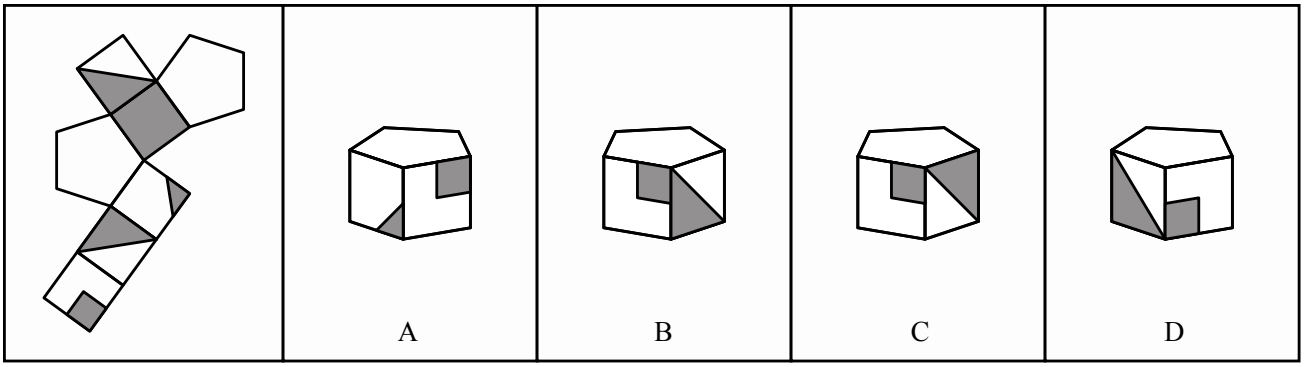
The correct answer is B, since it represents both the correct shape and pattern of shaded faces in the folded three-dimensional figure. There should be four shaded sides that exist side-by-side, and two unshaded sides on opposite ends of the cube.

Please proceed to the questions

76.



77.



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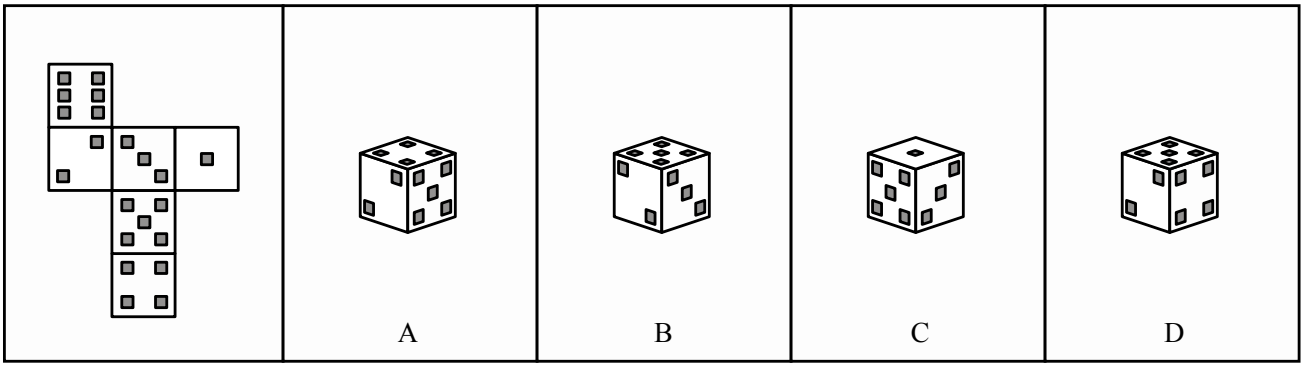

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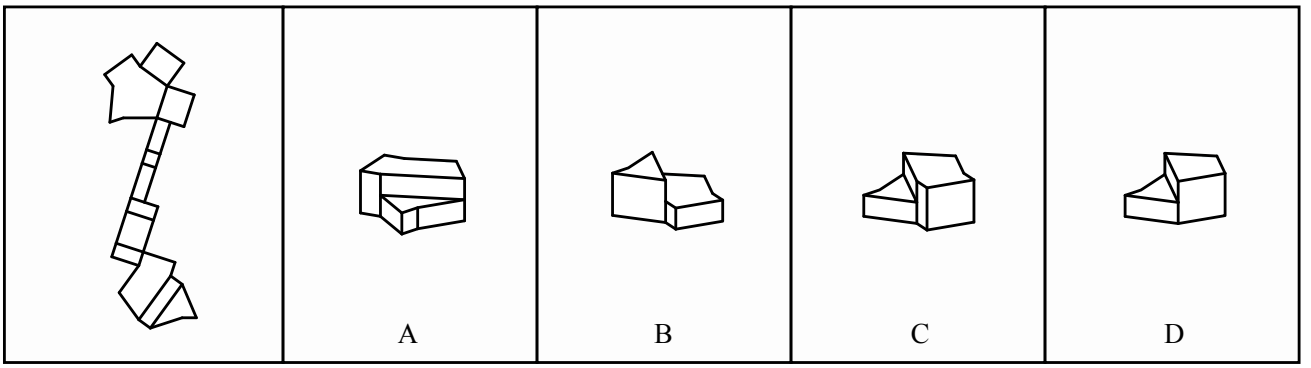
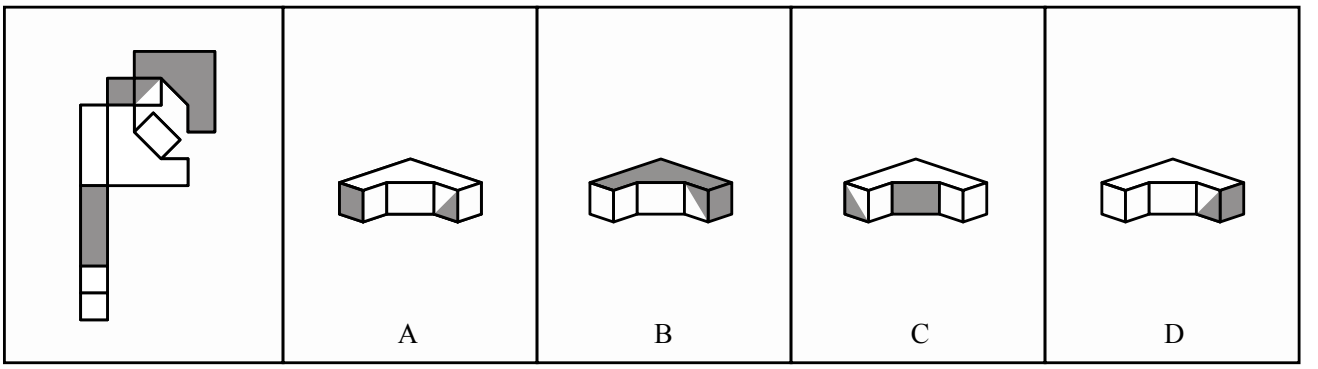
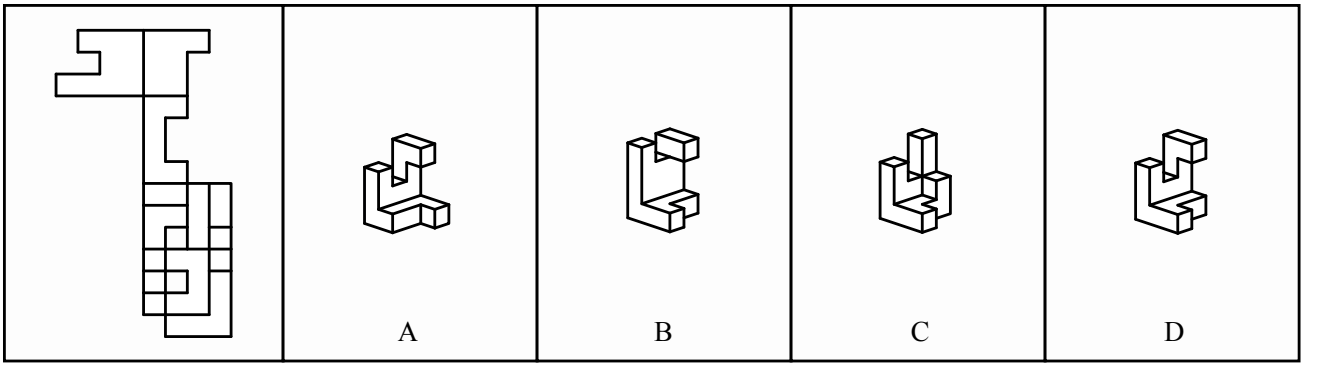


80.



81.



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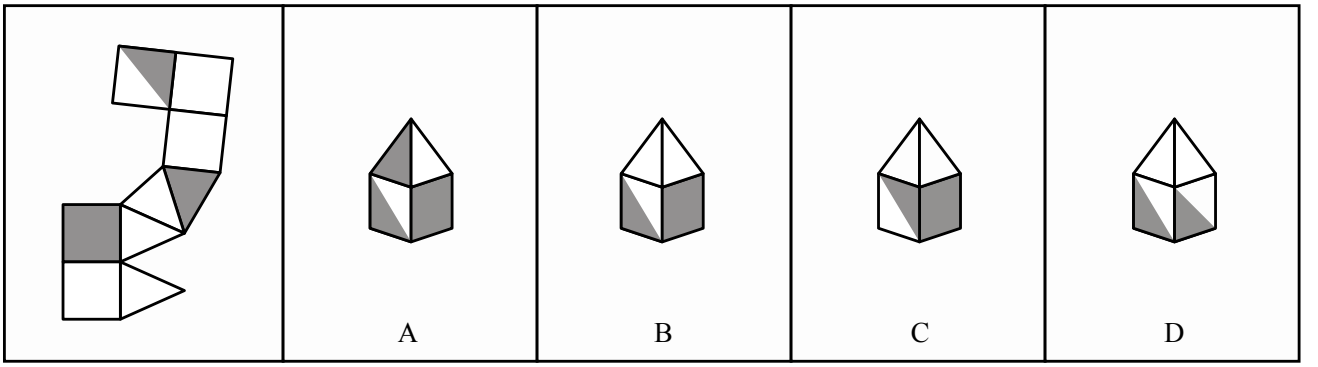
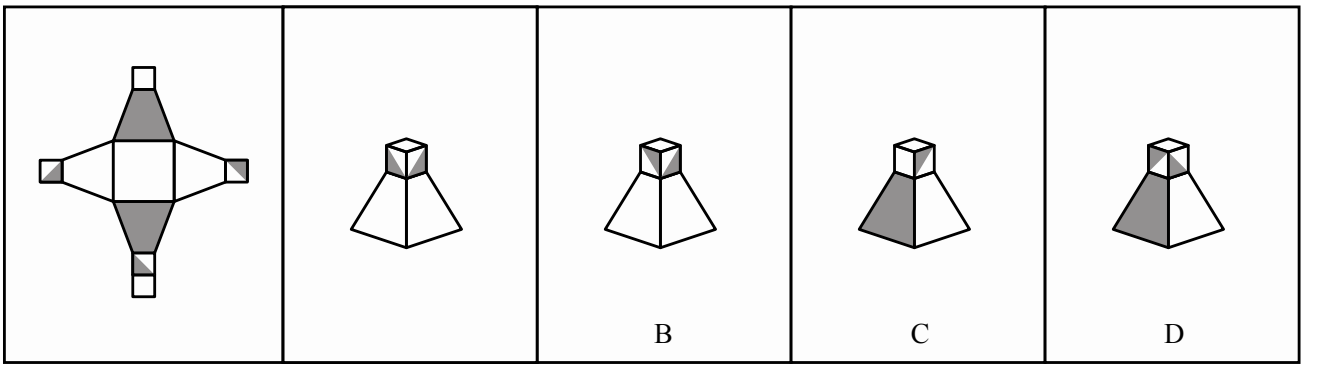
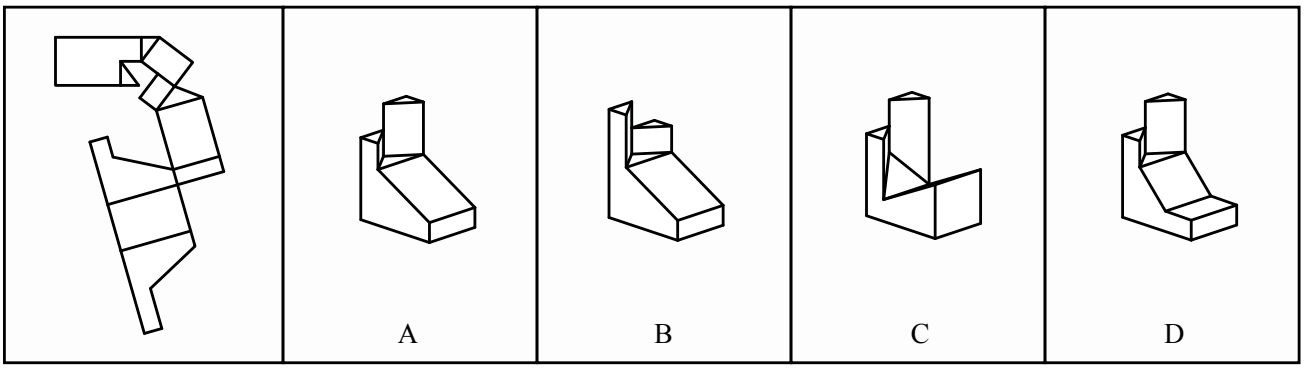


83.



84.



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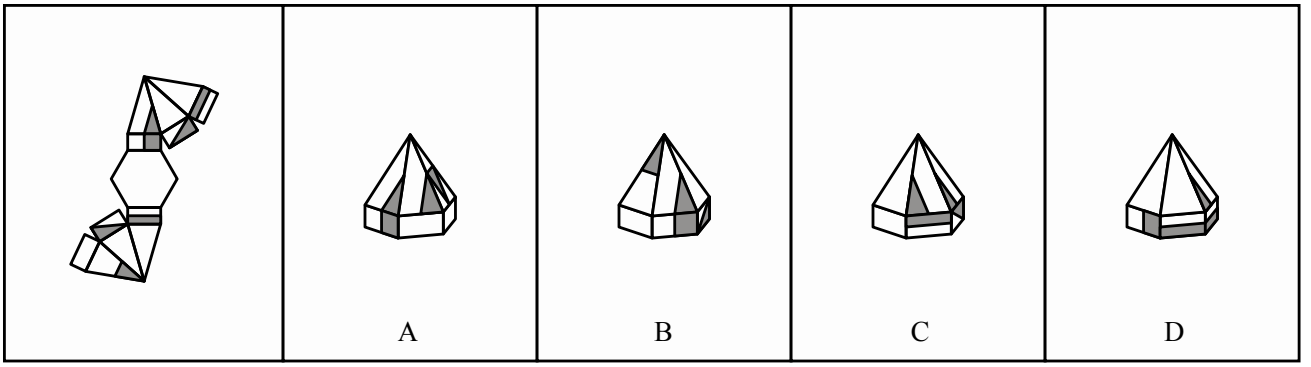

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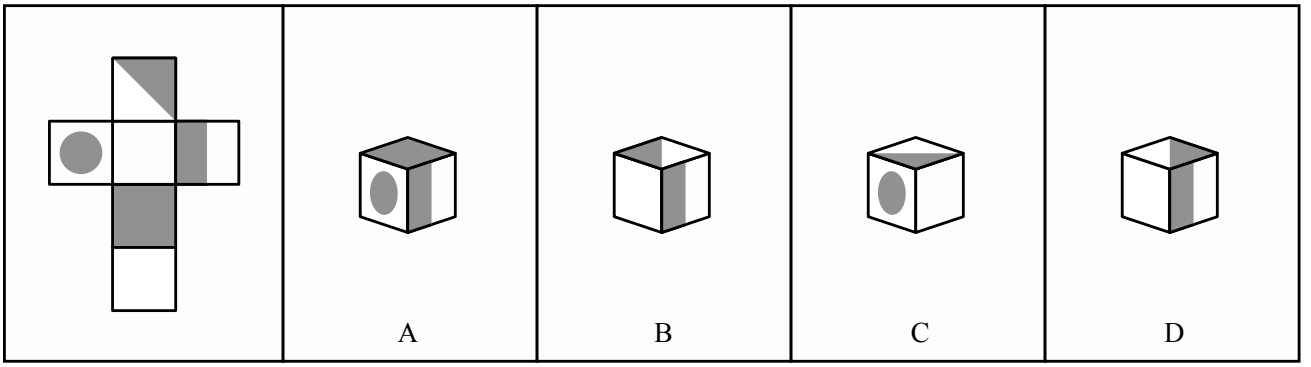
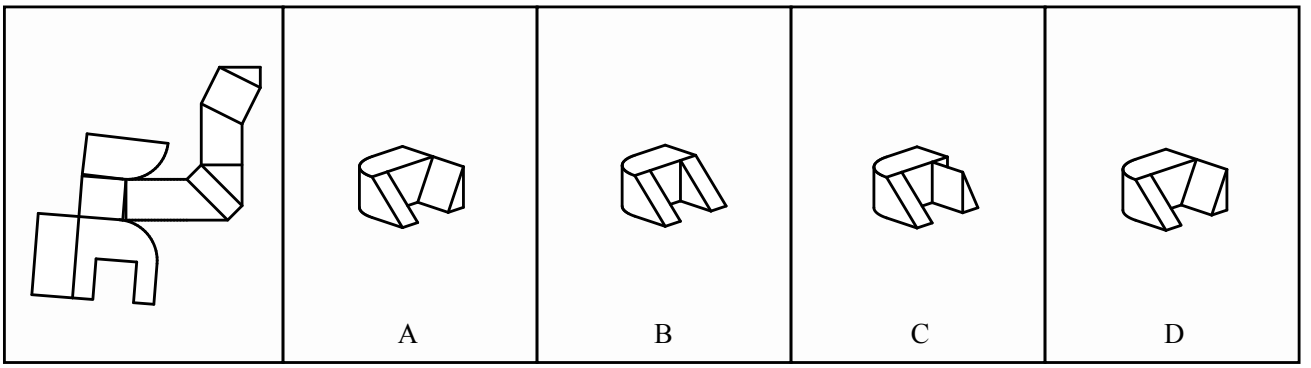


87.



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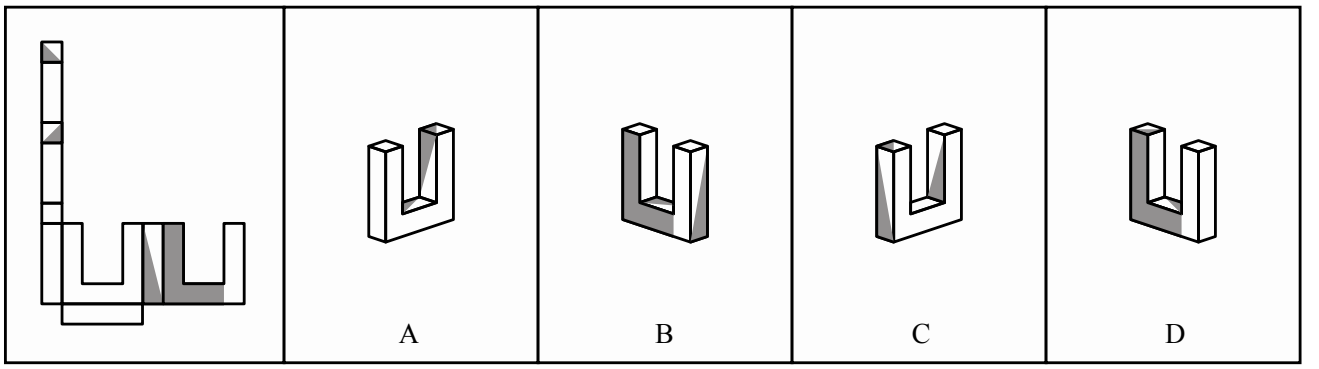
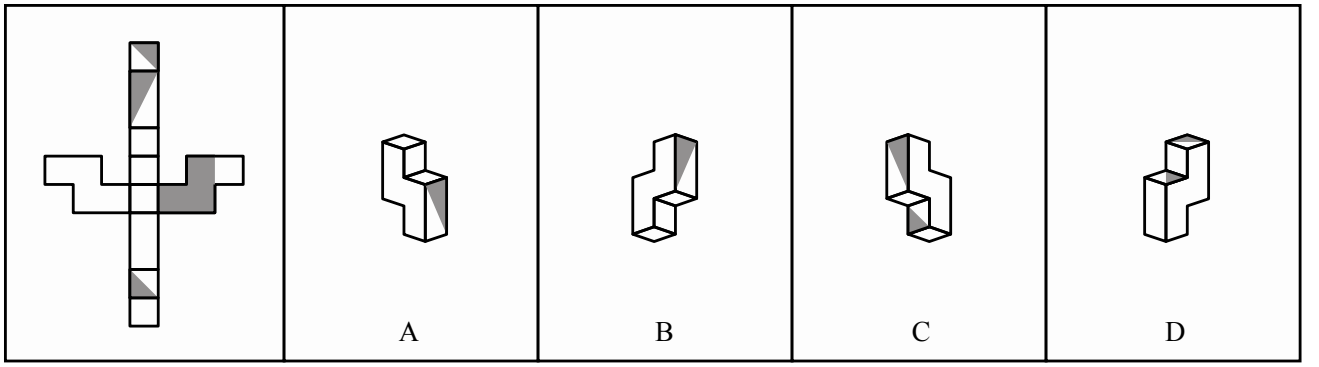
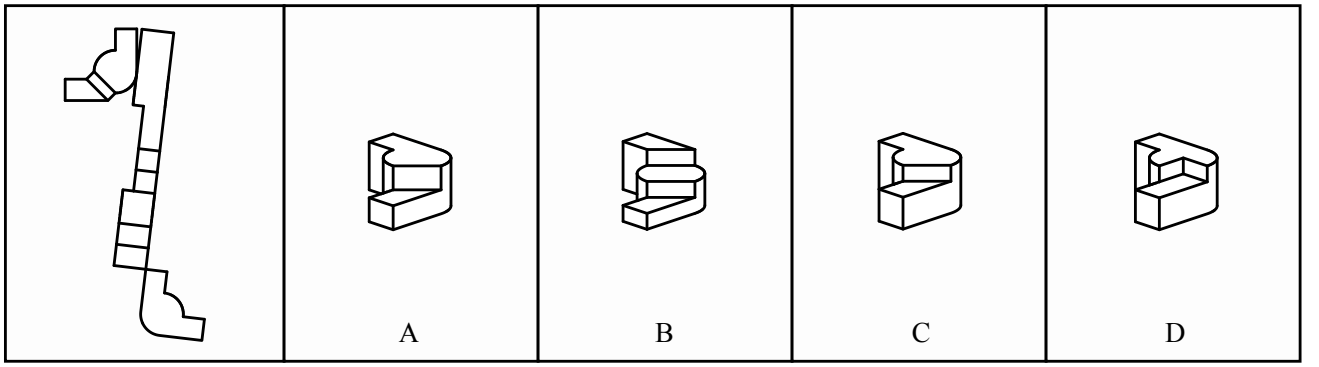


89.



90.



STOP

You have completed the PAT section of the DAT.
You will receive a 10 min break before the next section.

FULL-LENGTH 2 MEDIUM DIFFICULTY

READING COMPREHENSION TEST

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Reading Comprehension Test:

1. This test will evaluate your reading comprehension skills. It is composed of three passages. Reach each passage carefully, then proceed to the corresponding questions. Decide which of the presented choices best answers/completes the question/statement. Bubble in the appropriate answer choice on the answer sheet
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 50 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. At the end of this section, the answer sheet is collected and the Dental Aptitude Test simulation is now complete

TIME LIMIT:
50 minutes

TEST NAME:
RCT

TEST NUMBER:
02

This is a DAT simulation.

Passage 1

Trends in Forensic Odontology

Forensic odontology is an evolving science and has a greater scope of development. It has established as an indispensable science in medico-legal matters and in the identification of the dead person. The dental tissues are often preserved even if the deceased person is skeletonized, decomposed, burnt, or dismembered. Various methods have been developed to determine age, sex, and ethnicity of the person, using dental tissues. In recent years, data collection methods and supplementary technologies used in forensic dental identification have undergone significant transformation.

Teeth are the hardest and most robust tissues of the human body. They are often resistant to decomposition even in major accidents, crime, burial, or other severe exposure to the elements. Dental patterns are unique for every individual. This uniqueness is also due to variety of treatments given by the dentist. Therefore, dentition of a person is useful for individual identification and comparison, if records exist for the purpose. Forensic dental identification plays a primary role in the identification of remains when postmortem changes, traumatic tissue injury, or lack of fingerprint record invalidate the use of visual or fingerprint method. The history of forensic odontology goes long back. In courts, the dental evidence has been used for the past many years. The techniques used in forensic odontology has evolved through the evolution of humankind.

Forensic odontology has three major areas of utilization as follows: (1) diagnostic and therapeutic examination and evaluation of injuries to jaws, teeth, and oral soft tissues. (2) The identification of individuals, especially casualties in criminal investigations and/or mass disasters. (3) Identification, examination, and evaluation of bite marks which occur with some frequency in sexual assaults, child abuse cases, and in personal defence situations.

The common methods used for individual identification are using visual identification, personal information (such as height, build, age, presence or absence of hair), medical information (such as scars, tattoos, birthmarks, implants, amputations, prosthesis), footprint records from a chiropodist/podiatrist, clothing, personal effects, fingerprints, DNA profiling and dental identification. Identification by dental means gains more importance because the dental tissues are often preserved even if the deceased person is skeletonized, decomposed, burnt or dismembered. Dental tissues are often used to determine age, sex, and ethnicity of the person who can either be a victim or a suspect.

Data collection methods and supplementary technologies used in forensic dental identification have undergone significant transformation. Evolving trends have been observed in the conventional methods used such as dental record maintenance, dental imaging techniques, bite-mark analysis, cheiloscopy, and rugoscopy. In addition, the recent concepts such as facial reconstruction, denture identification, and tongue prints have been introduced in the field of forensic odontology.

Forensic dental identification most of the times are dependent on the availability, adequacy, and accuracy of antemortem dental records. Maintenance of dental records is the duty of a dentist and is an essential component, serving as an information source for the dentists and the patients, in medico-legal, administrative, and for forensic purposes. Identification by comparative dental analysis plays an important role similar to fingerprints and DNA analysis. The dental records were successfully utilized in many disasters such as World Trade Centre disaster, Indian Ocean tsunami disaster in December 2004, etc. Dental records are available in various forms such as dental notes, dental charts, radiographs, photographs, and models. Maintenance of these records is mandatory in the Western countries. Different countries have different guidelines regarding the retention of dental records.

In cases where previous records are not available for comparison, an alternative aid used for individual identification is radiograph. The radiographic images of the deceased can be obtained and compared with the available antemortem radiographic image of the suspected person. Historically, the use of radiographs in forensic sciences was introduced in 1896, just a year after the discovery of X-ray by Roentgen, to reveal the

presence of lead bullets inside the head of a victim. Dental radiographs are easily available and serve as a vital clue for forensic identification. The parameters used in dental radiographs are shape of the teeth and roots, teeth present, missing teeth, residual roots, supernumerary teeth, noncarious lesions such as attrition, abrasion, fractures, bone resorption due to periodontal disease, bone pathology, diastemas, dental caries, endodontic treatment, intraradicular posts, intracoronal posts, and dental prostheses. Conventional radiography allows observation of coronal shape and size, pulp anatomy, crestal bone, etc. Computed tomography (CT) images reveal the cross-section of the areas exposed and produce multiple images. Antemortem CT images provide information which can be used in the construction of a postmortem facsimile image, considering that craniometrical points can be precisely located and measurements can be accurately performed. The frontal sinus configuration is peculiar to each individual which can be used as a parameter for individual identification. The parameters used for comparison of frontal sinus images are variations in its size, shape, symmetry, border outline, and number and presence of septa and cells.

Bite marks on human tissues can be observed in violent incidents such as sex-related crimes, child abuse cases, and offences involving physical altercations, such as homicide. It can occur in instances where the attacker bites the victim or the victim bite the attacker as an act of defence. Male victims are most often bitten on the arms and shoulders, while female victims are most commonly bitten on the breasts, arms, and legs. The biting surfaces of the individual groups of teeth are unique and related to the function. And also, it shows individual characteristics such as fractures, rotations, missing, or extra teeth. In addition, the width of the dental arches could be related to the age of the attacker.

Cheiloscopy is a forensic investigation technique which deals with identification of humans based on their lip traces. While using teeth as antemortem record, sometimes, we find loss of teeth and destruction of restorations may lead to difficulty in comparing the antemortem records and postmortem records. To overcome these difficulties, an immutable parameter should be used. Similar to the prints present in the finger, palm and foot, and lip prints are also unique and do not change during the life of a person. Lip prints provide sufficient information for forensic investigations as the lips also possess furrows and grooves. Lip prints can be obtained at the crime scene either directly from the lips of the deceased or from the clothing, cups, glasses, cigarettes, windows, or doors. Lip prints have to be obtained within 24 h of death to prevent erroneous data that would result from postmortem alterations of lip. Lip print pattern depends on whether mouth is opened or closed. In closed mouth position, lip shows well-defined grooves; whereas in open mouth position, the grooves are relatively ill defined and hard to interpret. Pathology of the lip such as mucocele, postsurgical alterations, loss of support due to loss of anterior teeth, presence of debris or fluid on the lip surface, application of a thick layer of lipstick, or over stretching of cellophane tape can alter lip print recording.

In case of teeth loss, due to reasons such as trauma, palatal rugae pattern serves as an alternative method for identification because of its uniqueness. Since the rugae are located inside the oral cavity and are protected by the tongue and a pad of buccal fat, they remain undisturbed from heat and other assaults. However, rugae patterns can still change with age and other environmental influences such as orthodontic movements, tooth extraction, cleft palate surgery, periodontal surgery, and impacted canine eruption.

Faces play a major role in forensic sciences. If the face of the deceased remains unchanged, the identity of the individual can be easily determined without the need for forensic professionals. Forensic dentistry functions only in cases where the face is destroyed by various means. Most often in major disasters and in accidents, the body of the dead person may be decomposed or skeletonized. In such cases, the only part retained may be the skull and the other bones. Skulls can remain unaltered even for millions of years and can provide an inimitable means of identification. The cranial appearance is very much helpful in determining the sex of the individual. Computerized facial reconstruction method uses a laser video camera interfaced with a computer or with CT scanning. Skull data are then imaged as a fully shaded 3D surface. Although an exact model of the face may not be reconstructed,

this method greatly helps in identifying the individual.

Victims possessing all or most of their dentition can be identified using their teeth through various methods, whereas those missing all of their teeth lack such information. In such circumstances, the only identifiable remains are the victim's dentures. A denture as such without any markings is of less or no use in forensic dentistry. The dentures can reveal the positive identity of a person, only if it is marked. Labeling the denture is one of the easiest and reliable methods of identification. Methods of denture labeling falls under two categories: the surface marking method and the inclusion method. The surface marking methods include scribbling or engraving the denture and marking with embossed letters. Inclusion methods include metal identification bands, computer-printed denture micro-labeling system, lead paper labeling, embedding the patient photograph, denture bar coding, T-bar, laser etching, lenticular card system (using a polyethylene terephthalate, in which the first flip shows patient's name, sex, and age, and the second flip shows address and driving license number, when viewed from a different angle), radio-frequency identification tags, electronic microchips. Both the methods of denture marking can be incorporated in full and partial dentures, mouth guards and removable orthodontic appliances. Among these two categories, the surface methods are easy to apply and relatively inexpensive. The only disadvantage is they worn off easily and needed to be reapplied. Whereas, the inclusion methods are more permanent; however, it can weaken the denture structure and create porosity.

The tongue is unique to each person in its shape and surface textures and is the only internal organ that can be protruded from the body and easily exposed for inspection. Use of tongue prints for forensic identification is at budding stage now. For this technique to be successful, the antemortem photograph or impression of the tongue should be available. The lingual morphological aspects can be preserved using the alginate molding technique for duplicating the minute details which are unique for each and every individual. The lingual impression, together with its photographic image, may constitute secure methods for forensic dentistry identification. The tongue prints present in the human tongue recently becomes a new member of the biometrics family. Tongue biometric template can be made using three views such as left lateral view, right lateral view, and profile view. Extraction of tongue algorithm of collecting points gives efficient template for shape of the tongue whereas for texture analysis, normalized histogram with Scale Invariant Feature Transform is used. Matching is done by combining both the extraction techniques templates.

In summary, forensic odontology is an upcoming branch of dentistry with a lot of scope for development. At the crime scene, forensic odontologists play a major role in investigating and interpreting the dental evidence. The unique nature of dental anatomy and custom restorations ensure accuracy when identification techniques are appropriately employed. A consistent effort has to be made to computerize all the data available to facilitate comparison. Efforts have to be made to maintain the dental records which will serve as antemortem data. Each dental professional has a responsibility to understand the forensic involvements associated with their dental practice. Dentists and dental students alike should be made aware of the available technologies and their uses in forensic dentistry. Further research into the field of forensic dentistry should be encouraged, paving the way for us to incorporate newer technologies into the science of establishing the human identity.

Adapted from *Jeddy, N., Ravi, S., & Radhika, T.* (2017). *Current trends in forensic odontology. Journal of forensic dental sciences*, 9(3), 115–119. doi:10.4103/jfo.jfds_85_16. This passage is licensed under a Creative Commons Attribution-ShareAlike 4.0 License.

1. Dentition is useful for forensic identification because it is resistant to decomposition and unique to each individual
   A. Both the statement and reason are correct and related
   B. Both the statement and reason are correct but NOT related
   C. The statement is correct but the reason is NOT
   D. The statement is NOT correct, but the reason is correct
   E. NEITHER the statement NOR the reason is correct

2. Which of the following is NOT a common method for forensic identification?
   A. Visual/physical descriptions
   B. Medical history
   C. Personal belongings
   D. Full genome sequencing
   E. Dental identification

3. Which of the following was one of the first uses of radiography in the forensic sciences?
   A. To visualize lead bullets in victims that have been shot
   B. To visualize knife penetration in victims that have been stabbed
   C. To compared the dentition of the deceased with that of antemortem images
   D. To reveal identifying features such as the shape of roots, supernumerary teeth, and noncarious lesions
   E. To produce multiple cross-section images that can be used to construct a postmortum facsimile image

4. Which of the following locations is most commonly bitten in both males and females?
   A. Legs
   B. Shoulders
   C. Hands
   D. Arms
   E. Neck

5. Forensic dental identification is often dependent on the availability, adequacy, and accuracy of postmortum dental records.

   The frontal sinus configuration is similar in many individuals and cannot be used as a parameter for individual identification
   A. Both statements are TRUE
   B. Both statements are FALSE
   C. The first statement is TRUE, the second is FALSE
   D. The first statement is FALSE, the second is TRUE

6. Which of the following individual characteristics can NOT be identified using bite marks?
   A. Width of dental arches
   B. Missing teeth
   C. Extra teeth
   D. Periodontium
   E. Biting surfaces

7. If the lips, teeth, and palate of a deceased individual are dismembered, which technique is most suitable for forensic identification?
   A. Cheiloscopy
   B. Dental radiographs
   C. Denture identification
   D. Dental records
   E. Rugoscopy

8. Which of the following factors does NOT contribute to the uniqueness of an individual's dentition?
   A. Supernumerary teeth
   B. Dental carries
   C. Orthodontic treatment
   D. Gum recession
   E. Abrasion

9. Maintenance of dental records is the responsibility of the hospital or clinic.

   The mandatory retention time of dental records is the same in every Western country.

   A. Both statements are TRUE
   B. Both statements are FALSE
   C. The first statement is TRUE, the second is FALSE
   D. The first statement is FALSE, the second is TRUE

10. Which of the following statements regarding lip prints are TRUE?

    A. Lip prints must be obtained within 24 hrs of death to avoid postmortem alterations
    B. Lip print patterns of open mouths have ill-defined grooves that are hard to interpret
    C. Tooth loss does not affect lip prints
    D. Lip print patterns of closed mouths have well-defined grooves
    E. Pathology of the lip can alter lip print recording

11. In which of the following scenarios are bite marks most commonly found on the victims?

    A. Mass casualties
    B. Suicide
    C. Rape
    D. Senior abuse
    E. Motor vehicle collision

12. Which of the following statements regarding denture marking is INCORRECT?

    A. Laser engraving is an inclusion method
    B. Radio-frequency identification is an inclusion method
    C. Surface methods are easy to apply
    D. Surface methods can weaken the structure
    E. Inclusion methods can create porosity

13. Which of the following best describes the author's tone in last paragraph

    A. Scornful
    B. Agnostic
    C. Skeptical
    D. Defensive
    E. Optimistic

14. Which of the following is NOT an example of an inclusion method?

    A. Lenticular cards
    B. Barcodes
    C. Micro-labeling
    D. Embossing
    E. Lead paper labeling

15. The tongue is a special organ for forensic identification because:

    A. It is unique to each individual
    B. It is the only internal organ that can be easily protruded from the body
    C. It is resistant to decomposition, skeletonization, and fire damage
    D. It is the only internal organ that can be preserved using alginate molding
    E. Antemortem records are required

16. Which of the following factors do NOT alter palatal rugae patterns?

    A. Orthodontic treatment
    B. Cleft palate surgery
    C. Age
    D. Impacted teeth
    E. Mouth position

17. Cranial appearance is useful for determining which of the following identity traits?

    A. Height
    B. Age
    C. Sex
    D. Race
    E. Weight

18. Which of the following is farthest from the author's intended meaning of the phrase "other assaults" in paragraph ten?
    A. Chemical burns
    B. Penetrating trauma
    C. Skeletonization
    D. Blunt force trauma
    E. Exposure to the elements

19. What is the main purpose of the second paragraph?
    A. To summarize the qualities of teeth that are important with respect to forensic odontology
    B. To explain the history of dental evidence with respect to the law
    C. To summarize the evolution of forensic technology
    D. To introduce the major applications of forensic odontology
    E. To explain the different categories of postmortum changes

20. Which of the following statements is the author of the passage most likely to agree with?
    A. Forensic odontology is for the most part, an imprecise and unreliable science
    B. Radiographs should be the first source of evidence for forensic identification
    C. The accuracy of bite mark analysis is questionable and may lead to wrongful convictions
    D. The science of forensic odontology has not fully matured yet
    E. Lip print patterns are consistent and reproducible sources of evidence

Passage 2

Alexander Fleming: Discoverer of penicillin

On August 6, 1881, Alexander Fleming was born to Hugh Fleming and Grace Stirling Morton in Lochfield Farm, Scotland. Initially schooled in Scotland, Fleming eventually moved to London with three brothers and a sister, and completed his youth education at the Regent Street Polytechnic. He did not enter medical school immediately after; instead, he worked in a shipping office for four years. When his uncle John died, he willed equal shares of his estate to his siblings, nieces and nephews, and Fleming was able to use his share to pursue a medical education. In 1906, he graduated with distinction from St Mary's Medical School at London University.

Fleming did not intend to begin a career in research. While serving as a private in the London Scottish Regiment of the Territorial Army, he became a recognized marksman. Wishing to keep Fleming in St Mary's to join its rifle club, the club's captain convinced him to pursue a career in research rather than in surgery, as the latter choice would require him to leave the school. The captain introduced him to Sir Almroth Wright, a keen club member and a pioneer in immunology and vaccine research, who agreed to take Fleming under his wing. It was with this research group that Fleming stayed throughout his entire career.

When World War I broke out, Fleming served in the Army Medical Corps as a captain. During this time, he observed the death of many of his fellow soldiers, not always from wounds inflicted in battle, but from the ensuing infection that could not be controlled. The primary means to combat infection was antiseptics, which frequently did more harm than good. In an article he wrote during this time, Fleming discussed the presence of anaerobic bacteria in deep wounds, which proliferated despite antiseptics. Initially, his research was not accepted, but Fleming continued undaunted and in 1922, he discovered lysozyme, an enzyme with weak antibacterial properties. History tells us that, while infected with a cold, Fleming transferred some of his

nasopharyngeal mucus onto a Petri dish. Not known for fastidious laboratory organization, he placed the dish among the clutter at his desk and left it there, forgotten, for two weeks. In that time, numerous colonies of bacteria grew and proliferated. However, the area where the mucus had been inoculated remained clear. Upon further investigation, Fleming discovered the presence of a substance in the mucus that inhibited bacterial growth and he named it lysozyme. He also discovered lysozyme in tears, saliva, skin, hair and fingernails. He was soon able to isolate larger amounts of lysozyme from egg white, but in subsequent experiments found that this enzyme was effective against only a small number of non-harmful bacteria. Nevertheless, this would lay the groundwork for Fleming's next great discovery.

In 1928, Fleming began a series of experiments involving the common staphylococcal bacteria. An uncovered Petri dish sitting next to an open window became contaminated with mould spores. Fleming observed that the bacteria in proximity to the mould colonies were dying, as evidenced by the dissolving and clearing of the surrounding agar gel. He was able to isolate the mould and identified it as a member of the *Penicillium* genus. He found it to be effective against all Gram-positive pathogens, which are responsible for diseases such as scarlet fever, pneumonia, gonorrhoea, meningitis and diphtheria. He discerned that it was not the mould itself but some 'juice' it had produced that had killed the bacteria. He named the 'mould juice' penicillin. Later, he would say: "*When I woke up just after dawn on September 28, 1928, I certainly didn't plan to revolutionize all medicine by discovering the world's first antibiotic, or bacteria killer. But I suppose that was exactly what I did*."

Although Fleming published the discovery of penicillin in the British Journal of Experimental Pathology in 1929, the scientific community greeted his work with little initial enthusiasm. Additionally, Fleming found it difficult to isolate this precious 'mould juice' in large quantities. It was not until 1940, just as he was contemplating retirement, that two scientists, Howard Florey and Ernst Chain, became interested in penicillin. In time, they were able to mass-produce it for use during World War II.

Fleming received many awards for his achievements. In 1928, he became Professor of Bacteriology at St Mary's. He was elected a Fellow of the Royal Society in 1943 and elevated to the level of Emeritus Professor of Bacteriology at the University of London in 1948. A recipient of some thirty honorary degrees, in 1945, he won the most prestigious award, the Nobel Prize in Physiology/Medicine. He was made a Knight Bachelor by King George VI in 1944 and a Knight Grand Cross of the Order of Alfonso X the Wise in 1948. Time Magazine named Fleming one of the 100 most important people of the 20th century.

Fleming was a quiet, patient and modest gentleman, not given to displays of emotion, with a natural shyness that made him avoid accolades and attention. He could be silent to the point of being inscrutable, making it difficult even for his wife and closest friends to gauge his moods and desires. He was occasionally brusque and aloof, yet charming and gentle among friends and loved ones. In 1915, he married an Irish-born nurse named Sarah Marion McElroy, who went by the nickname Sareen. After nine years of marriage, they had a son named Robert Fleming, who went on to become a general practitioner. Sareen died after 34 years of marriage, and her death affected Fleming profoundly. He subsequently buried himself in his work, spending longer hours in his laboratory behind closed doors. A biographer wrote: "*As if overnight, Fleming, with red-rimmed eyes and trembling hands, seemed to have become an old man*." However, in 1953, Fleming remarried Dr. Amalia Koutsouri-Vourekas in a Greek church in London.

On March 11, 1955, Alexander Fleming suddenly died of coronary thrombosis at home. He had been suffering from what he perceived to be gastric upset for some weeks. When his wife called their family physician regarding the onset of nausea on March 11, he reassured them that a house visit was not necessary. However, within minutes, he succumbed to the coronary event. His cremated ashes were placed in St Paul's Cathedral, and "*[h]e died as he wished; quietly, without a gradual decline in physical or mental capacity, and even without inconveniencing his physician*".

Tan, S. Y., & Tatsumura, Y. (2015). *Alexander Fleming (1881-1955): Discoverer of penicillin*. Singapore medical journal, 56(7), 366–367. doi:10.11622/smedj.2015105. © Singapore Medical Association. Reproduced with permission.

21. Why did the caption of the London Scottish Regiment convince Fleming to do research?
    A. Surgical training was too expensive
    B. Fleming's uncle was a scientist
    C. He wanted Fleming to work for the army
    D. He wanted Fleming to stay at St Mary's
    E. There was a shortage of immunologists

22. The first anti-bacterial substance discovered by Fleming was:
    A. Penicillin
    B. Streptomycin
    C. Doxycycline
    D. Lysozyme
    E. Antiseptics

23. Fleming's discovery was initially greeted with little enthusiasm by the scientific community

    The isolation of penicillin for medicine was not accomplished until the end of 1945
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

24. Which of the following statements regarding penicillin is FALSE?
    A. It is effective against pneumonia
    B. It is derived from mucus
    C. It revolutionized modern medicine
    D. It was discovered in 1928
    E. It was discovered by accident

25. According to the author, which of the following best describes Fleming's natural personality?
    A. Ambitious and hardworking
    B. Pretentious and arrogant
    C. Humble and enigmatic
    D. Antisocial, cynical and paranoid
    E. Bold and aloof

26. Unlike penicillin, lysozyme was not used in World War II medicine because it is naturally found in human tears, saliva, skin, hair, and fingernails
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

27. What was the cause of Fleming's death?
    A. Gastric upset
    B. Meningitis
    C. Scarlet fever
    D. Pulmonary embolism
    E. Coronary thrombosis

28. Which of the following accurately describes the order in which Fleming received his accolades?
    A. Nobel prize, professorship, fellowship, Knight Bachelor, emeritus professorship, Knight Grand Cross
    B. Professorship, Knight Bachelor, fellowship, Nobel prize, emeritus professorship, Knight Grand Cross
    C. Knight Grand Cross, emeritus professorship, Nobel prize, Knight Bachelor, fellowship, professorship
    D. Professorship, fellowship, Knight Bachelor, Nobel prize, emeritus professorship, Knight Grand Cross
    E. Knight Bachelor, Knight Grand Cross, professorship, fellowship, Nobel prize, emeritus professorship

29. Why did Fleming not enter medical school until after working in a shipping office for four years?
    A. His uncle died
    B. He could not afford tuition
    C. He initially wanted a career in the trades
    D. He did not have good grades
    E. He was drafted into World War I

30. Which of the following was NOT an accurate difference between World War I and II?
    A. Fleming was a captain in WWII, not WWI
    B. Penicillin was mass-produced during WWII, but not WWI
    C. Antiseptics were widely used in WWI
    D. Many preventable deaths in WWI were due to anaerobic bacteria
    E. WWI occurred around the 1920s, while WWII occurred around the 1940s

31. Which of the following was the last name of Fleming's second wife?
    A. Chain Florey
    B. Marion McElroy
    C. Wright
    D. Koutsouri-Vourekas
    E. Amalia

32. Which of the following statements describes the main idea of the passage?
    A. Penicillin was a miraculous discovery that revolutionized modern medicine
    B. Antibiotic resistance is a serious threat to the efficacy of many modern drugs
    C. Alexander Fleming was a humble scientist who serendipitously discovered penicillin and revolutionized modern medicine
    D. Lysozyme was accidentally discovered by Alexander Fleming after experimenting on his own mucus
    E. World War II was the greatest atrocity in human history, with deaths due not only to wounds, but from the ensuing infection

33. Which of the following diseases would be resistant against penicillin treatment?
    A. Diphtheria
    B. Pneumonia
    C. Gonorrhoea
    D. Hepatitis C
    E. Meningitis

34. Which of the following substances contains the highest amount of lysozyme?
    A. Egg white
    B. Tears
    C. Egg yolk
    D. Saliva
    E. Skin

35. Which of the following best describes the author's tone in the last paragraph?
    A. Serious
    B. Solemn
    C. Light-hearted
    D. Melancholy
    E. Sympathetic

Passage 3

Isoniazid-Resistant Tuberculosis

For decades, people working in tuberculosis (TB) knew that monoresistance to isoniazid was common. Isoniazid has been in clinical use since the 1950s, and drug resistance was expected because its use became widespread. But this knowledge did not necessarily lead to testing for isoniazid-resistant, rifampicin-susceptible TB (Hr-TB) or to the use of special drug regimens for this form of TB. Indeed, for decades, no drug-susceptibility testing for any drug was done unless patients failed first-line therapy or had risk factors for drug-resistant TB (DR-TB). Simply put, we chose to ignore the problem.

When the TB world woke up to the need for universal drug-susceptibility testing and included it as a key goal in the End TB Strategy released in 2015, the focus became rapid testing for rifampicin resistance as a means of achieving universal drug-susceptibility testing. Novel technologies such as Xpert MTB/RIF were rolled out in 2010, but the technology did not include isoniazid-resistance testing. Even today, access to any drug-susceptibility testing remains low, and when performed, testing is often limited to rifampicin resistance.

In 2020, we can no longer hide from this worrisome problem because Hr-TB is much more common than rifampicin resistance and could seriously jeopardize progress in the fight against TB. This is confirmed by an analysis of aggregated drug resistance data from 2003 to 2017 across 156 countries presented in the accompanying research study by Anna Dean and colleagues in *PLOS Medicine*, showing that—on average—7.4% (95% CI 6.5–8.4) of new cases and 11.4% (9.4–13.4) of previously treated patients have Hr-TB. The overall prevalence of isoniazid resistance (with or without concomitant rifampicin resistance) ranged between 10.7% (9.6–11.9) and 27.2% (24.6–29.9) depending on the treatment history and reached even more alarming levels in certain countries, particularly in the European and Western Pacific regions.

The analysis by Dean and colleagues highlights major flaws in national surveillance systems, which go hand in hand with limited laboratory capacity. The small sample sizes available from some countries make national prevalence estimates imprecise. Furthermore, the diversity of detection methods employed across settings along with the widespread lack of quality control underscores the need for improved surveillance by countries.

From a clinical standpoint, if isoniazid resistance is not detected, new patients are managed as if they had pansusceptible TB, with a substantially increased risk of treatment failure or relapse and a greater propensity to acquire further resistance. Yet, most research and policy efforts so far have been focused solely on rifampicin resistance as a proxy for multidrug-resistant (MDR)-TB. This means that hundreds of thousands of patients with Hr-TB are staying in the shadows, not receiving appropriate care, and all too often ending up developing MDR-TB.

Thankfully, some progress has been made in the last couple of years. In 2018, the World Health Organization (WHO) issued new treatment recommendations for Hr-TB, replacing the previous 9-month course of rifampicin, pyrazinamide, and ethambutol with a 6-month regimen based on levofloxacin plus ethambutol. This recommendation is reflected in the updated guideline for DR-TB jointly released in 2019 by the American Thoracic Society, Centers for Disease Control and Prevention, European Respiratory Society, and Infectious Disease Society of America, which also suggests reducing the duration of pyrazinamide to 2 months in case of noncavitary and lower-burden disease or if a high risk of pyrazinamide-induced toxic effects are anticipated.

However, high-TB-burden countries will struggle to routinely implement these new guidelines for Hr-TB because easy access to isoniazid-resistance testing is a challenge. Although there are WHO-endorsed technologies (such as line-probe assays and liquid cultures) that can detect isoniazid resistance, these tools are limited to centralized or reference laboratories. Also, even in settings where the prevalence of Hr-TB is the highest, starting a quinolone-containing regimen empirically requires caution, in spite of the low levels of resistance to levofloxacin and/or pyrazinamide, as documented by a recent surveillance project.

The year 2020 might bring some hope, as the Xpert MTB/XDR cartridge is expected to be released and will include resistance testing for isoniazid, fluoroquinolones, and second-line injectables. The TB diagnostics pipeline also includes several next-generation, high-throughput molecular tests that are able to simultaneously detect rifampicin and isoniazid resistance in centralized laboratories.

Whole-genome sequencing data continue to shed light on the wide range of mutations associated with drug resistance, thus not only improving our understanding of transmission dynamics but also helping to refine therapeutic choices for the individual patient. Importantly, a deeper examination of the genotypic diversity of isoniazid resistance would be of great benefit to inform treatment guidelines that are currently based on low-quality evidence. At present, nationwide scale-up of whole-genome sequencing for routine TB diagnosis may not seem within reach in most high-TB-burden countries owing to cost and infrastructure requirements. However, this technology is becoming cheaper and easier and offers an incredible opportunity to generate better quality information on isoniazid resistance, thanks to its ability to detect clinically relevant mutations that are not captured by conventional rapid tests, which usually target only the most common *katG* and *inhA* mutations. Recently, Unitaid and the Foundation for Innovative New Diagnostics (FIND) have partnered to launch the Seq&Treat project that will pilot next-generation genome sequencing, an innovation that will enable fast, accurate diagnosis of DR-TB.

Beyond technologies and guidelines, we need to acknowledge the human impact of DR-TB, which imposes a tremendous physical, mental, financial, and social burden on patients. In addition to the 3 million TB patients who fail to get diagnosed or notified, there are large numbers of people with Hr-TB who are misdiagnosed and consequently mismanaged. Therefore, access to quality TB care is a human rights issue. In 2020, quality TB care must include universal drug-susceptibility testing—not just rifampicin resistance testing—for all individuals with TB, followed by individualized therapy, based on test results.

Sulis G, Pai M. (2020) *Isoniazid-resistant tuberculosis: A problem we can no longer ignore.* PLOS Medicine 17(1): e1003023. https://doi.org/10.1371/journal.pmed.1003023. This passage is licensed under a Creative Commons Attribution 4.0 International License.

36. A total of 2 million TB-positive individuals have gone either undiagnosed or unnotified.

    7.4% of previously treated patients have Hr-TB.

    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

37. Which of the following is NOT a major flaw in national surveillance systems for isoniazid resistance?

    A. Diversity of detection methods
    B. Limited laboratory capacity
    C. Small sample sizes
    D. Poor administrative communication
    E. Lack of quality control

38. Which of the following statements would the author most likely agree with?

    A. Technological limitations are mainly responsible for the current lack of drug-susceptibility testing
    B. Quality care for TB is a privilege for individuals living in developed nations
    C. The 2010 debut of Xpert MTB/RIF introduced a promising technology for universal drug-susceptibility testing
    D. A proper diagnosis for MDR-TB should involve both rifampicin and isoniazid resistance testing

39. Which of the following is a CORRECT difference between the new and old treatment recommendations for Hr-TB?
    A. The new recommendation is a 9-month course of drugs rather than 6-months
    B. The old recommendation included ethambutol instead of levofloxacin
    C. The new recommendation replaces rifampicin and pyrazinamide with levofloxacin
    D. The old recommendation is a 2-month drug regimen instead of a 6-month regimen
    E. The new recommendation does not include ethambutol

40. Why is whole-genome sequencing technology still not common in high-TB-burden countries?
    A. Lack of education and awareness
    B. Red tape and bureaucracy
    C. Lack of a public health institution
    D. Limited Infrastructure and high cost
    E. Limited technology and manufacturing capabilities

41. Which one of the following is NOT a reason why it is difficult for high TB-burden countries to implement the new WHO guidelines for Hr-TB?
    A. Line-probe assays are limited to centralized or reference laboratories
    B. Empirically starting a drug regimen that contains quinolone is risky
    C. Liquid cultures are limited to centralized or reference laboratories
    D. Providing easy access to isoniazid resistance testing is a challenge
    E. WHO-endorsed technologies are not available in high TB-burden countries

42. Which of the following is NOT a burden that patients with DR-TB experience?
    A. Societal
    B. Financial
    C. Physical
    D. Social
    E. Mental

43. Which of the following words best describes the author's tone throughout the passage?
    A. Persuasive
    B. Scornful
    C. Cynical
    D. Skeptical
    E. Accusatory

44. What is the purpose of the first paragraph?
    A. To explain the mechanism of drug resistance
    B. To critique the use of novel technologies to achieve universal drug-susceptibility testing
    C. To explain how the issue of DR-TB came to be
    D. To convey the urgency of fighting Hr-TB
    E. To introduce the role of the World Health Organization (WHO)

45. What percentage of new tuberculosis cases are isoniazid-resistant and rifampicin-susceptible?
    A. 95%
    B. 11.4%
    C. 10.7%
    D. 7.4%
    E. 27.2%

46. Which of the following institutions was not involved in the release of the new WHO recommendations for Hr-TB?
    A. European Respiratory Society
    B. Infectious Disease Society of America
    C. Centers for Disease Control and Prevention
    D. American Thoracic Society
    E. Doctors of Thoracic Surgery

47. If isoniazid resistance is not detected, new patients are managed as if they had Hr-TB.

    Rifampicin resistance is commonly used as a proxy for multidrug-resistant (MDR)-TB.

    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

48. Which of the following values could be the overall prevalence of isoniazid resistance?

    A. 10%
    B. 15%
    C. 30%
    D. 35%
    E. 50%

49. Rank TB, MDR-TB, and Hr-TB in order of least drug-resistant to most drug-resistant

    A. Hr-TB < MDR-TB < TB
    B. TB < MDR-TB < Hr-TB
    C. TB < Hr-TB < MDR-TB
    D. MDR-TB < Hr-TB < TB
    E. Hr-TB < TB < MDR-TB

50. Why would a deeper examination of the genotypic diversity of isoniazid resistance be beneficial for TB treatment?

    A. Sequence data will uncover the full range of mutations associated with drug resistance
    B. Treatment guidelines are currently based on low-quality evidence
    C. Mutations in katG and inhA will be detected
    D. Genotype data is required for the creation of new antibiotics
    E. Genome editing can be used to reverse drug resistance in many strains of TB

STOP

You have completed the RCT section of the DAT.
The exam is now over.

FULL-LENGTH 2 MEDIUM DIFFICULTY

SOLUTIONS

Survey of Natural Sciences

1. Which embryonic germ tissue develops into the musculoskeletal system?
   A. Ectoderm
   B. Epiderm
   C. Mesoderm
   D. Endoderm
   E. Neural crest

   All structures of the body are derived from three embryonic germ layers: the ectoderm, mesoderm, and endoderm. Here is a summary of what each layer develops into:

   Endoderm – Pharynx, trachea, bronchi, digestive system, liver, pancreas, bladder, lungs, thyroid, and parathyroid

   Mesoderm – Musculoskeletal system, circulatory system, spleen, lymphatic system, notochord, genitourinary system, and dermis

   Ectoderm – Nervous system, hair, nails, sweat glands, and epidermis

2. Which structure stores chromosomal DNA within bacteria?
   A. Capsule
   B. Nucleus
   C. Plasmid
   D. Nucleolus
   E. Nucleoid

   A → Incorrect. The capsule is an outer polysaccharide layer that protects bacteria from phagocytosis and the environment
   B → Incorrect. Bacteria are prokaryotic and do not contain membrane-bound organelles like the nucleus
   C → Incorrect. The plasmid is a structure in bacteria that contains non-chromosomal DNA
   D → Incorrect. The nucleolus is a region of the nucleus that contains chromosomes. It is not found in prokaryotes
   E → Correct answer

3. Which of the following animals is an acoelomate?
   A. Starfish
   B. Snail
   C. Earthworm
   D. Nematode
   E. Lobster

   The five animal phyla that have a coelom are chordata, arthropoda, annelida, mollusca, and echinodermata.
   A → Incorrect. A starfish is an echinoderm
   B → Incorrect. A snail is a mollusc
   C → Incorrect. An earthworm is an annelid
   D → Correct. Nematodes do not have a coelom
   E → Incorrect. A lobster is an arthropod

4. If a male with type B^+ blood and a female with type AB^- blood have children, which of the following would NOT be a possible blood type for their progeny?
   A. AB^+
   B. B^+
   C. AB^-
   D. O^+
   E. B^-

   The Rhesus factor is inherited in an autosomal dominant fashion. Since we do not know if the father is homozygous or heterozygous positive, the progeny can be either Rh^+ or Rh^-.

   Blood type is inherited in an autosomal codominant fashion. Since we do not know if the father is homozygous or heterozygous, we draw two Punnet squares to determine all the possibilities:

	B	O
A	AB	AO
B	BB	BO

	B	B
A	AB	AB
B	BB	BB

5. In a sample of dysfunctional tissue, the epithelium no longer adheres to the basement membrane. Which of the following components is most likely damaged?
   A. Desmosome
   B. Tight junction
   C. Gap junction
   D. Adherens junction
   E. Hemidesmosome

   A → Incorrect. Desmosomes connect neighbouring cells via intermediate filaments
   B → Incorrect. Tight junctions form water-tight seals between neighbouring cells
   C → Incorrect. Gap junctions form tunnels between neighbouring cells, allowing the free flow of water and ions
   D → Incorrect. Adherens junctions connect neighbouring cells via actin filaments
   E → Correct. Hemidesmosomes connect cells with the extracellular matrix (ECM). The basement membrane is a type of ECM

6. Which of the following ocular structures contains the highest density of cone cells?
   A. Retina
   B. Sclera
   C. Fovea
   D. Iris
   E. Cornea

   A → Incorrect. The retina is a layer of light-sensitive cells on the back wall of the eye. It contains both rod and cone cells
   B → Incorrect. The sclera is the white outer layer of the eye. It does not contain light-sensitive cells
   C → Correct. The fovea is a small indentation in the retina that contains mostly cone cells. It is responsible for high-definition vision at the centre of our visual field
   D → Incorrect. The iris is a pigmented muscle that controls the diameter of the pupil. It has no light-sensitive cells
   E → Incorrect. The cornea is a clear refractive covering that protects the iris and pupil

7. A rodent runs away from a lightbulb as soon as it is turned on. What is this an example of?
   A. Chemotaxis
   B. Photokinesis
   C. Chemokinesis
   D. Phototaxis
   E. Fixed action pattern

   Kinesis is when an animal instinctively changes its rate of movement in response to environmental cues. Taxis is when an animal instinctively moves towards or away from a stimulus. Since the behaviour described by the question stem is directional, it is an example of phototaxis (movement towards/away from light). Answer E) is incorrect because a fixed action pattern must be consistent between members of a species and must also run to completion once started, both of which are not demonstrated by the question stem

8. A male mates with a female who's father was colour-blind. If the couple has three children, what is the probability that all three will be both male and colour-blind?
   A. $\frac{1}{16}$
   B. $\frac{1}{64}$
   C. $\frac{1}{256}$
   D. $\frac{1}{4}$
   E. $\frac{1}{2}$

   Color-blindness is inherited in an X-linked recessive fashion. Since the male is not affected, he carries a normal X chromosome. Since the female's father is affected, she carries one affected and one normal X chromosome. We can find the probabilities of possible offspring by drawing a Punnet square

	X	Y
X^A	X^AX	X^AY
X	XX	XY

   We can see that the probability of having a son that is affected is ¼. To calculate the probability of all three children being both male and affected, use the multiplication rule:

$$\text{Probability} = \frac{1}{4} \times \frac{1}{4} \times \frac{1}{4} = \frac{1}{64}$$

9. During which phase of meiosis does synapsis or crossing-over occur?
   A. Anaphase I
   B. Telophase I
   C. Prophase I
   D. Metaphase II
   E. Prophase II

   A → The homologous chromosomes are pulled apart during anaphase I
   B → The chromosomes uncoil during telophase I
   C → Correct answer
   D → The sister chromatids align at the metaphase plate during metaphase II
   E → The chromosomes coil/condense during prophase II

10. Top-level predators (such as humans) are at greatest risk for ingesting relatively high levels of heavy metals in fish. Which of the following phenomena is most responsible for this?
    A. Parasitism
    B. Bioaccumulation
    C. Bottom-up model
    D. Biological magnification
    E. Top-down model

    A → Incorrect. Parasitism is a symbiotic relationship in which a parasite benefits and a host is harmed
    B → Incorrect. Bioaccumulation is the gradual acquisition of toxic substances within an organism. It does not describe the increase in concentration as the substance works its way up the food chain
    C → Incorrect. A bottom-up model is when a change in the biomass of lower trophic levels impacts higher levels, but not vice versa
    D → Correct. Biological magnification describes how toxic substances can increase in concentration as they work their way up the food chain
    E → Incorrect. A top-down model is when a change in the biomass of higher trophic levels impacts lower levels, but not vice versa

11. Which of the following lists is sorted in the correct order of taxonomic hierarchy?
    A. Class, Domain, Phylum, Family, Genus
    B. Domain, Phylum, Class, Family, Genus
    C. Family, Genus, Class, Domain Phylum
    D. Genus, Family, Class, Phylum, Domain
    E. Class, Phylum, Domain, Family, Genus

    The taxonomic hierarchy is represented with the mnemonic: "Dear King Phillip Came Over For Good Soup" → Domain Kingdom Phylum Class Order Family Genus Species

12. What is the role of the ascending loop of Henle in the urinary system?
    A. Resorb sodium from the filtrate
    B. Resorb water from the filtrate
    C. Filter blood plasma via hydrostatic pressure
    D. Resorb glucose and amino acids
    E. Secrete sodium into the filtrate

    A → Correct answer
    B → Incorrect. This occurs in the descending loop of Henle. The ascending loop of Henle is impermeable to water
    C → Incorrect. This occurs in the glomerulus
    D → Incorrect. This occurs in the proximal convoluted tubule
    E → Incorrect. This is the opposite of what occurs

13. A population of wolves are in Hardy-Weinberg equilibrium. The allele for grey fur (F) has a frequency of 0.11, and the allele for white fur (f) has a frequency of 0.89. What is the percentage of heterozygotes in the population?
    A. 0.18
    B. 0.82
    C. 0.81
    D. 0.01
    E. 0.5

    Using the Hardy-Weinberg equation, solve for the percentage of heterozygotes within the population (pq):

    $$p^2 + 2pq + q^2 = 1$$
    $$2pq = 1 - p^2 - q^2$$
    $$2pq = 1 - (0.11)^2 - (0.89)^2$$
    $$2pq \approx 1 - (0.1)^2 - (0.9)^2$$
    $$2pq \approx 1 - 0.01 - 0.81$$
    $$2pq \approx 1 - 0.82$$
    $$2pq \approx 1 - 0.18$$

14. Which of the following cells are involved in both innate and adaptive immunity?
    A. Plasma cells
    B. Neutrophils
    C. Natural killer cells
    D. Macrophages
    E. Regulatory T cells

    Innate immunity describes the body's non-specific defences against pathogens, which do not require previous exposure to an antigen. In contrast, adaptive immunity describes the body's specific defences, which are acquired after previous exposure to an antigen.

    A → Incorrect. Plasma cells function solely within the adaptive immune system. They produce pathogen-specific antibodies, resulting in phagocytosis and activation of the complement system
    B → Incorrect. Neutrophils function solely within the innate immune system. They are specialized to phagocytose and kill bacteria via oxidative/respiratory burst
    C → Incorrect. NK cells function solely within the innate immune system. They destroy virus-infected or cancerous cells via perforin and granzyme
    D → Correct. Macrophages phagocytose pathogens (innate immunity) and present antigens on MHC II to helper T cells (adaptive immunity)
    E → Incorrect. Regulatory T cells function solely within the adaptive immune system. They down-regulate the induction and proliferation of effector T cells

15. Two psychiatric patients both have a NCID1 gene deletion. One develops bipolar disorder, while the other develops intellectual disability. Which of the following best describes this phenomenon?
    A. Epistasis
    B. Pleiotropy
    C. Polygenetic inheritance
    D. Low penetrance
    E. X inactivation

    A → Incorrect. Epistasis is when one gene affects the expression of a different gene
    B → Correct. Pleiotropy is when one gene influences multiple phenotypic traits that are seemingly unrelated (mood and intelligence in this example)
    C → Incorrect. Polygenetic inheritance is when one trait is controlled by multiple genes
    D → Incorrect. Penetrance is the probability that individuals with a particular genotype will show an associated phenotype
    E → Incorrect. X inactivation is the silencing of the X chromosome in females via packaging of the DNA into transcriptionally inactive heterochromatin

16. Which of the following biomes have the highest level of biodiversity?
    A. Boreal forest
    B. Tropical forest
    C. Marine
    D. Savanna
    E. Temperate forest

    A → Incorrect. The boreal forest/taiga biome is the largest biome on Earth, not the most diverse. Located just south of the arctic circle, it is characterized by snowfall during cold winters and warm summers. Conifer trees dominate, with scattered shrubs. Mammals include brown bears and caribou. Examples include North America and Russia
    B → Correct. The tropical forest biome contains the highest level of biodiversity, thanks to high rainfall and year-round temperatures. Located along the equator, examples include the Amazon rainforest, Borneo, and South Africa
    C → Incorrect. The marine biome is defined by its saltwater chemical composition. Although home to many aquatic species, it is not as diverse as the tropic rainforest biome
    D → Incorrect. The savanna biome is not the most diverse. Located along and below the equator, it is characterized by seasonal rainfall, warm year-round temperatures, and common forest fires. Large herbivorous mammals (wildebeests, zebras) exist, along with carnivorous predators. Examples include Kenya and North Australia
    E → Incorrect. The temperate forest biome is not the most diverse. Located midlatitude, it is characterized by moderate winters and summers. Deciduous trees dominate, forming distinct layers (canopy, tree strata, shrubbery, herbs). In the winter, most mammals hibernate, and birds migrate to warmer biomes. Examples include Ontario and Shanghai

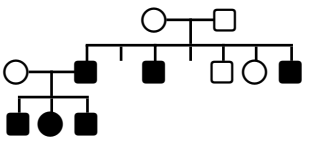
17. After intense exercise, levels of ___ are low and levels of ___ are high in the blood
    A. CO_2; ethanol
    B. O_2; ethanol
    C. CO_2; lactate
    D. O_2; lactate
    E. O_2; insulin

    During intense exercise, there is a shortage of oxygen in the muscles due to the increased rate of glycolysis. This triggers the process of anaerobic fermentation, during which pyruvate is temporarily converted into lactate in order to regenerate NAD^+. Ethanol fermentation does not occur in humans

18. Which of the following describes the proliferative phase of the menstrual cycle?
    - ***A. Endometrium thickens in preparation for implantation of the blastocyst***
    - B. Endometrium is shed in the form of a period
    - C. Endometrium thickens in preparation for implantation of the zygote
    - D. Implantation occurs and estrogen is produced by the corpus luteum
    - E. Granulosa cells of the corpus luteum begin to produce progesterone and inhibin

    A → Correct answer
    B → Incorrect. This describes the menstrual phase
    C → Incorrect. The embryo is implanted in the endometrium at the blastocyst stage, not the zygote stage
    D → Incorrect. This describes the secretory phase
    E → Incorrect. This does not describe the menstrual cycle, but rather the luteal phase of the ovarian cycle

19. A genetic disease is identified to have the following pedigree within a family of dogs. What is the most likely inheritance pattern?



    - A. Autosomal recessive
    - B. Autosomal dominant
    - ***C. X-linked recessive***
    - D. X-linked dominant
    - E. Y-linked

    A → Incorrect. For an autosomal recessive inheritance pattern, all offspring must be unaffected if only one parent is affected. This rule is violated by the second mating
    B → Incorrect. For an autosomal dominant inheritance pattern, all offspring must be unaffected if both parents are unaffected. This rule is violated by the original mating
    C → Correct. Since males are disproportionately affected, we can reasonably conclude that the inheritance pattern is X-linked recessive. The two females involved in the two matings must both be carriers
    D → Incorrect. For an X-linked dominant inheritance pattern, the mother and daughters of an affected male must also be affected. This rule is violated
    E → Incorrect. Females can not be affected in a Y-linked inheritance pattern. This rule is violated

20. At which stage during embryonic development does the three germ layers form?
    - A. Neurulation
    - B. Blastulation
    - C. Cleavage
    - D. Organogenesis
    - ***E. Gastrulation***

    A → Incorrect. Neurulation is a major component of organogenesis, during which the central nervous system (brain and spinal chord) forms
    B → Incorrect. During blastulation, a hollow cavity called the blastocoel forms
    C → Incorrect. During cleavage, a series of rapid mitotic divisions increases the number of cells
    D → Incorrect. During organogenesis, the three germ layers differentiate into organ-specific tissue
    E → Correct. During gastrulation, the embryonic gut (archenteron), coelom, and three germ layers develop

21. Which of the following series of events occurs during anaphase?
    - A. Spindle fibres attach to chromatids via the kinetochore; formation of the metaphase plate
    - B. Chromosomes condense; centrioles move to poles; mitotic spindle forms; nuclear membrane dissolves
    - ***C. Centrosomes split and chromatids get pulled towards the poles***
    - D. Spindle dissolves; nuclear membrane reforms; chromosomes uncoil
    - E. A cleavage furrow forms in animal cells and a cell plate forms in plant cells to divide the organelles and cytoplasm into two daughter cells

    A → Incorrect. This occurs during metaphase
    B → Incorrect. This occurs during prophase
    C → Correct answer
    D → Incorrect. This occurs during telophase
    E → Incorrect. This describes cytokinesis, which occurs during telophase

22. Which of the following cells actively engage in bone formation?

A. Osteocytes
B. Osteoblasts
C. Chondrocytes
D. Osteoclasts
E. Chondroblasts

A → Incorrect. Osteocytes are osteoblasts that have become trapped in bone matrix. They are found in hollow spaces called lacunae and have reduced bone synthesis activity
B → Correct. Osteoblasts synthesize and deposit uncalcified bone matrix called osteoid
C → Incorrect. Chondrocytes are chondroblasts that have become trapped in cartilage matrix
D → Incorrect. Osteoclasts resorb bone matrix
E → Incorrect. Chondrocytes secrete cartilage matrix

23. Which of the following factors are NOT required for evolution to occur?

A. Variation
B. Overpopulation
C. Inheritance
D. Non-random mating
E. Natural selection

A → Incorrect. Offspring must show differences in their traits such that variations can be selected for or against
B → Incorrect. Darwin identified that more offspring must be produced than can survive in order for evolution to occur
C → Incorrect. Individuals with favourable variations must be able to transmit them to their offspring
D → Correct. This is a requirement for Hardy-Weinberg equilibrium, not evolution
E → Incorrect. Some individuals must have variations that give them an advantage over others, thus increasing fitness

24. Which of the following plant structures is involved in the mass transport of sugar?

A. Stomata
B. Plasmodesmata
C. Vessel elements
D. Sieve tube elements
E. Tracheids

A → Incorrect. Stomata are openings on the inferior surface of a leaf. They are surrounded by two guard cells, which control gas exchange in and out of the leaf
B → Incorrect. Plasmodesmata are special gap junctions only found in plants. They join the cytoplasm of adjacent cells
C → Incorrect. Vessel elements are a type of cell found in xylem tissue, which transports water and minerals
D → Correct. Sieve tube elements are anuclear cells found in phloem tissue, which is specialized for sugar transport
E → Incorrect. Tracheids are a type of cell found in xylem tissue, which transports water and minerals

25. Which of the following extraembryonic membranes is the umbilical chord derived from in placental animals?

A. Yolk sac and allantois
B. Chorion and amnion
C. Allantois and chorion
D. Yolk sac and amnion
E. Chorion and yolk sac

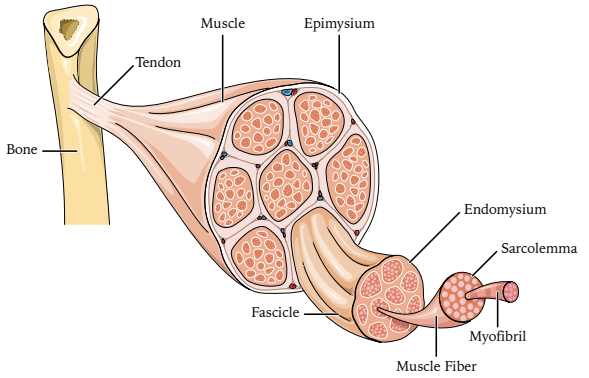
In placental animals, the umbilical chord develops from remnants of the yolk sac and allantois. This occurs by the fifth week of development, providing a source of nutrients for the embryo. The chorion develops into the placenta, not umbilical chord. The amnion surrounds the embryo and is filled with amniotic fluid

26. Which of the following cells is NOT found in the small intestine?

A. Enterocytes
B. Mucus neck cells
C. Paneth cells
D. Goblet cells
E. S cells

A → Incorrect. Enterocytes are duodenal epithelial cells that have microvilli for nutrient absorption
B → Correct. Mucus neck cells and goblet cells are both mucus-producing cells, but the former is located in the stomach while the latter is located in the duodenum
C → Incorrect. Paneth cells are duodenal cells that secrete anti-microbial lysozyme
D → Incorrect. Goblet cells are duodenal cells that secrete mucus
E → Incorrect. S cells are duodenal cells that secrete secretin hormone, which promotes bicarbonate secretion

27. Which of the following is the correct order of muscle organization, from largest to smallest?
    A. Fascicle, muscle, fiber, myofibril, sarcomere
    B. Muscle, fiber, fascicle, myofibril, sarcomere
    C. Muscle, fascicle, fiber, myofibril, sarcomere
    D. Myofibril, sarcomere, muscle, fascicle, fiber
    E. Sarcomere, myofibril, fiber, fascicle, muscle



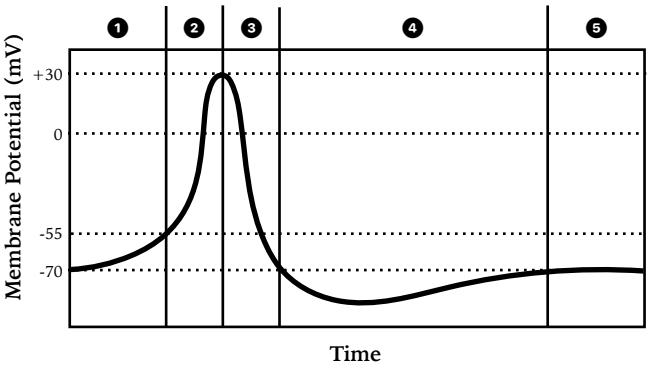
28. Which of the following is NOT a property of gram negative bacteria?
    A. Appears pink under Gram stain
    B. Has a thin peptidoglycan layer
    C. Contains teichoic acid in the cell wall
    D. Secretes exotoxin
    E. Secretes endotoxin (lipopolysaccharides)

A → Incorrect because it is true. Gram negative bacteria stain pink because their peptidoglycan layer is thinner than that of gram positive bacteria, which stains purple
B → Incorrect because it is true. Gram negative bacteria have a thin peptidoglycan layer
C → Correct because it is false. Only gram positive bacteria contain teichoic acid, which is an acid polysaccharide that connects the peptidoglycan cell wall to the cell membrane
D → Incorrect because it is true. Both gram positive and gram negative bacteria secrete exotoxin
E → Incorrect because it is true. Gram negative bacteria secrete lipopolysaccharides

29. Which of the following statements regarding the heart is INCORRECT?
    A. Oxygenated blood flows into the left atrium from the pulmonary veins
    B. Blood flows from the right atrium into the right ventricle via the bicuspid valve
    C. Oxygenated blood leaves the left ventricle through the aortic valve
    D. The left ventricle contains the thickest walls
    E. The systemic circuit extends from the left ventricle to the right atrium

A → Incorrect because it is true
B → Correct because it is false. Blood flows from the right atrium into the right ventricle via the *tricuspid* valve
C → Incorrect because it is true
D → Incorrect because it is true
E → Incorrect because it is true

30. Which of the following numbers corresponds to the relative and absolute refractory periods of an action potential, respectively?



    A. Relative – 4 and 5; Absolute – 3
    B. Relative – 2 and 3; Absolute – 4
    C. Relative – 4; Absolute – 2
    D. Relative – 4; Absolute – 2 and 3
    E. Relative – 5; Absolute – 1 and 2

The relative refractory period occurs when the cell is hyperpolarized (membrane potential < −70 mV). During this period, more depolarizing stimulation is needed to reach threshold potential. In contrast, the absolute refractory period occurs during depolarization and repolarization. During this time, the Na^+ channels are either in use or inactivated. Therefore, an action potential cannot occur no matter how strong the depolarizing stimulus

31. Which of the following is NOT a sporophyte-dominant plant species?
    A. Lycophytes
    B. Angiosperms
    C. Pterophytes
    D. Hornworts
    E. Gymnosperms

Bryophytes/nonvascular plants (liverworts, hornworts, mosses) are gametophyte-dominant, meaning the haploid gametophytes are much larger than the diploid sporophytes. In contrast, vascular plants (lycophytes, pterophytes, angiosperms, gymnosperms) are sporophyte-dominant, meaning the diploid sporophytes are much larger than the microscopic haploid gametophytes (pollen and embryo sac)

32. Which of the following biomes is characterized by low rainfall, variable extreme temperatures, and C4/CAM plants?

A. Savanna
B. Tropical forest
C. Alpine tundra
D. Desert
E. Chaparral

A → Incorrect. A savanna biome is characterized by seasonal rainfall, warm year-round temperatures, and common forest fires. Examples include Kenya and North Australia
B → Incorrect. A tropical forest biome is characterized by high rainfall, high year-round temperatures, and the highest level of biodiversity of any biome. Examples include the Amazon rainforest, Borneo, and South Africa
C → Incorrect. An alpine tundra biome is characterized by high elevation, high winds, and low temperatures
D → Correct answer. Examples include the southwestern United States and North Africa
E → Incorrect. A chaparral biome is characterized by rainy, cool winters and dry, warm summers. Examples include the Mediterranean and California

33. A strand of DNA is composed of 20% guanine. What is the percentage of thymine?

A. 30%
B. 60%
C. 40%
D. 20%
E. 15%

According to Chargaff's rule, the percentage of guanine equals the percentage of cytosine:

$\%G = 20$, therefore $\%C = 20$

Since all DNA has a 1:1 ratio of purines and pyrimidines, we know that $\%CG = 100 - \%AT$. Therefore:

$$\%AT = 100 - \%CG = 100 - 40 = 60$$

$$\%A = \%T = \frac{1}{2}\%AT = \frac{1}{2}(60) = 30$$

34. During DNA electrophoresis, what property of the samples determines their pattern of separation within the gel?

A. Isoelectric point
B. Overall charge
C. Number of base pairs
D. Genetic sequence
E. Temperature

A → Incorrect. Isoelectric point determines separation pattern in protein electrophoresis, not DNA electrophoresis
B → Incorrect. All DNA is negatively charged
C → Correct. The overall size of a stand of DNA is dependent on the number of base pairs. Smaller strands are better able to move through the gel matrix, so they migrate farther from the wells than larger strands
D → Incorrect. Genetic sequences has no effect on separation
E → Incorrect. Temperature has no significant effect

35. Which of the following embryonic structures develops into the root of a plant?

A. Epicotyl
B. Cotyledon
C. Hypocotyl
D. Plumule
E. Radicle

A → Incorrect. The epicotyl is the part of the embryonic shoot located above the cotyledon
B → Incorrect. The cotyledon is an embryonic leaf
C → Incorrect. The hypocotyl is the part of the embryonic shoot located below the cotyledon
D → Incorrect. The plumule is a region of the epicotyl that develops into the plant's first true leaves
E → Correct answer

36. Which blood types are known as the "universal donor" and "universal acceptor", respectively?

A. Type A; type O
B. Type O; type AB
C. Type B; type AB
D. Type AB; type O

O blood contains neither A nor B surface antigens. People with this blood type are called universal donors because they can give blood to any recipient without triggering an immune reaction.

AB blood contains both A and B surface antigens. People with this blood type are called universal acceptors because they recognize both antigens as "self", preventing an immune response

37. Which of the following statements regarding menstruation is CORRECT?
    A. Progesterone levels are at their highest during the proliferative phase
    B. If implantation occurs, the endometrium is maintained by estrogen from the corpus luteum
    C. If implantation does not occur, the corpus luteum is resorbed by polar bodies
    D. Menstruation occurs from birth to menopause
    E. The menstrual cycle lasts around 14 days

    A → Incorrect. Progesterone levels are highest during the secretory phase
    B → Correct answer
    C → Incorrect. The corpus luteum degrades but is not resorbed by polar bodies. Polar bodies are residual haploid cells that result from uneven oocyte cytokinesis. They undergo apoptosis after meiosis is complete
    D → Incorrect. Menstruation occurs from puberty to menopause
    E → Incorrect. Menstruation lasts around 28 days. Ovulation occurs on day 14

38. A population of 60 European colonialists settle an uninhabited island in the Pacific. Years later, the resulting population has an abnormally high incidence of cystic fibrosis. Which of the following best explains this phenomenon?
    A. Bottleneck effect
    B. Genetic drift
    C. Artificial selection
    D. Founder effect
    E. Random outbreeding

    A → Incorrect. The bottleneck effect occurs when a huge reduction in population size due to a random event leads to the loss of biodiversity
    B → Incorrect. This answer is not specific enough. Genetic drift occurs when random forces result in a change in a population's allele frequency, often leading to a loss of biodiversity. The bottleneck effect and founder effect are both examples of genetic drift
    C → Incorrect. Artificial selection occurs when humans select for certain phenotypes in another species in order to benefit themselves
    D → Correct. The founder effect occurs when a small group migrates away from their main population and contain different allele frequencies by chance. This reduces biodiversity in the resulting migrant population and may lead inbreeding and many genetic pathologies
    E → Incorrect. Random outbreeding is a source of genetic variation. It occurs when unrelated individuals mate

39. Which of the following substances is NOT filtered into the Bowman's capsule of the nephron?
    A. Na^+
    B. K^+
    C. Glucose
    D. Amino acids
    E. Polypeptides

    Due to high hydrostatic pressure, blood plasma from the glomerulus is squeezed through fenestrated endothelial cells and podocytes. The filtered plasma ends up in Bowman's capsule, and contains substances with relatively low molecular size, such as ions, glucose, amino acids, small vitamins, and small hormones. Polypeptides and proteins are not filtered into Bowman's capsule

40. Which of the following best describes the citric acid cycle?
    A. Glucose is broken down into two molecules of pyruvate, generating ATP through substrate-level phosphorylation
    B. Acetyl-CoA is broken down into carbon dioxide, generating ATP through substrate-level phosphorylation
    C. Pyruvate is reduced into lactic acid, regenerating NAD^+
    D. Electrons undergo a series of redox reactions, generating ATP through oxidative phosphorylation
    E. Pyruvate is oxidized into acetyl-CoA, producing carbon dioxide

    A → Incorrect. This describes glycolysis
    B → Correct answer
    C → Incorrect. This describes lactic acid fermentation
    D → Incorrect. This describes the electron transport chain
    E → Incorrect. This describes pyruvate oxidation

41. Exactly 300 g of mercury is required to fill an unknown container at 20°C. If this mercury has a density of 14 g/cm^3, what mass of water is required to fill the container at the same temperature?
    A. 0.05 g
    B. 1 g
    C. 10 g
    D. 20 g
    E. 40g

    First we calculate the volume of the unknown container. Write the density formula and rearrange for volume:

    $$\rho = \frac{m}{V}$$
    $$V = \frac{m}{\rho}$$

    Substitute known values and solve:

    $$V = \frac{300\ \text{g}}{15\ \text{g/cm}^3}$$
    $$V = 20\ \text{cm}^3$$

    Since water has a density of 1 g/cm^3, 20 grams of water is required to fill the container.

42. Which of the following interactions is strongest?
    A. London dispersion
    B. Dipole-dipole
    C. Hydrogen bond
    D. Covalent bond
    E. Induced dipole

    The relative strengths of intermolecular and intramolecular forces are: London Dispersion < Induced Dipole < Dipole-Dipole < Hydrogen Bond < Covalent Bond < Ionic Bond. London dispersion occurs when the random distribution of electrons in a non-polar molecule allows a momentary polarization to occur, forming a transient dipole. Induced dipole occurs between the dipole of a polar molecule and and the transient, induced dipole of a non-polar molecule. Dipole-dipole occurs between two polar molecules. Hydrogen bonds are strong dipole-dipole interactions between a partially positive hydrogen atom and a nearby electronegative atom. Finally, covalent and ionic bonds are the strongest interactions, resulting from the sharing and donation of electrons, respectively

43. Which of the following measurements contains the least number of significant digits?
    A. 401 cm
    B. 23,000 mL
    C. 3.20×10^{24}
    D. 0.00430 g
    E. 0.500 m^3

    These rules determine the number of significant digits:
    - All non-zero digits are significant
    - Any zeros between two significant digits are also significant
    - Trailing zeros are significant only if they occur after the decimal
    - Leading zeros in a decimal are not significant

    Considering this, we have:
    401 cm → 3 significant digits
    23,000 mL → 2 significant digits
    3.20×10^{24} → 3 significant digits
    0.00430 g → 3 significant digits
    0.500 m^3 → 3 significant digits

44. NaCl is added to an aqueous solution until it cannot dissolve any more solute. Which of the following terms best describes the resulting solution?
    A. Supersaturated
    B. Hyposaturated
    C. Hypersaturated
    D. Saturated
    E. Unsaturated

    An undersaturated solution contains less than its maximum level of solute ($Q_{sp} < K_{sp}$), and can therefore still dissolve more solute. A saturated solution contains the maximum amount of solute that it can hold ($Q_{sp} = K_{sp}$). Any additional solute added will result in the formation of a precipitate. A supersaturated solution contains more than its maximum level of solute ($Q_{sp} > K_{sp}$). It is unstable and will crystallize if a nucleation site is provided.

45. If the concentration of iron in a solution of Fe_2S_3 is 3 M, what is the concentration of sulphur?

A. 2 M
B. 3 M
C. 3.5 M
D. 4 M
E. 4.5 M

We can use the molar ratio between Fe and S to calculate the concentration of S:

$$\frac{3\text{ mol}}{2\text{ mol}} = \frac{x}{3\text{ M}}$$

$$x = \frac{(3\text{ mol})(3\text{ M})}{2\text{ mol}}$$

$$x = \frac{9}{2} = 4.5\text{ M}$$

46. What is the maximum number of electrons that the d subshell can hold?

A. 14
B. 10
C. 6
D. 5
E. 2

The maximum electron capacity of any subshell can be calculated with $4l + 2$. Since the p subshell corresponds with an l of 2, then the maximum number of electrons it can hold is $4(2) + 2 = 10$

47. If the K_{sp} of AgBr is 5×10^{-13}, then what is its molar solubility?

A. $x = 5 \times 10^{-11}$
B. $x = 5 \times 10^{-15}$
C. $x = \sqrt{5 \times 10^{-15}}$
D. $x = \sqrt{5 \times 10^{-13}}$
E. $x = 5 \times 10^{-13}$

The formula for the solubility product (K_{sp}) of AgBr is:

$$K_{sp} = [Ag^+][Br^-]$$

Since molar ratio of Ag to Br is 1:1, their concentration will be equal after dissolution. Therefore, we can write the equation as:

$$K_{sp} = (x)(x)$$

We can obtain the molar solubility by solving for x:

$$x^2 = K_{sp}$$

$$x^2 = 5 \times 10^{-13}$$

$$x = \sqrt{5 \times 10^{-13}}$$

48. An electrochemical cell consists of half-reactions with the following standard reduction potentials:

$$E^\circ_r(F_2) = 2.87\text{ V}$$
$$E^\circ_r(Ca^{2+}) = -2.87\text{ V}$$

Which of the following best describes the cell?

A. Voltaic cell with $E^\circ_{cell} = (2)(2.87)$ V
B. Galvanic cell with $E^\circ_{cell} = (2)(2.87)$ V
C. Voltaic cell with $E^\circ_{cell} = -(2)(2.87)$ V
D. Galvanic cell with $E^\circ_{cell} = -(2)(2.87)$ V
E. Voltaic cell with $E^\circ_{cell} = 0$ V

Cell potential (E°_{cell}) is equal to the sum of the reduction (E°_r) and oxidation (E°_o) potentials of a cell's half-reactions. Reduction half-reactions always have a positive E°_r while oxidation half-reactions always have a negative E°_r. Since the Li^+ half-reaction has a negative E°_r, we can assume that Li is oxidized. Therefore we can write our sum as follows:

$$2F^- \rightarrow F_2 + 2e^- \qquad E^\circ_r = 2.87$$
$$+ \quad Ca \rightarrow Ca^{2+} + 2e^- \qquad E^\circ_o = 2.87$$
$$2F^- + Ca \rightarrow F_2 + Ca^{2+} \qquad E^\circ_{cell} = 2(2.87)$$

Notice how we converted the E°_r of the Li^+ half-reaction into an E°_o simply by changing the minus sign to a positive sign. Since the resulting E°_{cell} is positive, the redox reaction is spontaneous. Therefore the cell is a galvanic cell by definition

49. In the following nuclear reaction, what is the identity of element "X"?

$$^{239}_{94}Pu \rightarrow {}^{4}_{2}He^{2+} + X$$

A. $^{239}_{92}U$
B. $^{235}_{94}Pu$
C. $^{238}_{92}U$
D. $^{243}_{96}Cm$
E. $^{235}_{92}U$

Since a helium nucleus was released during the reaction, we know that this is alpha decay. The product of alpha decay has a mass number of $A - 4$ and an atomic number of $Z - 2$:

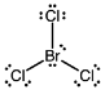
New Mass Number: $239 - 4 = 235$

New Atomic Number: $94 - 2 = 92$

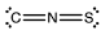
The atomic number of 92 corresponds to uranium on the periodic table, so the product is $^{235}_{92}U$

50. Which of the following molecules has a +2 formal charge on the central atom?

A. 

B. 

C.

D. 

E. 

Formal charge is calculated through the following formula:

$$\text{Valence Electrons} - \frac{1}{2}(\text{Bonding Electrons}) - \text{Nonbonding Electrons}$$

A → Incorrect. $5 - \frac{1}{2}(8) - 0 = 1$

B → Incorrect. $7 - \frac{1}{2}(6) - 4 = 0$

C → Correct. $6 - \frac{1}{2}(8) - 0 = 2$

D → Incorrect. $5 - \frac{1}{2}(8) - 0 = 1$

E → Incorrect. $3 - \frac{1}{2}(6) - 0 = 0$

51. If the temperature of a gas is doubled while holding pressure constant, the volume is:

A. Reduced to 1/2
B. Reduced to 1/3
C. Doubled
D. Tripled
E. Unchanged

According to Charle's law, volume and temperature are proportional under isobaric conditions:

$$\frac{V}{T} = k \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Therefore if temperature is doubled, then volume must also double, to keep k constant

52. How much energy does it take to raise the temperature of 10 grams of water from 25 to 50 °C? The specific heat capacity of liquid water is 4.18 J/g°C

A. (10)(4.18)(25)
B. $\dfrac{(10)(4.18)(25)}{18.02}$
C. (10)(18.02)(4.18)(25)
D. $\dfrac{(18.02)(4.18)(25)}{10}$
E. (10)(18.02)(4.18)(50)

First, convert moles into mass:

$m_{H_2O} = (10 \text{ mol})(18.02 \text{ g/mol})$

Then, write out the heat transfer equation:

$q = m\,c\,\Delta T$

Finally, substitute the known values and solve for q:

$q = (10 \text{ mol})(18.02 \text{ g/mol})(4.18 \text{ J/g°C})(50°\text{C} - 25°\text{C})$

$q = (10)(18.02)(4.18)(25)$

53. If a weak acid is titrated with a strong base, at which point is the concentrations of the acid and its conjugate equal?

A. Equivalence point
B. Triple point
C. Half-equivalence point
D. Critical point
E. Neutralization

A → Incorrect. The equivalence point occurs when there is an equal number of *moles* of *acid* and *base*. This is different from the half-equivalence point, which occurs when there are equal *concentrations* of acid and it's *conjugate* base
B → Incorrect. The triple point represents the equilibrium of solid, liquid, and gas phases
C → Correct answer
D → Incorrect. The critical point represents when liquid and gas phases merge to become one phase – a supercritical fluid
E → Incorrect. Neither the equivalence point nor the half-equivalence point have to occur at a neutral pH

54. What mass of butane (C_4H_{10}) must be burned in excess oxygen to produce 44.8 L of carbon dioxide? Assume standard temperature and pressure (STP) conditions.

A. 29 g
B. 58 g
C. 2 g
D. 0.5 g
E. 116 g

First, write out the balanced combustion equation for butane:

$$2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$$

Next, find the mass of carbon dioxide produced. At STP, one mole of any gas has a volume of 22.4 L. Therefore:

$$n(CO_2) = \frac{44.8\text{ L}}{22.4\text{ mol/L}} = 2\text{ mol}$$

Then, use stoichiometric ratios to find the number of moles of butane needed:

$$n(C_4H_{10}) = \frac{2}{8} \times n(CO_2)$$

$$n(C_4H_{10}) = \frac{1}{4} \times 2\text{ mol}$$

$$n(C_4H_{10}) = 0.5\text{ mol}$$

Finally, convert moles of butane to grams:

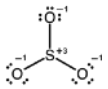
$$m(C_4H_{10}) = 0.5\text{ mol} \times 58\text{ g/mol}$$

$$m(C_4H_{10}) = 29\text{ g}$$

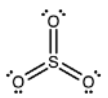
55. What is the molecular geometry of SO_3?

A. Tetrahedral
B. Linear
C. Trigonal pyramidal
D. Trigonal planar
E. Square planar

SO_3 has a total of 6 + 3(6) = 24 valence electrons. Sulphur is the least electronegative element, so we draw it as our central atom. Then, we connect the three oxygens to it via single bonds. After completing octets of each surrounding atom, we have accounted for every valence electron:



However, this sulphur has a +3 formal charge while each oxygen has a −1 formal charge. To minimize formal charges, we can form three double bonds:



Since sulphur is in the third row of the periodic table, it can have an expanded octet. This is the final lewis diagram for SO3. According to the VSEPR table, this corresponds to a trigonal planar geometry.

56. Which of the following pieces of laboratory glassware is LEAST appropriate for the precise measurement of liquids?

A. Buret
B. Volumetric pipette
C. Graduated pipette
D. Transfer pipette
E. Volumetric flask

A → Incorrect. A buret is used for dispensing a precise volume of liquid, often during titrations. It is a calibrated piece of glassware
B → Incorrect. A volumetric pipette is used for measuring a precise volume of liquid. It contains one volume marking and is thus a calibrated piece of glassware
C → Incorrect. A graduated pipette is used for measuring a precise volume of liquid. It contains multiple volume markings along the side and is thus a calibrated piece of glassware
D → Correct. A transfer pipette (also known as a dropper) is used to transfer liquid, but does not contain calibrated volume markings. It should never be used to measure a precise volume of liquid
E → Incorrect. A volumetric flask is used to measure and store a larger volume of liquid. It contains one volume marking and is thus a calibrated piece of glassware

57. Which of the following changes will shift the equilibrium shown below to the reactants side?

$$2NH_{3(g)} \rightleftharpoons N_{2(g)} + 3H_{2(g)}$$

A. Adding more $NH_{3(g)}$
B. Increasing pressure
C. Decreasing pressure
D. Removing $N_{2(g)}$
E. Increasing temperature

A → Incorrect. Increasing $[NH_{3(g)}]$ will shift the equilibrium to the right in an effort to reduce the additional $NH_{3(g)}$
B → Correct. There are two moles of gas on the left side and four moles of gas on the right side. Therefore, increasing pressure will shift the equilibrium to the left, in an effort to reduce the additional pressure
C → Incorrect. See explanation for answer choice B)
D → Incorrect. Reducing $[N_{2(g)}]$ will shift the equilibrium to the right in an effort to generate more $N_{2(g)}$
E → Incorrect. Since the question stem does not state whether this reaction is endothermic or exothermic, we cannot predict the effect of heat on this equilibrium

58. Which of the following compounds will produce an aqueous solution with a pH greater than 7?

A. CH_3COOH
B. KCl
C. $NaNO_3$
D. NH_4^+
E. $NaNO_2$

A → Incorrect. This is the formula for acetic acid, a weak monoprotic acid. Therefore this would result in pH < 7
B → Incorrect. K^+ is a weak acid (conjugate of strong base) while Cl^- is a weak base (conjugate of strong acid). Therefore this salt will produce a neutral aqueous solution
C → Incorrect. Na^+ is a weak acid (conjugate of strong base) while NO_3 is a weak base (conjugate of strong acid). Therefore this salt will produce a neutral aqueous solution
D → Incorrect. This is the formula for ammonium, a weak acid. It is the conjugate of ammonia (NH_3), a weak base
E → Correct. Na^+ is a weak acid (conjugate of strong base) while NO_2^- is a strong base (must be a conjugate of a weak acid because the NO_2^- ion is not part of any of the known strong acids). Therefore this salt would produce a basic aqueous solution with pH > 7

59. Which of the following is the correct electron configuration for Al^{1+}?

A. $1s^2 2s^2 2p^6 3s^2$
B. $1s^2 2s^6 2p^6 3s^2$
C. $1s^2 2s^2 3p^6 3s^2$
D. $1s^2 2s^2 2p^6 3s^2 3p^1$
E. $1s^2 2s^2 2p^6 3s^2 3p^6$

We start in the first row of the s-block and fill the first subshell ($1s^2$). Then we move to the next row and fill the next subshell ($2s^2$). Next we fill the first subshell of the p-block ($2p^6$). Finally, we fill the third subshell of the s-block ($3s^2$). Normally, neutral aluminium would also have an electron in the second subshell of the p-block ($3p^1$), but we are writing the electron configuration for a 1+ ion. Therefore, we remove an electron from the subshell with the highest n ($3p^1$).

60. Which set of coefficients would balance the following reaction?

$$\_\ SnO_2 + \_\ H_2 \rightarrow \_\ Sn + \_\ H_2O$$

A. 2, 2, 2, 1
B. 1, 1, 1, 2
C. 2, 1, 2, 1
D. 1, 2, 1, 2
E. 1, 4, 1, 4

We begin by balancing the Sn atoms. There is 1 on the left and 1 on the right, so no coefficients need to be added:

1 SnO_2 + _ H_2 → **1** Sn + _ H_2O

Next we balance the O atoms. There are 2 on the left and 1 on the right, so multiply H_2O by 2:

1 SnO_2 + _ H_2 → 1 Sn + **2** H_2O

Finally we balance the H atoms. There are 2 on the left and 4 on the right, so multiply H_2 by 2:

1 SnO_2 + **2** H_2 → 1 Sn + 2 H_2O

61. What is the oxidation state of sulphur in $S_2O_3^{2-}$?

A. +1
B. +2
C. −1
D. −2
E. 0

Since the overall charge of the molecule is 2−, therefore we know that the sum of oxidation states for this compound is −2. The oxidation state of oxygen is usually −2. Since we have three oxygen, $-2 \times 3 = -6$.

We can find the oxidation state of sulphur via the equation:

$2x + (-6) = -2$

Solve for x:

$2x = -2 + 6$

$2x = 4$

$x = 2$

62. Which of the following elements has the lowest ionization energy?

A. F
B. Cl
C. B
D. N
E. Be

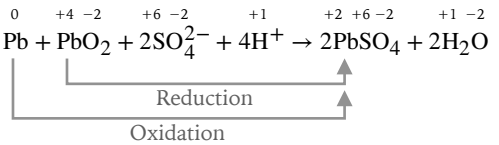
Ionization energy describes the energy required to remove an electron from a neutral atom in its gaseous state. It tends to increase from left to right on the periodic table, since electronegativity increases. It also tends to decrease from top to bottom, since electronegativity deceases. Considering this, the rank of elements from lowest to highest ionization energy would be: Be < B < N < Cl < F. However, boron actually has a lower ionization energy than beryllium in reality. This is because boron's electron configuration ($1s^2 2s^2 2p^1$) has a semi-occupied valence subshell, which is less stable than beryllium's fully-occupied configuration ($1s^2 2s^2$).

63. Given the redox equation shown below, which of the following statements is true?

$$Pb + PbO_2 + 2SO_4^{2-} + 4H^+ \rightarrow 2PbSO_4 + 2H_2O$$

A. Pb is the oxidizing agent
B. PbO_2 is the reducing agent
C. Pb is being reduced
D. This is a disproportionation reaction
E. PbO_2 is being oxidized

First, write out the oxidation states and identify the oxidation and reduction half-reactions:



Since the oxidation state of Pb increases, it is being oxidized. Therefore Pb is a reducing agent. Since the oxidation state of Pb in PbO_2 decreases, it is being reduced. Therefore PbO_2 is an oxidizing agent. This is not a disproportionation reaction because oxidation and reduction does not occur to the *same* reactant molecule. In this case, the half-reactions simply produce the same product

64. The half-life of a highly radioactive compound is 30 days. If 60 grams of this compound is stored in a closed container for three months, how much of it remains?

A. 3.5
B. 6
C. 7.5
D. 15
E. 30

First, convert all measures of time into the same units:

$t = (3 \text{ months})(30 \text{days/month}) = 90 \text{ days}$

Then, calculate the number of half-lives elapsed (n):

$$n = \frac{t}{t_{1/2}}$$

$$n = \frac{90 \text{ days}}{30 \text{ days}}$$

$$n = 3$$

Next, substitute into the equation for radioactive decay and solve for the amount of mass remaining (m):

$$m = A\left(\frac{1}{2}\right)^n$$

$$m = (60 \text{ g})\left(\frac{1}{2}\right)^3$$

$$m = \frac{60}{8} = 7.5 \text{ g}$$

65. The following table contains the empirical initial rates for the reaction:

$$2NO_{(g)} + O_{2(g)} \rightleftharpoons 2NO_{2(g)}$$

What is the correct rate law?

Trial	[NO]	[O_2]	Initial Rate
1	0.3 M	0.3 M	1.2×10^{-1} M/s
2	0.3 M	0.6 M	2.4×10^{-1} M/s
3	0.6 M	0.6 M	4.8×10^{-1} M/s

A. $r = k[NO][O_2]$
B. $r = k[NO][O_2]^2$
C. $r = k[NO]^2[O_2]$
D. $r = k[NO]^4[O_2]$
E. $r = k[NO][O_2]^4$

Comparing trial 1 and 2, $[O_2]$ is doubled:

$$\frac{0.6 \text{ M}}{0.3 \text{ M}} = 2$$

The initial rate is also doubled:

$$\frac{2.4 \times 10^{-1} \text{ M/s}}{1.2 \times 10^{-1} \text{ M/s}} = 2$$

Since $2^1 = 2$, therefore the reaction is first order with respect to O_2

Comparing trial 1 and 3, [NO] is doubled:

$$\frac{0.6 \text{ M}}{0.3 \text{ M}} = 2$$

The initial rate is quadrupled:

$$\frac{4.8 \times 10^{-1} \text{ M/s}}{1.2 \times 10^{-1} \text{ M/s}} = 4$$

Since $2^2 = 4$, therefore the reaction is second order with respect to NO

66. Considering the following reaction, how many grams of oxygen are required to produce 2 moles of carbon dioxide in excess carbon monoxide?

$$CO_{(g)} + O_{2(g)} \rightarrow CO_{2(g)}$$

A. 1 g
B. 2 g
C. 16 g
D. 32 g
E. 64 g

First, balance the equation. There are 3 oxygens on the left side and 2 on the right, so multiply O_2 by ½:

$$CO_{(g)} + \frac{1}{2}O_{2(g)} \rightarrow CO_{2(g)}$$

Now multiply all terms by 2, to cancel out the fractional coefficient:

$$2CO_{(g)} + O_{2(g)} \rightarrow 2CO_{2(g)}$$

According to the stoichiometric coefficients, 1 mole of oxygen is consumed for every 2 moles of CO_2 produced:

$$n(O_2) = n(CO_2) \times \frac{1}{2}$$

$$n(O_2) = 2 \text{ mol} \times \frac{1}{2} = 1 \text{ mol}$$

Finally, use molar mass to convert moles to grams:

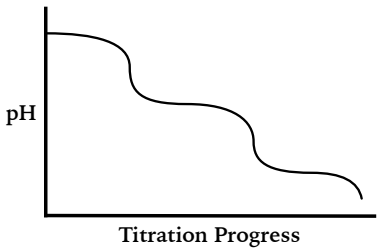
$$m(O_2) = 1 \text{ mol} \times 32 \text{ g/mol} = 32 \text{ g}$$

67. Which of the following describes the second law of thermodynamics?

A. Energy can neither be created nor destroyed
B. Spontaneous processes always increase the entropy of the system and surroundings
C. The total energy of the universe is constant
D. Spontaneous processes always increase the entropy of the system
E. Non-spontaneous processes always decrease the entropy of the system and surroundings

A → Incorrect. This is the first law of thermodynamics
B → Correct answer. The universe is composed of the system plus its surroundings
C → Incorrect. This is just another way to state the first law of thermodynamics
D → Incorrect. The entropy of a system may increase or decrease throughout a physical or chemical process. However, the total entropy of the universe (the system plus its surroundings) always increases
E → Incorrect. The entripy of the universe always increases

68. Which of the following compounds would lead to a titration curve similar to the one shown, when used as a titrant?



A. H_2SO_4
B. HCl
C. H_3PO_4
D. NH_4^+
E. H_3O^+

We see that the titration curve starts from a high pH and progresses to a lower pH. Therefore, the titrant must be an acid. Answer choice D) is eliminated. Next we observe that there are two near-vertical points within the curve. These correspond to the equivalence points of our titrant. Since there are two, our titrant must be a diprotic acid. Answer choice A) is diprotic, while answer choices B), C), and E) are monoprotic, triprotic, and monoprotic respectively

69. Which of the following elements is NOT a diatomic gas?

A. Oxygen
B. Hydrogen
C. Bromine
D. Iodine
E. Helium

Only the following seven elements in the periodic table are diatomic gasses: hydrogen, nitrogen, fluorine, oxygen, iodine, chlorine, and bromine. They can be memorized via the mnemonic "have no fear of ice cold beer"

70. Which of the following is NOT an example of a physical change?

A. Glass melting at 1600°C
B. Dissolving sugar into water
C. A steel wrench rusting over time
D. Mixing ethanol and methanol together
E. Making ice cubes

A physical process occurs when matter changes phase or shape. A chemical process occurs when matter undergoes a rearrangement of atoms or electrons.

A → Incorrect. This is a phase change
B → Incorrect. Dissolution/dissociation does not involve the rearrangement of atoms or electrons. The molecules are simply dissociated from the solid structure
C → Correct. Rusting is a redox reaction that occurs when iron is oxidized over time ($4Fe + 3O_2 \rightarrow 2Fe_2O_3$)
D → Incorrect. Ethanol and methanol are both types of alcohol. They are miscible but do not chemically react
E → Incorrect. This is a phase change

Solutions – Perceptual Ability Test

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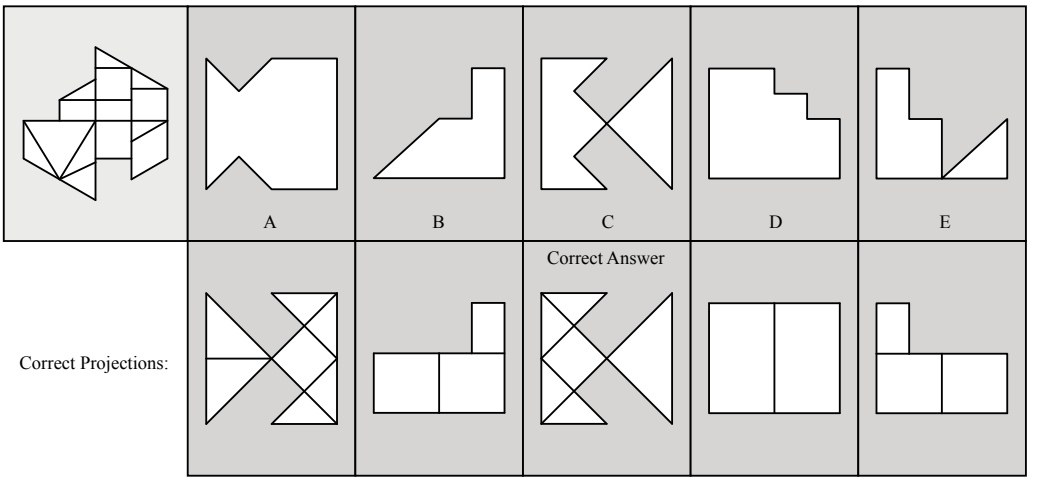

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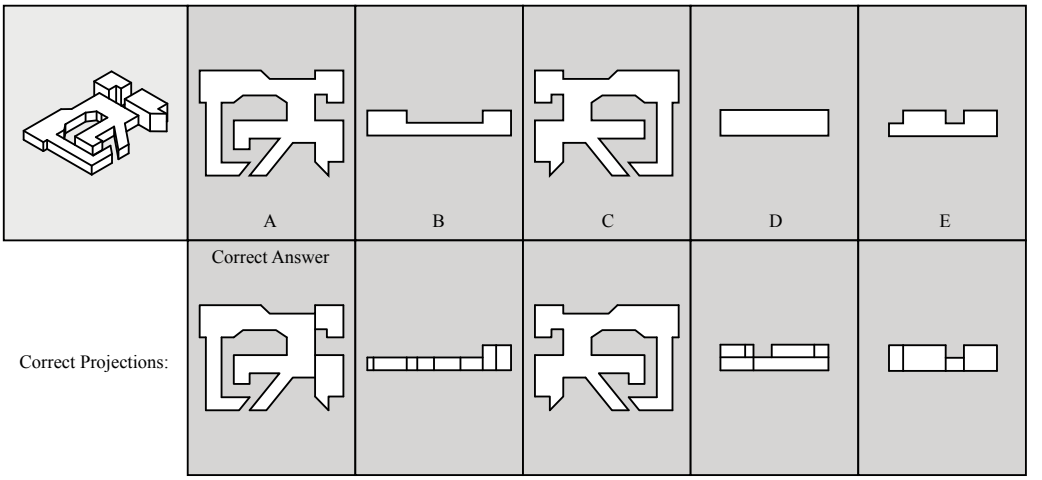

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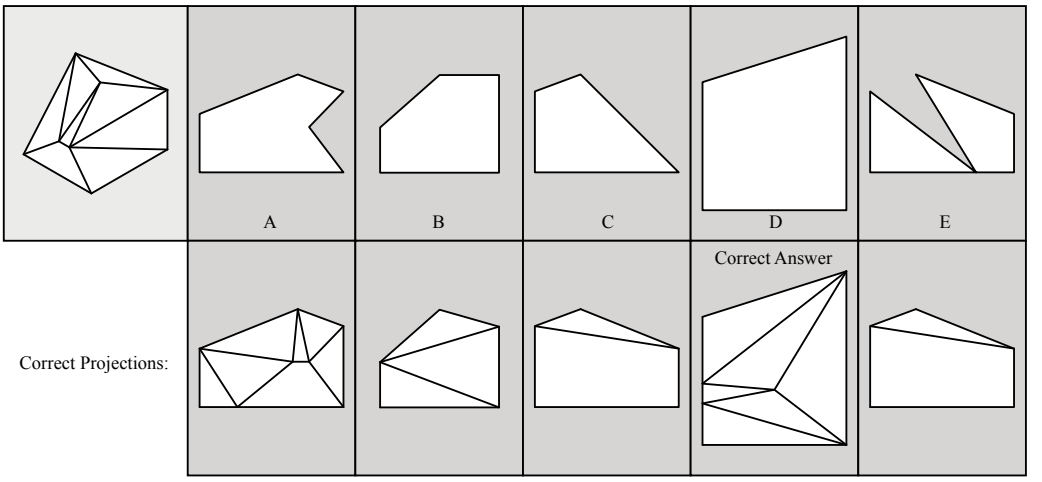

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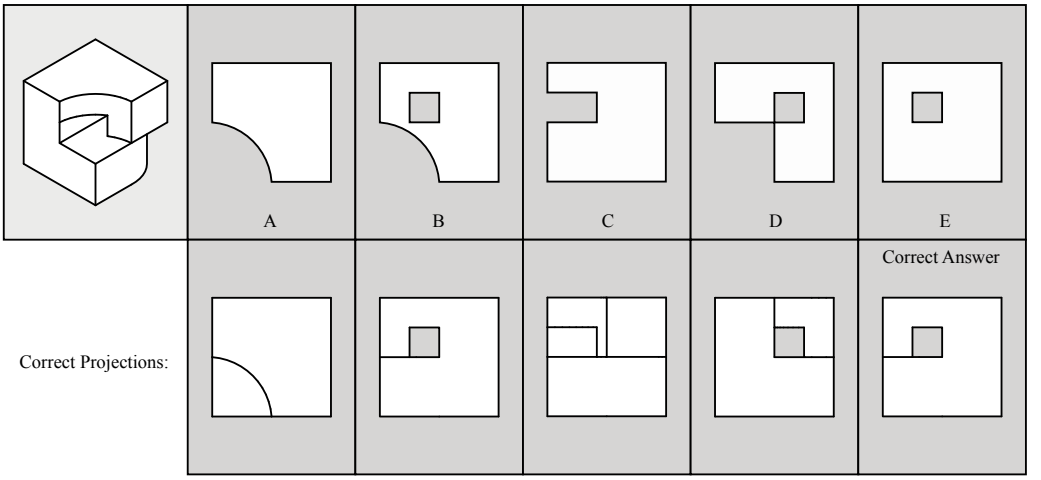
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Correct Answer
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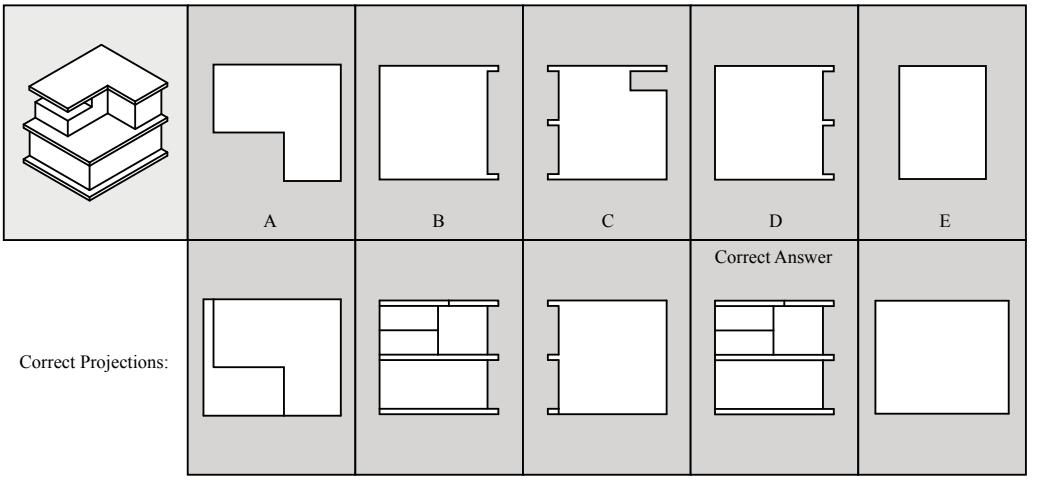
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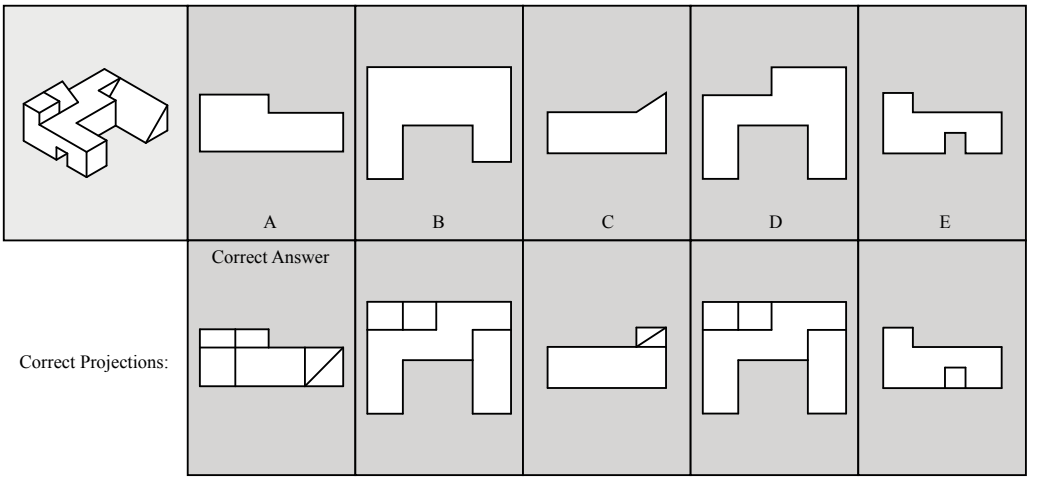
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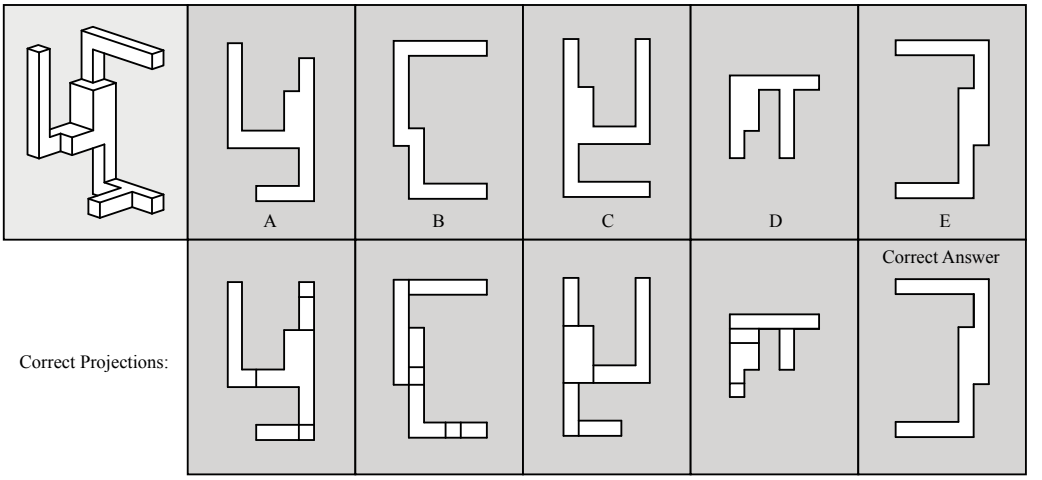
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Correct Answer
Correct Projections:

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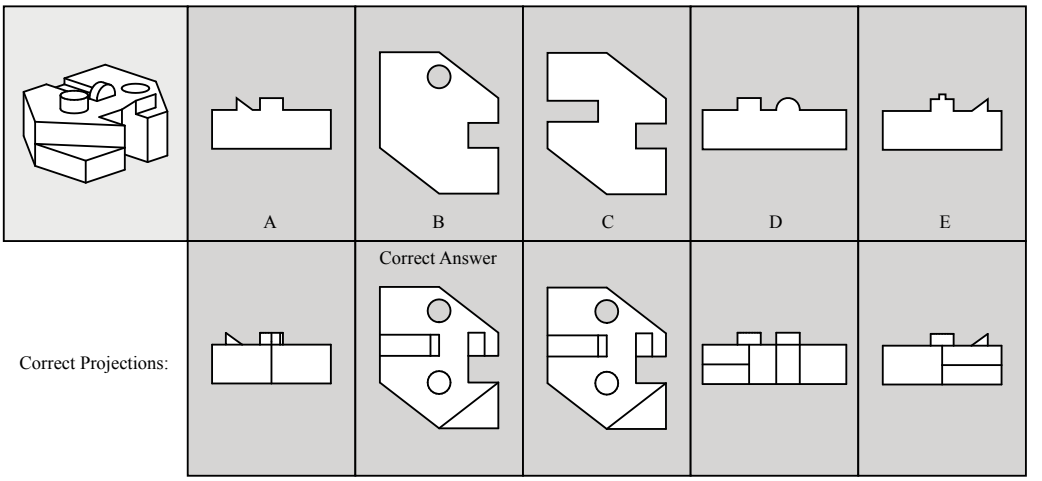
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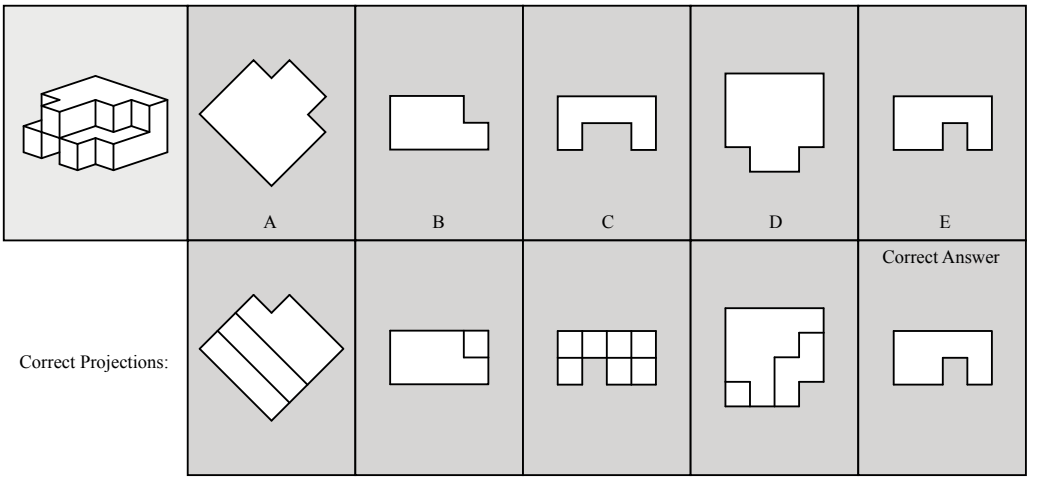
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Correct Answer
Correct Projections:

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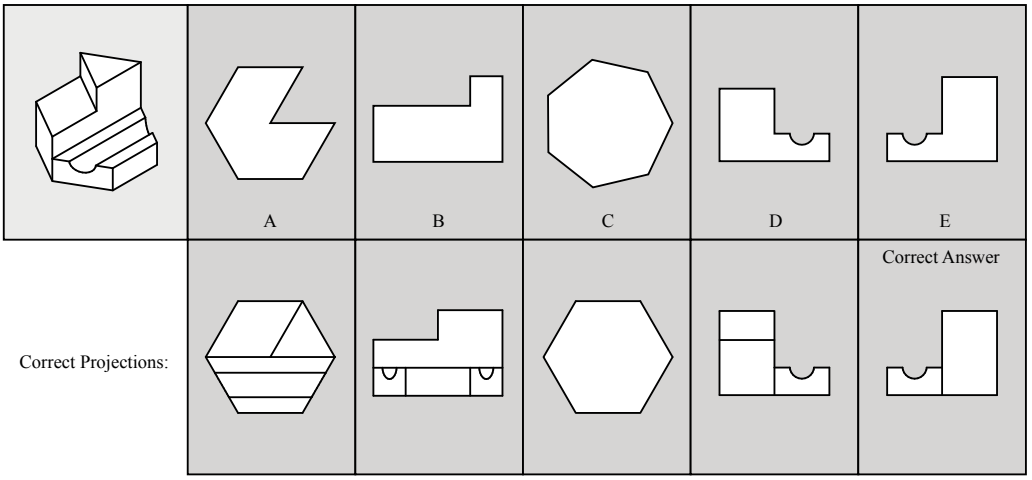
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Correct Answer
Correct Projections:

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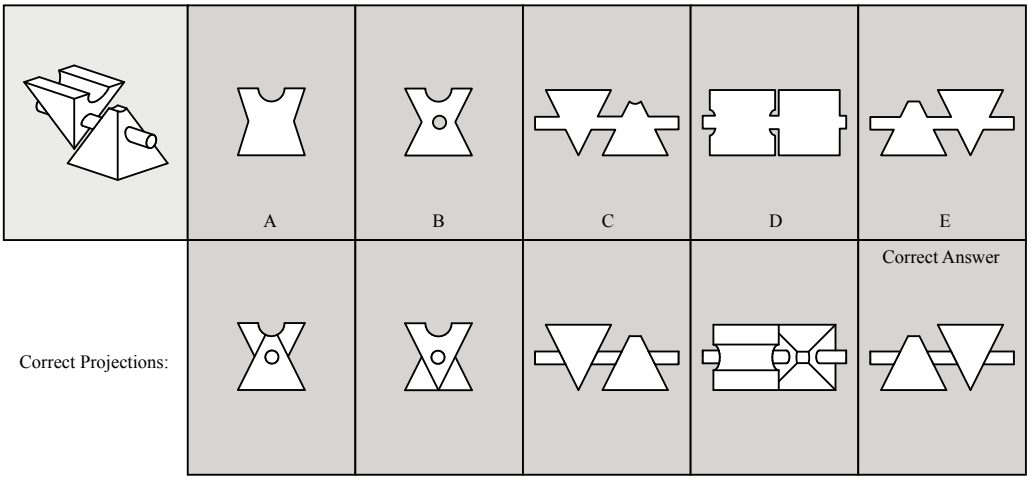
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Correct Answer
Correct Projections:

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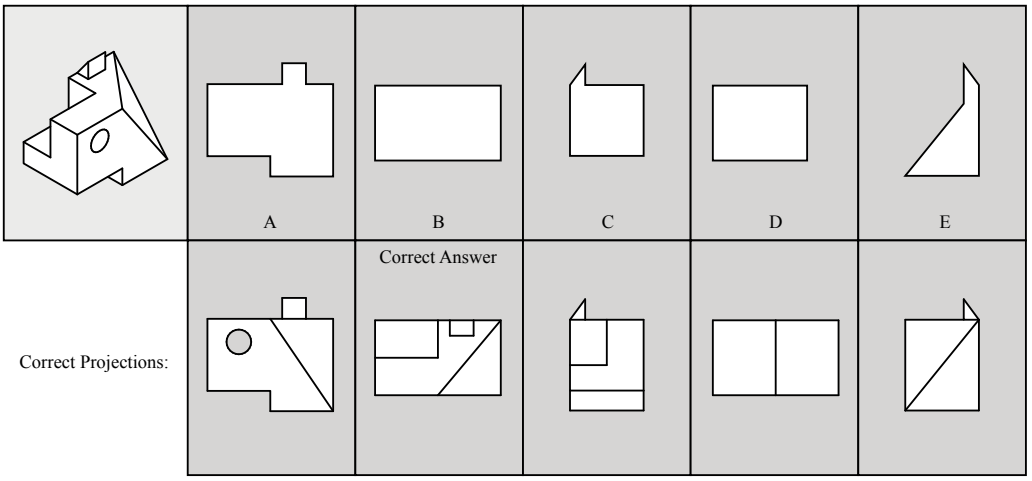
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Correct Projections:

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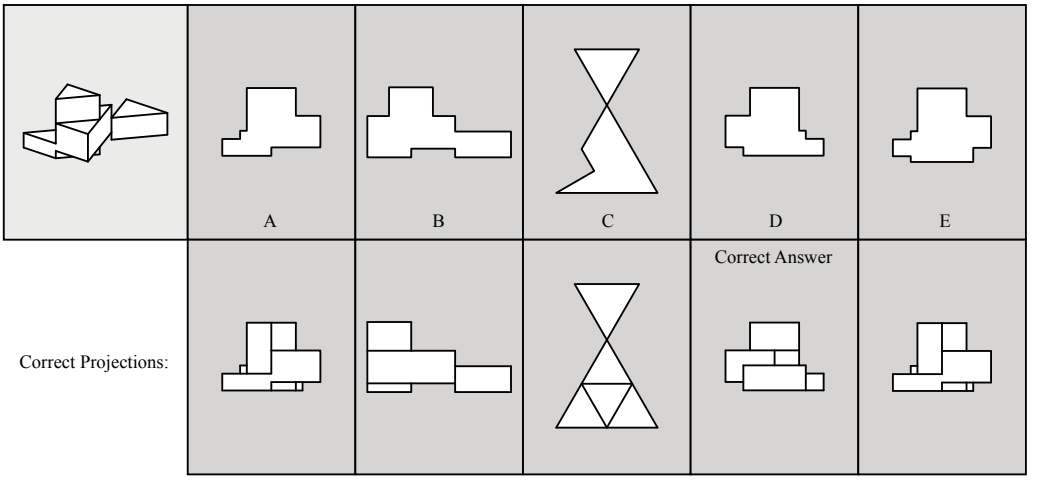
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Correct Answer
Correct Projections:

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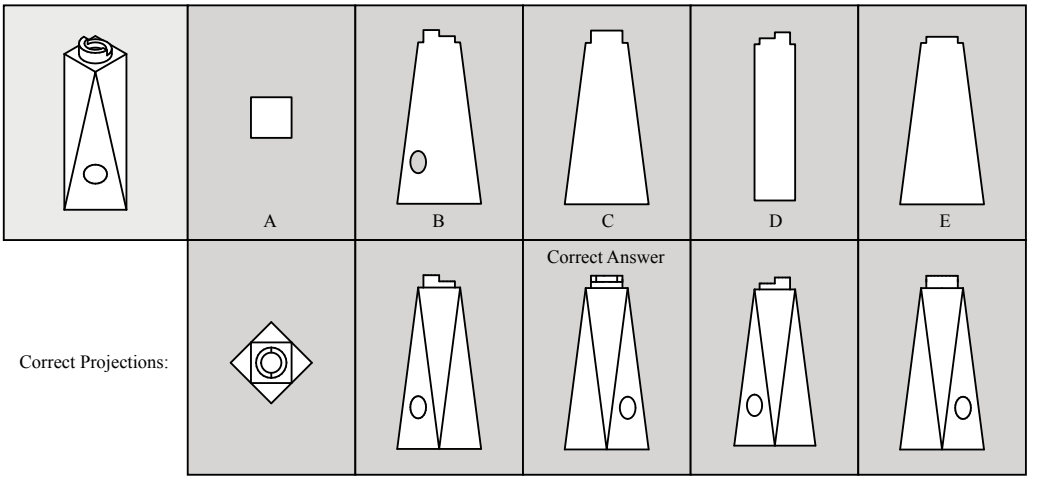
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Correct Answer
Correct Projections:

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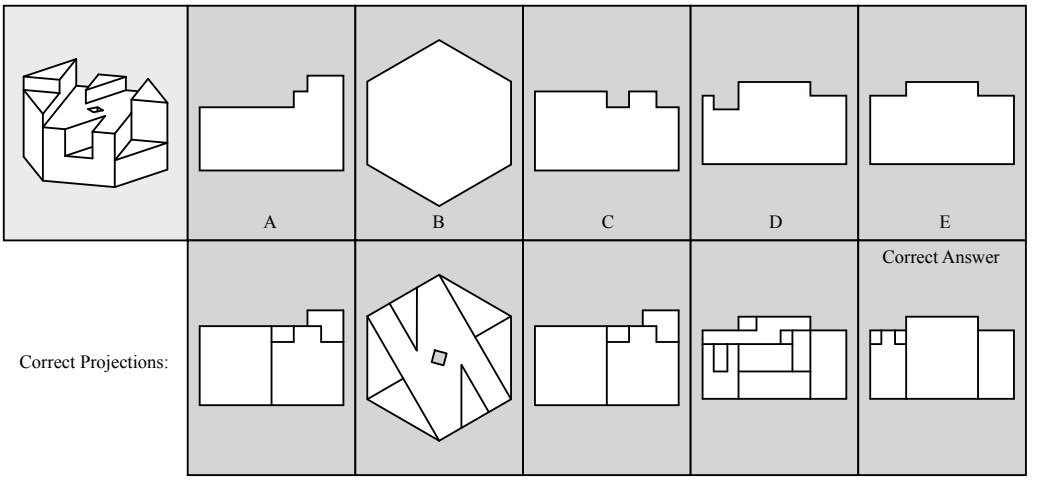
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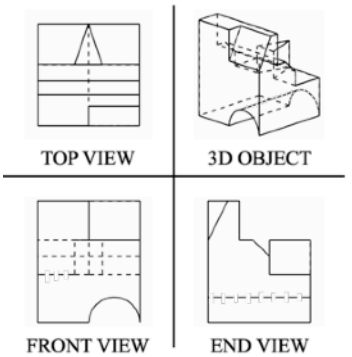
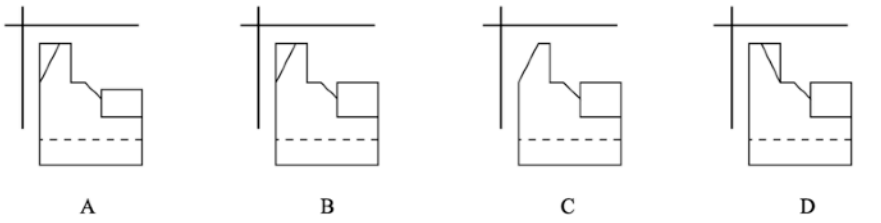
Correct Answer
Correct Projections:

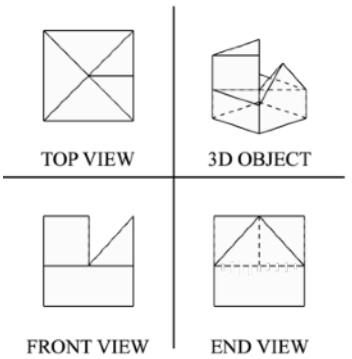
16. Choose the correct END VIEW

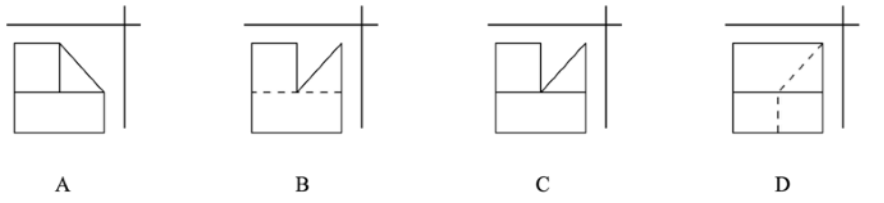




Correct Answer

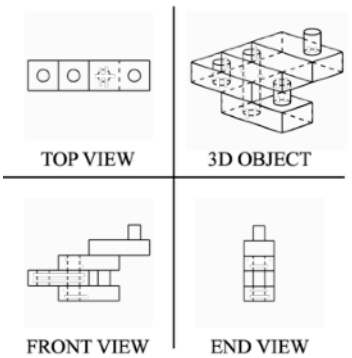
17. Choose the correct FRONT VIEW

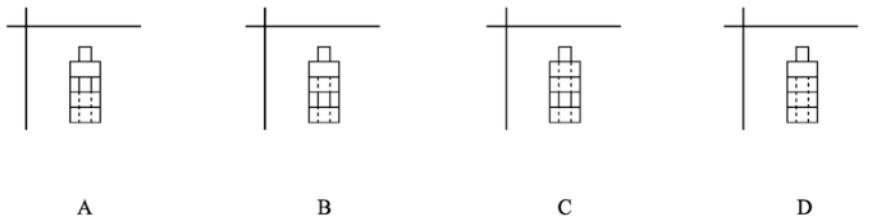




Correct Answer

18. Choose the correct END VIEW





Correct Answer

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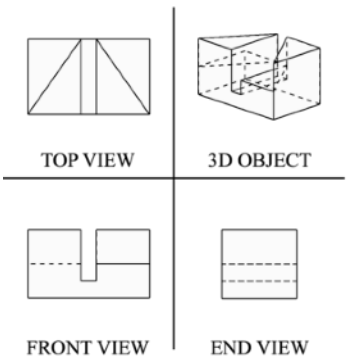
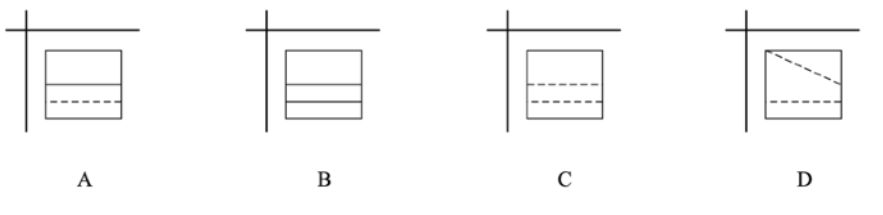
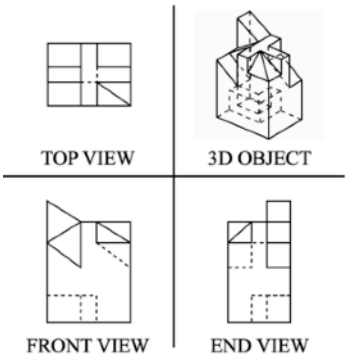
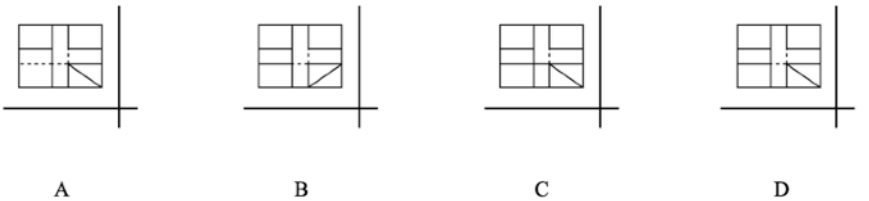




Correct Answer

20. Choose the correct TOP VIEW





Correct Answer

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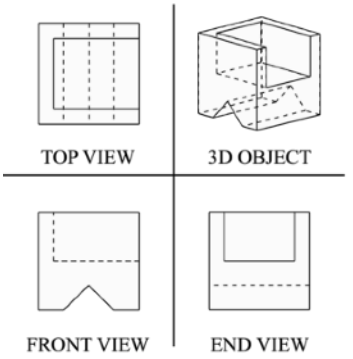

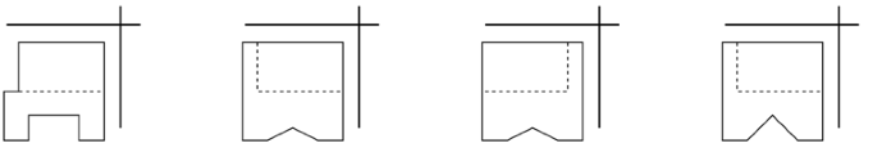

Correct Answer

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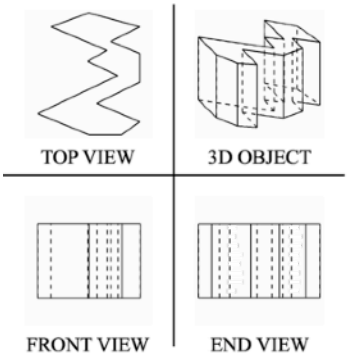

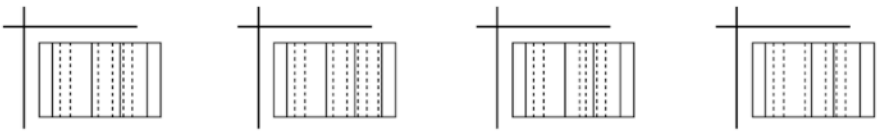

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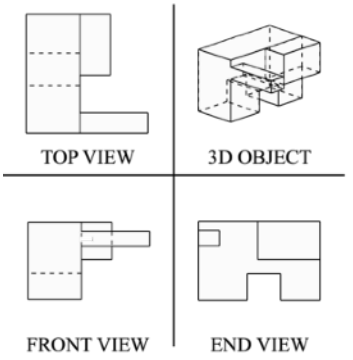

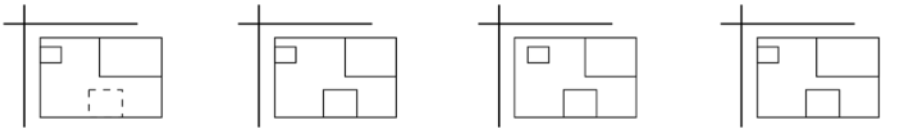

Correct Answer

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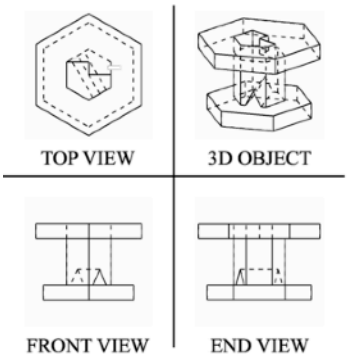

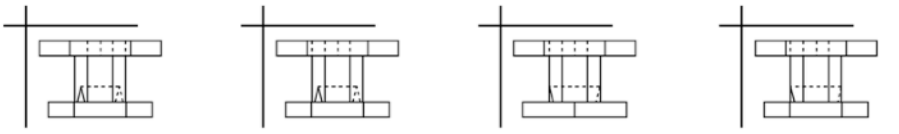

A B C D

Correct Answer

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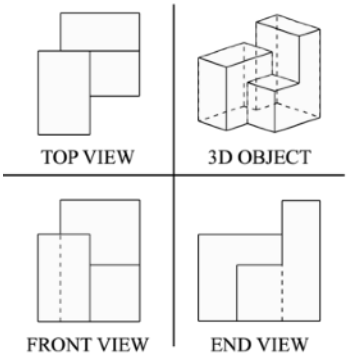

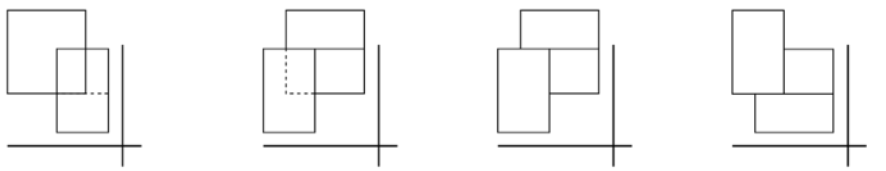

A B C D

Correct Answer

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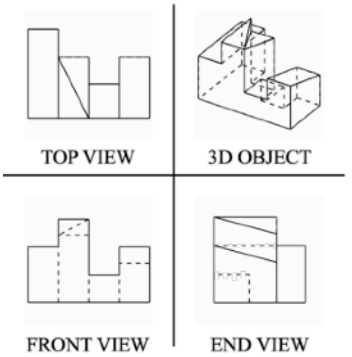
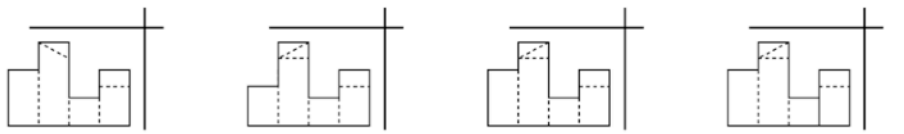
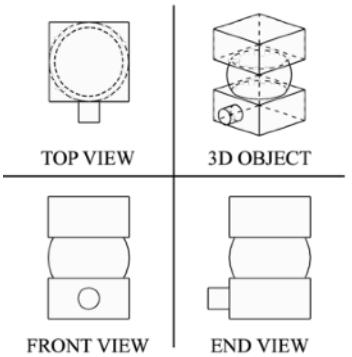


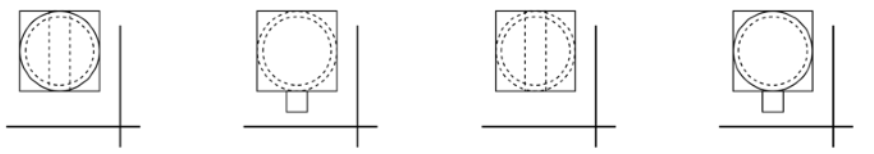


A B C D

Correct Answer

27. Choose the correct TOP VIEW

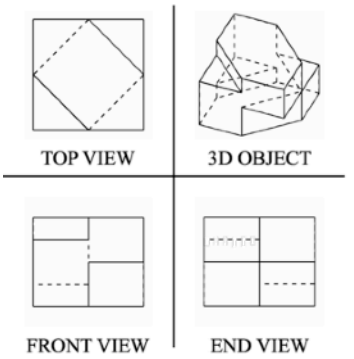


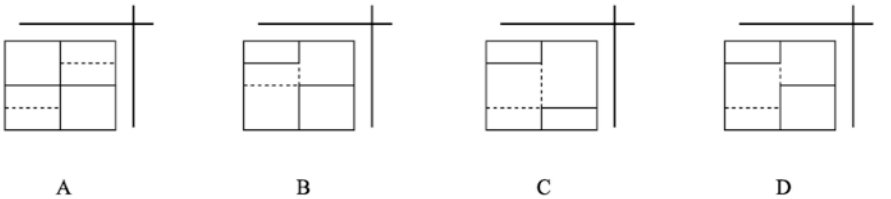


A B C D

Correct Answer

28. Choose the correct FRONT VIEW





Correct Answer

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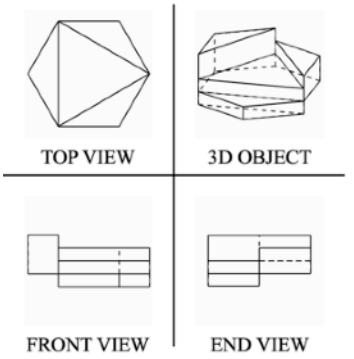

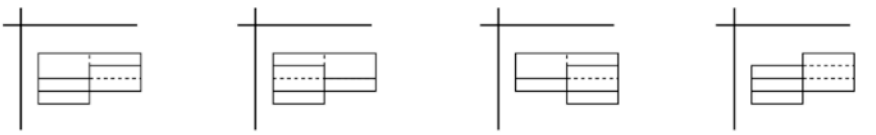

Correct Answer

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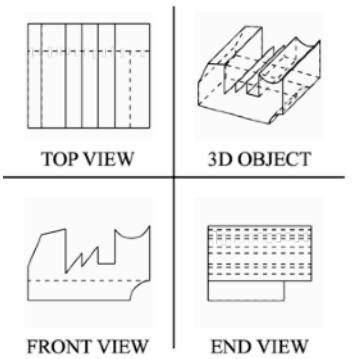

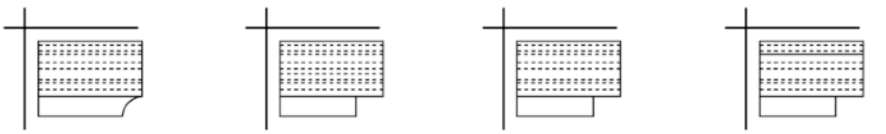

Correct Answer

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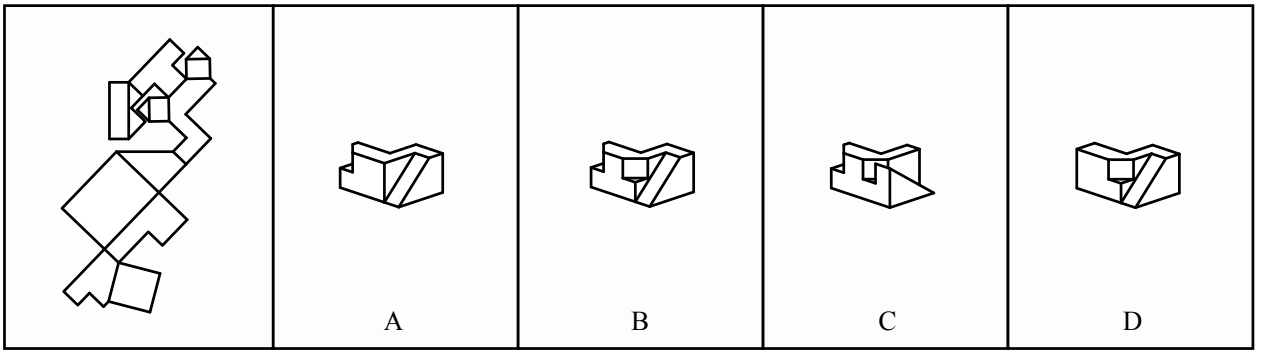

Correct Answer

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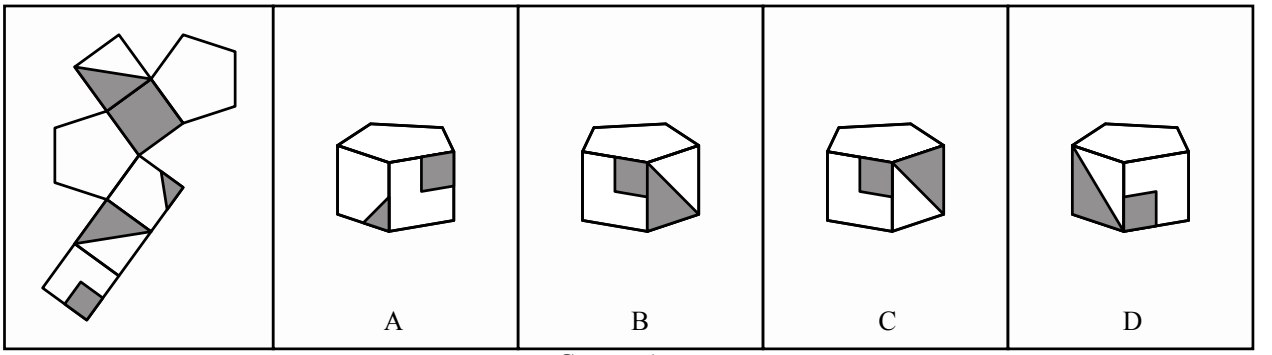

Correct Answer

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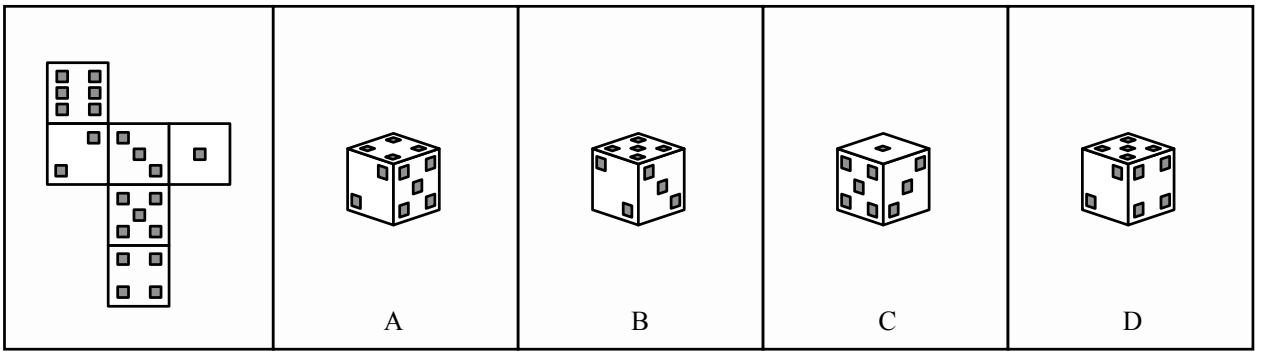

Correct Answer

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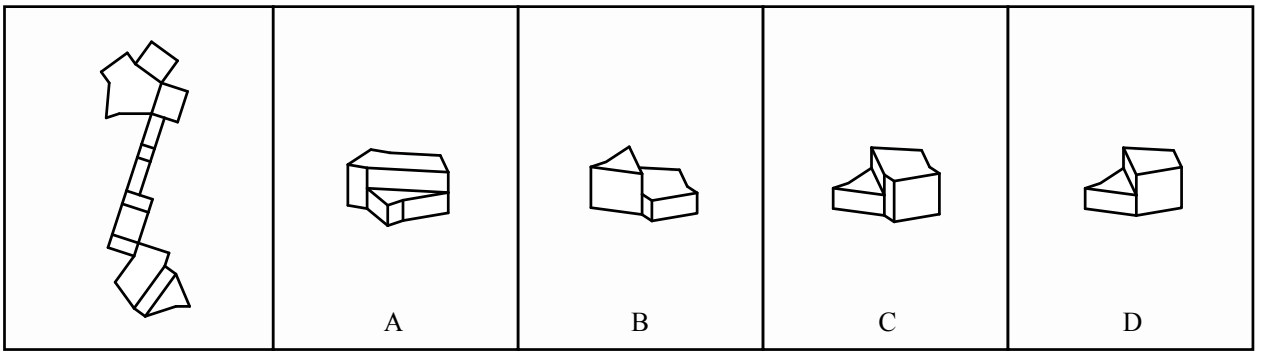

Correct Answer

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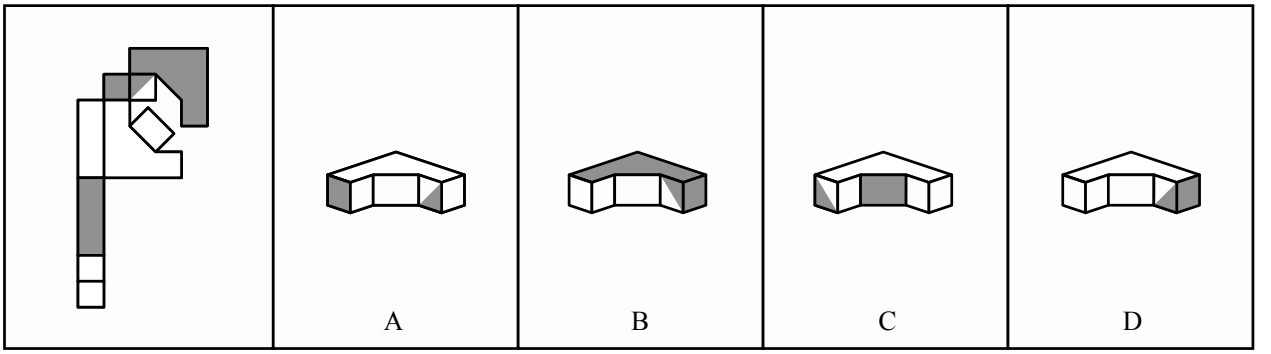

Correct Answer

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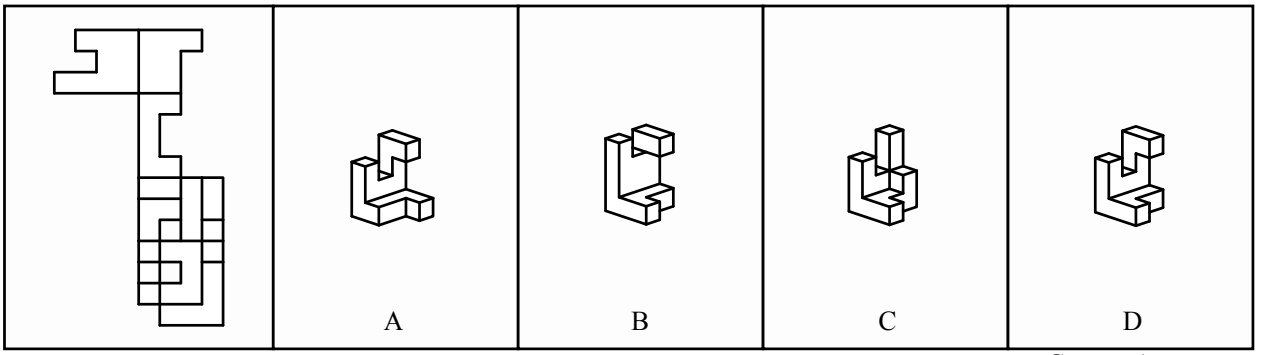

Correct Answer

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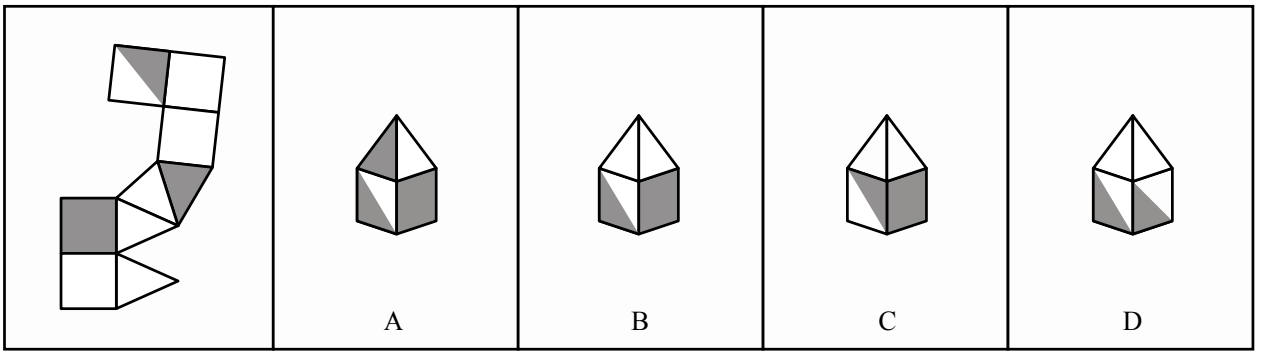
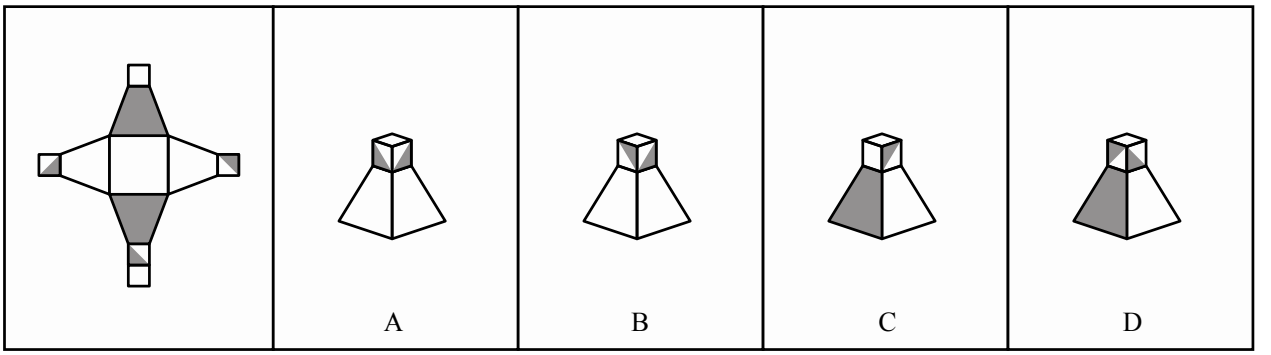


Correct Answer

83.



Correct Answer

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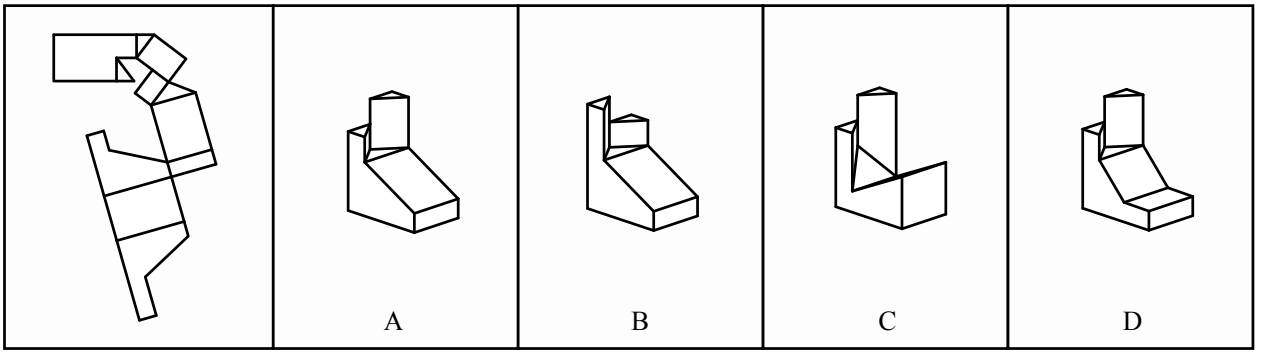

Correct Answer

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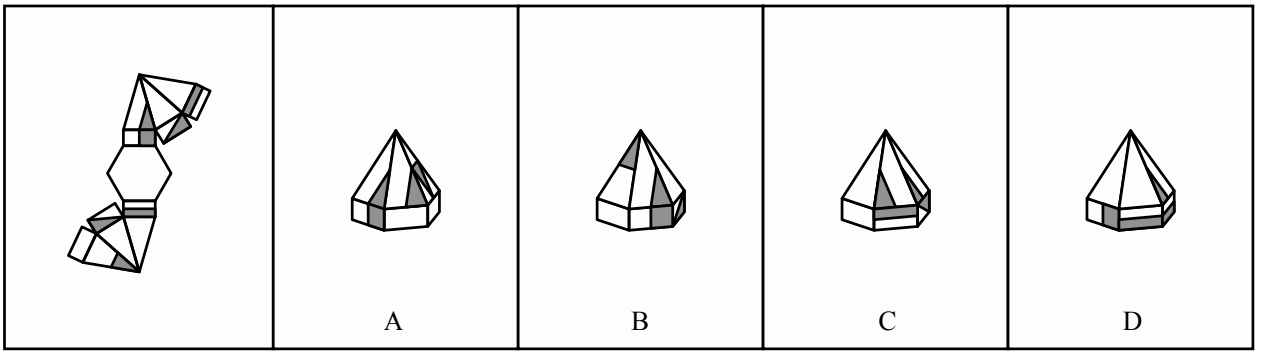
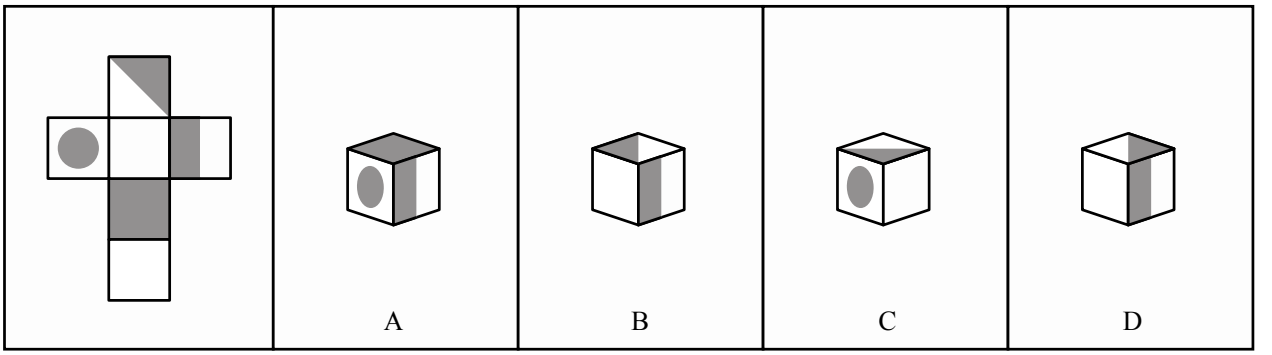


Correct Answer

86.



Correct Answer

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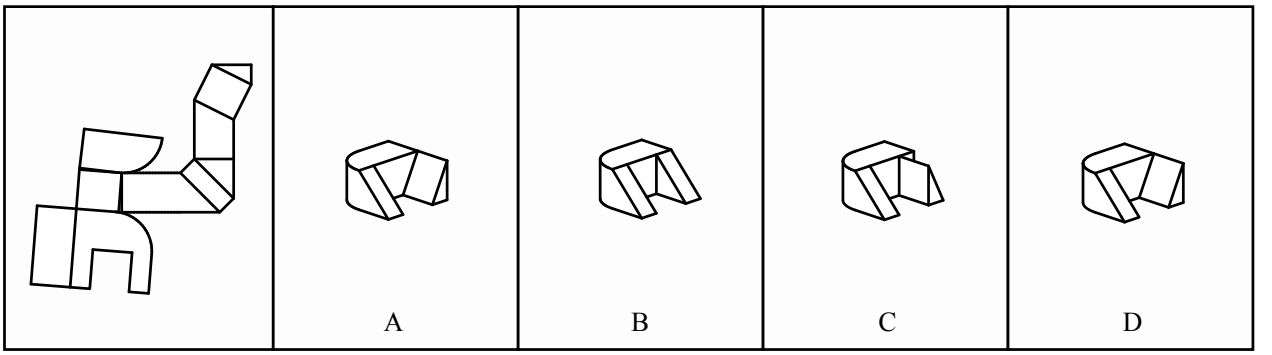

Correct Answer

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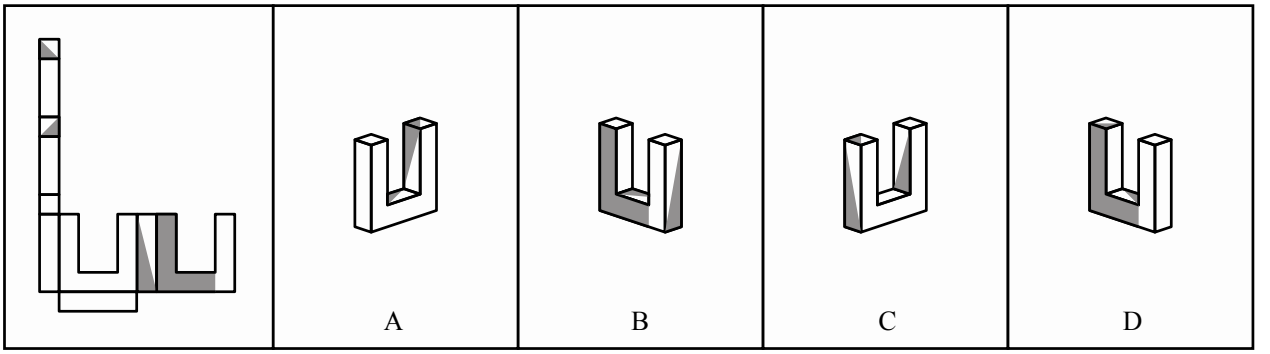

Correct Answer

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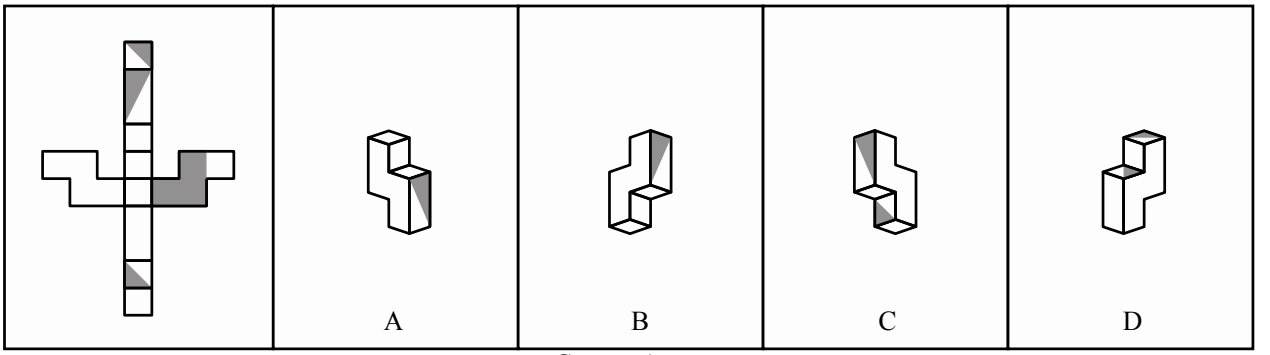

Correct Answer

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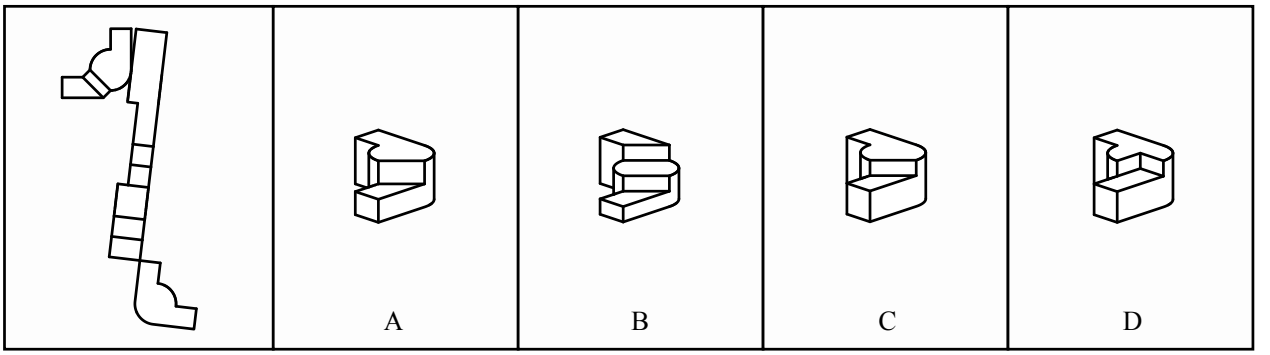


Correct Answer

Solutions – Reading Comprehension Test

1. Dentition is useful for forensic identification because it is resistant to decomposition and unique to each individual
   - ***A. Both the statement and reason are correct and related***
   - B. Both the statement and reason are correct but NOT related
   - C. The statement is correct but the reason is NOT
   - D. The statement is NOT correct, but the reason is correct
   - E. NEITHER the statement NOR the reason is correct

   According to paragraph two, "[teeth] are often resistant to decomposition even in major accidents, crime, burial, or other severe exposure to the elements. The dental patterns are unique for every individual … Therefore, dentition of a person is useful for individual identification and comparison"

2. Which of the following is NOT a common method for forensic identification?
   - A. Visual/physical descriptions
   - B. Medical history
   - C. Personal belongings
   - ***D. Full genome sequencing***
   - E. Dental identification

   A → Incorrect because it is true. Paragraph four mentions "The common methods used for individual identification are using visual identification, personal information (such as height, build, age, presence or absence of hair) …"
   B → Incorrect because it is true. Paragraph four mentions "medical information (such as scars, tattoos, birthmarks, implants, amputations, prosthesis)"
   C → Incorrect because it is true. Paragraph four mentions "… clothing, personal effects …"
   D → Correct, this is not a common method. Full genome sequencing is never mentioned as a forensic identification technique in paragraph four
   E → Incorrect because it is true. Paragraph four mentions "… fingerprints, DNA profiling and dental identification"

3. Which of the following was one of the first uses of radiography in the forensic sciences?
   - ***A. To visualize lead bullets in victims that have been shot***
   - B. To visualize knife penetration in victims that have been stabbed
   - C. To compared the dentition of the deceased with that of antemortem images
   - D. To reveal identifying features such as the shape of roots, supernumerary teeth, and noncarious lesions
   - E. To produce multiple cross-section images that can be used to construct a postmortum facsimile image

   A → Correct. According to paragraph seven, "Historically, the use of radiographs in forensic sciences was introduced in 1896, just a year after the discovery of X-ray by Roentgen, to reveal the presence of lead bullets inside the head of a victim"
   B → Incorrect. The author does not talk about stab wounds anywhere in the passage
   C → Incorrect. Although the author mentions this as a *current* use of radiographs, comparing dentition was not one of the *first* uses of the technology. See paragraph seven
   D → Incorrect. Although the author mentions this as a *current* use of radiographs, revealing identifying features was not one of the *first* uses of the technology. See paragraph seven
   E → Incorrect. In paragraph seven, the author mentions that *CT images* produce multiple cross-section images, not *radiographic images*: "Computed tomography (CT) images reveal the cross-section of the areas exposed and produce multiple images. Antemortem CT images provide information which can be used in the construction of a postmortem facsimile image …"

4. Which of the following locations is most commonly bitten in both males and females?
   - A. Legs
   - B. Shoulders
   - C. Hands
   - ***D. Arms***
   - E. Neck

   According to paragraph eight, "Male victims are most often bitten on the arms and shoulders, while female victims are most commonly bitten on the breasts, arms, and legs". Since males and females arm both commonly bitten on the arms, therefore D) is the correct answer

5. Forensic dental identification is often dependent on the availability, adequacy, and accuracy of postmortum dental records.

   The frontal sinus configuration is similar in many individuals and cannot be used as a parameter for individual identification

   A. Both statements are TRUE
   B. Both statements are FALSE
   C. The first statement is TRUE, the second is FALSE
   D. The first statement is FALSE, the second is TRUE

   According to paragraph six, "Forensic dental identification most of the times are dependent on the availability, adequacy, and accuracy of *antemortem* dental records".
   According to paragraph seven, "The frontal sinus configuration is peculiar to each individual which can be used as a parameter for individual identification."

6. Which of the following individual characteristics can NOT be identified using bite marks?

   A. Width of dental arches
   B. Missing teeth
   C. Extra teeth
   D. Periodontium
   E. Biting surfaces

   According to paragraph eight, "The biting surfaces of the individual groups of teeth are unique and related to the function. And also, it shows individual characteristics such as fractures, rotations, missing, or extra teeth. In addition, the width of the dental arches could be related to the age of the attacker."

7. If the lips, teeth, and palate of a deceased individual are dismembered, which technique is most suitable for forensic identification?

   A. Cheiloscopy
   B. Dental radiographs
   C. Denture identification
   D. Dental records
   E. Rugoscopy

   A → According to paragraph nine, "Cheiloscopy is a forensic investigation technique which deals with identification of humans based on their lip traces". Since the lips are damaged in this case, cheiloscopy is not a suitable technique
   B → According to paragraph seven, "The parameters used in dental radiographs are shape of the teeth and roots, teeth present, missing teeth …". Since the teeth are damaged in this case, dental radiography is not a suitable technique
   C → Correct. According to paragraph twelve, "Victims possessing all or most of their dentition can be identified using their teeth through various methods, whereas those missing all of their teeth lack such information. In such circumstances, the only identifiable remains are the victim's dentures … The dentures can reveal the positive identity of a person, only if it is marked". After eliminating all other answer choices, this is the most suitable technique
   D → According to paragraph six, dental records are a key resource in forensic identification. However, this technique is unsuitable for this case because the teeth are damaged
   E → According to paragraph ten, "In case of teeth loss, due to reasons such as trauma, palatal rugae pattern serves as an alternative method for identification because of its uniqueness". Since the palate is damaged in this case, rugoscopy is not a suitable technique

8. Which of the following factors does NOT contribute to the uniqueness of an individual's dentition?

   A. Supernumerary teeth
   B. Dental carries
   C. Orthodontic treatment
   D. Gum recession
   E. Abrasion

   According to paragraph two, "Dental patterns are unique for every individual. This uniqueness is also due to variety of treatments given by the dentist". Therefore, answer C) is true. According to paragraph seven, "Dental radiographs are easily available and serve as a vital clue for forensic identification. The parameters used in dental radiographs are shape of the teeth and roots, teeth present, missing teeth, residual roots, supernumerary teeth, noncarious lesions such as attrition, abrasion, fractures, bone resorption due to periodontal disease, bone pathology, diastemas, dental caries …". Therefore answers A, B, and E are also true. Option D) is false and therefore the correct answer

9. Maintenance of dental records is the responsibility of the hospital or clinic.

   The mandatory retention time of dental records is the same in every Western country.

   A. Both statements are TRUE
   B. Both statements are FALSE
   C. The first statement is TRUE, the second is FALSE
   D. The first statement is FALSE, the second is TRUE

   According to paragraph six, "Maintenance of dental records is the duty of a dentist …". Therefore the first statement is incorrect.

According to paragraph six, "Maintenance of these records is mandatory in the Western countries". However, "Different countries have different guidelines regarding the retention of dental records." Therefore the second statement is incorrect.

10. Which of the following statements regarding lip prints are TRUE?
    A. Lip prints must be obtained within 24 hrs of death to avoid postmortem alterations
    B. Lip print patterns of open mouths have ill-defined grooves that are hard to interpret
    C. Tooth loss does not affect lip prints
    D. Lip print patterns of closed mouths have well-defined grooves
    E. Pathology of the lip can alter lip print recording

A → Incorrect because it is true. According to paragraph nine, "Lip prints have to be obtained within 24 h of death to prevent erroneous data that would result from postmortem alterations of lip"
B → Incorrect because it is true. According to paragraph nine, "Lip print pattern depends on whether mouth is opened or closed. In closed mouth position, lip shows well-defined grooves; whereas in open mouth position, the grooves are relatively ill defined and hard to interpret"
C → Correct, this is false. According to paragraph nine, "… loss of support due to loss of anterior teeth … can alter lip print recording"
D → Incorrect because it is true. According to paragraph nine, "Lip print pattern depends on whether mouth is opened or closed. In closed mouth position, lip shows well-defined grooves …"
E → Incorrect because it is true. According to paragraph nine, "Pathology of the lip … can alter lip print recording"

11. In which of the following scenarios are bite marks most commonly found on the victims?
    A. Mass casualties
    B. Suicide
    C. Rape
    D. Senior abuse
    E. Motor vehicle collision

According to paragraph eight, "Bite marks on human tissues can be observed in violent incidents such as sex-related crimes, child abuse cases, and offences involving physical altercations, such as homicide"

12. Which of the following statements regarding denture marking is INCORRECT?
    A. Laser engraving is an inclusion method
    B. Radio-frequency identification is an inclusion method
    C. Surface methods are easy to apply
    D. Surface methods can weaken the structure
    E. Inclusion methods can create porosity

A → Incorrect because it is true. According to paragraph twelve, "Inclusion methods include metal identification bands, … denture bar coding, T-bar, laser etching, …"
B → In correct because it is true. According to paragraph twelve, "Inclusion methods include metal identification bands, … radio-frequency identification tags, …"
C → Incorrect because it is true. According to paragraph twelve, "… the surface methods are easy to apply and relatively inexpensive. The only disadvantage is they worn off easily and needed to be reapplied"
D → Correct because it is false. According to paragraph twelve, the author states that *inclusion* (not surface) methods can easily weaken the structure: "… the inclusion methods are more permanent; however, it can weaken the denture structure and create porosity"
E → Incorrect because it is true. According to paragraph twelve, "… the inclusion methods are more permanent; however, it can weaken the denture structure and create porosity"

13. Which of the following best describes the author's tone in last paragraph
    A. Scornful
    B. Agnostic
    C. Skeptical
    D. Defensive
    E. Optimistic

A → Incorrect. The author does not explicitly or implicitly express any dislike, disrespect, or contempt regarding the field of forensic odontology
B → Incorrect. The author seems to be in support of forensic odontology, claiming "Further research into the field of forensic dentistry should be encouraged …". Therefore the tone is not agnostic
C → Incorrect. The author does not express doubts or reservations about the field of forensic odontology
D → Incorrect. The author does not appear to be expecting criticism and is not seeking to defend any particular opinion
E → Correct. The author appears to be in support of forensic odontology, and shares a fairly optimistic vision of its future: "Further research into the field of forensic dentistry should be encouraged, paving the way for us to incorporate newer technologies into the science of establishing the human identity"

14. Which of the following is NOT an example of an inclusion method?
    A. Lenticular cards
    B. Barcodes
    C. Micro-labeling
    D. Embossing
    E. Lead paper labeling

    According to paragraph twelve, "Methods of denture labeling falls under two categories: the surface marking method and the inclusion method. The surface marking methods include scribbling or engraving the denture and marking with embossed letters. Inclusion methods include metal identification bands, computer-printed denture micro-labeling system, lead paper labeling, embedding the patient photograph, denture bar coding, T-bar, laser etching, lenticular card system …"

15. The tongue is a special organ for forensic identification because:
    A. It is unique to each individual
    B. It is the only internal organ that can be easily protruded from the body
    C. It is resistant to decomposition, skeletonization, and fire damage
    D. It is the only internal organ that can be preserved using alginate molding
    E. Antemortem records are required

    A → Incorrect. Although the author mentions in the second last paragraph that "The tongue is unique to each person in its shape …", this is also true for dentition, lips, and the palate. Therefore, this trait does not make the tongue a special organ
    B → Correct. According to the second last paragraph, "The tongue is unique to each person in its shape and surface textures and is the only internal organ that can be protruded from the body and easily exposed for inspection"
    C → Incorrect. There is no evidence in the passage that would suggest that the tongue is resistant to decomposition, skeletonization, and fire damage. In the first paragraph, the author claims that this is true for ***dental tissue*** only
    D → Incorrect. Although the author does mention in the second last paragraph that "The lingual morphological aspects can be preserved using the alginate molding technique …", they do not claim that this technique is exclusive to the tongue
    E → Incorrect. Although the author does mention in the second last paragraph that "For this technique to be successful, the antemortem photograph or impression … should be available", this statement is also true for the dentition, lips, and face. Therefore, this trait does not make the tongue a special organ

16. Which of the following factors do NOT alter palatal rugae patterns?
    A. Orthodontic treatment
    B. Cleft palate surgery
    C. Age
    D. Impacted teeth
    E. Mouth position

    According to paragraph ten, "… rugae patterns can still change with age and other environmental influences such as orthodontic movements, tooth extraction, cleft palate surgery, periodontal surgery, and impacted canine eruption"

17. Cranial appearance is useful for determining which of the following identity traits?
    A. Height
    B. Age
    C. Sex
    D. Race
    E. Weight

    According to paragraph eleven, "The cranial appearance is very much helpful in determining the sex of the individual"

18. Which of the following is farthest from the author's intended meaning of the phrase "other assaults" in paragraph ten?
    A. Chemical burns
    B. Penetrating trauma
    C. Skeletonization
    D. Blunt force trauma
    E. Exposure to the elements

    The author states in paragraph ten: "Since the rugae are located inside the oral cavity and are protected by the tongue and a pad of buccal fat, they remain undisturbed from heat and other assaults". In the context of this sentence, the phrase "other assaults" refers to any physical force resulting in *external* damage. Chemical burns, penetrating trauma, blunt force trauma, and exposure to the elements all fall under this description. Since skeletonization damages all *internal* and *external* structures apart from the skeleton, it is farthest from the author's intended meaning and therefore the correct answer choice. See paragraph eleven: "Most often in major disasters and in accidents, the body of the dead person may be decomposed or skeletonized. In such cases, the only part retained may be the skull and the other bones"

19. What is the main purpose of the second paragraph?
    - ***A. To summarize the qualities of teeth that are important with respect to forensic odontology***
    - B. To explain the history of dental evidence with respect to the law
    - C. To summarize the evolution of forensic technology
    - D. To introduce the major applications of forensic odontology
    - E. To explain the different categories of postmortum changes

    A → Correct. The author begins the second paragraph by explaining why teeth are useful for forensic identification. All other statements in the paragraph support this purpose
    B → Although the history of forensic odontology is discussed in two sentences, this is just supportive information and not the main purpose of the paragraph
    C → Although this is mentioned in the final sentence of the paragraph, it is simply a transition sentence and is not the main purpose of the paragraph
    D → This is the purpose of paragraph three, not two
    E → Although postmortum changes are mentioned in the paragraph, it is not the main topic of discussion

20. Which of the following statements is the author of the passage most likely to agree with?
    - A. Forensic odontology is for the most part, an imprecise and unreliable science
    - B. Radiographs should be the first source of evidence for forensic identification
    - C. The accuracy of bite mark analysis is questionable and may lead to wrongful convictions
    - ***D. The science of forensic odontology has not fully matured yet***
    - E. Lip print patterns are consistent and reproducible sources of evidence

    A → Incorrect. In fact, the author seems to believe the opposite: "Forensic dental identification plays a primary role in the identification of remains … The history of forensic odontology goes long back. In courts, the dental evidence has been used for the past many years"
    B → Incorrect. The author explicitly states that radiographic images should be used only when previous dental records are not available: "In cases where previous records are not available for comparison, an alternative aid used for individual identification is radiograph"
    C → Incorrect. The author seems to have a neutral opinion regarding bite mark analysis, and does not discuss the accuracy of the technique. See paragraph eight
    D → Correct. In paragraph one, the author states "Forensic odontology is an evolving science and has a greater scope of development". This implies that the field is still changing, and thus has not fully matured yet
    E → Incorrect. In fact, the author presents evidence in paragraph nine that implies that he has the opposite belief: "Lip print pattern depends on whether mouth is opened or closed. In closed mouth position, lip shows well-defined grooves; whereas in open mouth position, the grooves are relatively ill defined and hard to interpret"

21. Why did the caption of the London Scottish Regiment convince Fleming to do research?
    - A. Surgical training was too expensive
    - B. Fleming's uncle was a scientist
    - C. He wanted Fleming to work for the army
    - ***D. He wanted Fleming to stay at St Mary's***
    - E. There was a shortage of immunologists

    According to paragraph two, "Wishing to keep Fleming in St Mary's to join its rifle club, the club's captain convinced him to pursue a career in research rather than in surgery, as the latter choice would require him to leave the school"

22. The first anti-bacterial substance discovered by Fleming was:
    - A. Penicillin
    - B. Streptomycin
    - C. Doxycycline
    - ***D. Lysozyme***
    - E. Antiseptics

    According to paragraph three, "Upon further investigation, Fleming discovered the presence of a substance in the mucus that inhibited bacterial growth and he named it lysozyme". Penicillin was not discovered until 1928, six years later

23. Fleming's discovery was initially greeted with little enthusiasm by the scientific community

    The isolation of penicillin for medicine was not accomplished until the end of 1955
    - A. Both statements are TRUE
    - B. Both statements are FALSE
    - ***C. The first statement is TRUE, the second is FALSE***
    - D. The first statement is FALSE, the second is TRUE

    According to paragraph five, "Although Fleming published the discovery of penicillin in the British Journal of Experimental Pathology in 1929, the scientific community greeted his work with little initial enthusiasm …". Therefore the first statement is true

According to paragraph five, "… It was not until 1940, just as he was contemplating retirement, that two scientists, Howard Florey and Ernst Chain, became interested in penicillin. In time, they were able to mass-produce it for use during World War II". Therefore the second statement is false

24. Which of the following statements regarding penicillin is FALSE?
    A. It is effective against pneumonia
    B. It is derived from mucus
    C. It revolutionized modern medicine
    D. It was discovered in 1928
    E. It was discovered by accident

A → Incorrect because it is true. According to paragraph four, "[Fleming] found it to be effective against all Gram-positive pathogens, which are responsible for diseases such as scarlet fever, pneumonia, gonorrhoea, meningitis and diphtheria"
B → Correct because it is false. Lysozyme is derived from nasopharyngeal mucus, while penicillin is derived from mould. See paragraphs three and four
C → Incorrect because it is true. According to paragraph four, Fleming said " I certainly didn't plan to revolutionize all medicine by discovering the world's first antibiotic, or bacteria killer. But I suppose that was exactly what I did"
D → Incorrect because it is true. See paragraph four
E → Incorrect because it is true. According the paragraph four, "An uncovered Petri dish sitting next to an open window became contaminated with mould spores"

25. According to the author, which of the following best describes Fleming's natural personality?
    A. Ambitious and hardworking
    B. Pretentious and arrogant
    C. Humble and enigmatic
    D. Antisocial, cynical and paranoid
    E. Bold and aloof

A → Incorrect. According to paragraph seven, Fleming only buried himself in his work after the death of his wife Sareen
B → Incorrect. The author does not describe Fleming in a negative light in paragraph seven
C → Correct. According to paragraph seven, "Fleming was a quiet, patient and modest gentleman, not given to displays of emotion, with a natural shyness that made him avoid accolades and attention. He could be silent to the point of being inscrutable, making it difficult even for his wife and closest friends to gauge his moods and desires"
D → Incorrect. Although the author describes Fleming as shy, this is not the same as antisocial. Furthermore, paragraph seven says he was "… charming and gentle among friends and loved ones"
E → Incorrect. Passage seven describes Fleming as "… occasionally brusque and aloof …", but this was not how he normally acted and thus not his main personality

26. Unlike penicillin, lysozyme was not used in World War II medicine because it is naturally found in human tears, saliva, skin, hair, and fingernails
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

According to paragraph three and five, only penicillin was mass-produced for World War II. This is because lysozyme was found to be "… effective against only a small number of non-harmful bacteria". Therefore the statement is factually correct, but unrelated to the reason.
According to paragraph three, "[Fleming] discovered lysozyme in tears, saliva, skin, hair and fingernails". Therefore the reason is factually correct.

27. What was the cause of Fleming's death?
    A. Gastric upset
    B. Meningitis
    C. Scarlet fever
    D. Pulmonary embolism
    E. Coronary thrombosis

The last paragraph states: "On March 11, 1955, Alexander Fleming suddenly died of coronary thrombosis at home"

28. Which of the following accurately describes the order in which Fleming received his accolades?
    A. Nobel prize, professorship, fellowship, Knight Bachelor, emeritus professorship, Knight Grand Cross
    B. Professorship, Knight Bachelor, fellowship, Nobel prize, emeritus professorship, Knight Grand Cross
    C. Knight Grand Cross, emeritus professorship, Nobel prize, Knight Bachelor, fellowship, professorship
    D. Professorship, fellowship, Knight Bachelor, Nobel prize, emeritus professorship, Knight Grand Cross
    E. Knight Bachelor, Knight Grand Cross, professorship, fellowship, Nobel prize, emeritus professorship

    According to paragraph six, "Fleming received many awards for his achievements. In 1928, he became Professor of Bacteriology at St Mary's. He was elected a Fellow of the Royal Society in 1943 and elevated to the level of Emeritus Professor of Bacteriology at the University of London in 1948. A recipient of some thirty honorary degrees, in 1945, he won the most prestigious award, the Nobel Prize in Physiology/ Medicine. He was made a Knight Bachelor by King George VI in 1944 and a Knight Grand Cross of the Order of Alfonso X the Wise in 1948. Time Magazine named Fleming one of the 100 most important people of the 20th century"

29. Why did Fleming not enter medical school until after working in a shipping office for four years?
    A. His uncle died
    B. He could not afford tuition
    C. He initially wanted a career in the trades
    D. He did not have good grades
    E. He was drafted into World War I

    Although the author mentioned that Fleming's uncle died in the first paragraph, this was not the reason why Fleming was unable to attend medical school. Instead, it is most likely that he could not afford tuition, as his uncle's estate money enabled him to finally pursue a medical education: "When his uncle John died, he willed equal shares of his estate to his siblings, nieces and nephews, and Fleming was able to use his share to pursue a medical education"

30. Which of the following was NOT an accurate difference between World War I and II?
    A. Fleming was a captain in WWII, not WWI
    B. Penicillin was mass-produced during WWII, but not WWI
    C. Antiseptics were widely used in WWI
    D. Many preventable deaths in WWI were due to anaerobic bacteria
    E. WWI occurred around the 1920s, while WWII occurred around the 1940s

    A → Correct because it is false. According to paragraph three, "When World War I broke out, Fleming served in the Army Medical Corps as a captain"
    B → Incorrect because it is true. According to paragraph five, penicillin was only mass produced just prior to WWII
    C → Incorrect because it is true. According to paragraph three, "… The primary means to combat infection was antiseptics, which frequently did more harm than good"
    D → Incorrect because it is true. According to paragraph three, "During this time, [Fleming] observed the death of many of his fellow soldiers, not always from wounds inflicted in battle, but from the ensuing infection that could not be controlled … Fleming discussed the presence of anaerobic bacteria in deep wounds, which proliferated despite antiseptics"
    E → Incorrect because it is true. According to paragraph three, Fleming began researching lysozyme around WWI in 1922. Furthermore, paragraph five states that penicillin was mass produced for WWII in 1940

31. Which of the following was the last name of Fleming's second wife?
    A. Chain Florey
    B. Marion McElroy
    C. Wright
    D. Koutsouri-Vourekas
    E. Amalia

    According to paragraph seven, "… Fleming remarried Dr. Amalia Koutsouri-Vourekas in a Greek church in London"

32. Which of the following statements describes the main idea of the passage?
    A. Penicillin was a miraculous discovery that revolutionized modern medicine
    B. Antibiotic resistance is a serious threat to the efficacy of many modern drugs
    C. Alexander Fleming was a humble scientist who serendipitously discovered penicillin and revolutionized modern medicine
    D. Lysozyme was accidentally discovered by Alexander Fleming after experimenting on his own mucus
    E. World War II was the greatest atrocity in human history, with deaths due not only to wounds, but from the ensuing infection

    A → Incorrect. Although this statement is supported by the author, it does not account for the lengthy discussion around Fleming's professional and personal life
    B → Incorrect. Antibiotic resistance was never mentioned by the author in the passage
    C → Correct. The majority of the passage focuses on Fleming and his accidental discovery of penicillin. His impact on World War II and modern medicine are also discussed
    D → Incorrect. This is one of the main ideas for paragraph three, but not the main idea for the entire passage
    E → Incorrect. The author mentions that deaths during WWI (not WWII) occurred mainly due to infection. Furthermore, this is unrelated to the main idea of the passage

33. Which of the following diseases would be resistant against penicillin treatment?
    A. Diphtheria
    B. Pneumonia
    C. Gonorrhoea
    D. Hepatitis C
    E. Meningitis

    According to paragraph four, penicillin is "effective against all Gram-positive pathogens, which are responsible for diseases such as scarlet fever, pneumonia, gonorrhoea, meningitis and diphtheria". Since the author did not include hepatitis in this list, it is the least likely to be affected by penicillin. Furthermore, hepatitis C is a virus, and paragraph four suggests that penicillin only works on bacteria

34. Which of the following substances contains the highest amount of lysozyme?
    A. Egg white
    B. Tears
    C. Egg yolk
    D. Saliva
    E. Skin

    According to paragraph three, "[Fleming] discovered lysozyme in tears, saliva, skin, hair and fingernails. He was soon able to isolate larger amounts of lysozyme from egg white". Therefore, we can conclude that egg white has the highest amounts of lysozyme out of all other answer choices

35. Which of the following best describes the author's tone in the last paragraph?
    A. Serious
    B. Solemn
    C. Light-hearted
    D. Melancholy
    E. Sympathetic

    A → Incorrect. The author does not imply that Fleming's death had profound implications or should be discussed seriously. In fact, the last sentence is purposely included to lighten the mood of the paragraph
    B → Incorrect. The author does not speak in a serious, formal, and dignified manner. Furthermore, the author does not seek to convey a feeling of sadness. In fact, the last sentence is purposely included to lighten the mood of the paragraph
    C → Correct. The author includes the last sentence to purposely lighten the mood of the paragraph: "[h]e died as he wished; quietly, without a gradual decline in physical or mental capacity, and even without inconveniencing his physician"
    D → Incorrect for the same reasons as answer choice B)
    E → Incorrect. The author does not show pity or understanding when describing Fleming's death

36. A total of 2 million TB-positive individuals have gone either undiagnosed or unnotified.

    7.4% of previously treated patients have Hr-TB.

    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

    According to the last paragraph, "In addition to the 3 million TB patients who fail to get diagnosed or notified, there are large numbers of people with Hr-TB who are misdiagnosed and consequently mismanaged". Therefore the first statement is false
    According to paragraph three, "… on average—7.4% (95% CI 6.5–8.4) of new cases and 11.4% (9.4–13.4) of previously treated patients have Hr-TB". Therefore the second statement is false.

37. Which of the following is NOT a major flaw in national surveillance systems for isoniazid resistance?

    A. Diversity of detection methods
    B. Limited laboratory capacity
    C. Small sample sizes
    D. Poor administrative communication
    E. Lack of quality control

    According to paragraph four, "The analysis by Dean and colleagues highlights major flaws in national surveillance systems, which go hand in hand with limited laboratory capacity. The small sample sizes available from some countries make national prevalence estimates imprecise. Furthermore, the diversity of detection methods employed across settings along with the widespread lack of quality control underscores the need for improved surveillance by countries." The only shortcoming that is not mentioned by the author is answer choice D)

38. Which of the following statements would the author most likely agree with?

    A. Technological limitations are mainly responsible for the current lack of drug-susceptibility testing
    B. Quality care for TB is a privilege for individuals living in developed nations
    C. The 2010 debut of Xpert MTB/RIF introduced a promising technology for universal drug-susceptibility testing
    D. A proper diagnosis for MDR-TB should involve both rifampicin and isoniazid resistance testing

    A → Incorrect. In the first paragraph, the author states "Indeed, for decades, no drug-susceptibility testing for any drug was done unless patients failed first-line therapy or had risk factors for drug-resistant TB (DR-TB). Simply put, we chose to ignore the problem". Therefore, the author believes that the lack of motivation (not technology) was responsible. Furthermore, the author states in paragraph nine that "… this technology is becoming cheaper and easier and offers an incredible opportunity to generate better quality information on isoniazid resistance". This further suggests that the author believes technology is not the main issue
    B → Incorrect. In the last paragraph, the author states "… access to quality TB care is a human rights issue". This suggests that the author views quality TB care as a right, not a privilege
    C → Incorrect. In paragraph two, the author states "Novel technologies such as Xpert MTB/RIF were rolled out in 2010, but the technology did not include isoniazid-resistance testing. Even today, access to any drug-susceptibility testing remains low, and when performed, testing is often limited to rifampicin resistance". This suggests that the author believes the 2010 version of Xpert MTB/RIF had many shortcomings and was not promising
    D → Correct. In paragraph five, the author states "From a clinical standpoint, if isoniazid resistance is not detected, new patients are managed as if they had pansusceptible TB, with a substantially increased risk of treatment failure or relapse and a greater propensity to acquire further resistance. Yet, most research and policy efforts so far have been focused solely on rifampicin resistance as a proxy for multidrug-resistant (MDR)-TB. This means that hundreds of thousands of patients with Hr-TB are staying in the shadows, not receiving appropriate care, and all too often ending up developing MDR-TB". Since the author indicates that not testing for isoniazid resistance has significant clinical consequences, therefore a proper diagnosis should involve both types of resistance testing

39. Which of the following is a CORRECT difference between the new and old treatment recommendations for Hr-TB?

    A. The new recommendation is a 9-month course of drugs rather than 6-months
    B. The old recommendation included ethambutol instead of levofloxacin
    C. The new recommendation replaces rifampicin and pyrazinamide with levofloxacin
    D. The old recommendation is a 2-month drug regimen instead of a 6-month regimen
    E. The new recommendation does not include ethambutol

    According to paragraph six, "In 2018, the World Health Organization (WHO) issued new treatment recommendations for Hr-TB, replacing the previous 9-month course of rifampicin, pyrazinamide, and ethambutol with a 6-month regimen based on levofloxacin plus ethambutol"

40. Why is whole-genome sequencing technology still not common in high-TB-burden countries?
    A. Lack of education and awareness
    B. Red tape and bureaucracy
    C. Lack of a public health institution
    D. Limited Infrastructure and high cost
    E. Limited technology and manufacturing capabilities

    According to the second last paragraph, "At present, nationwide scale-up of whole-genome sequencing for routine TB diagnosis may not seem within reach in most high-TB-burden countries owing to cost and infrastructure requirements. However, this technology is becoming cheaper and easier …"

41. Which one of the following is NOT a reason why it is difficult for high TB-burden countries to implement the new WHO guidelines for Hr-TB?
    A. Line-probe assays are limited to centralized or reference laboratories
    B. Empirically starting a drug regimen that contains quinolone is risky
    C. Liquid cultures are limited to centralized or reference laboratories
    D. Providing easy access to isoniazid resistance testing is a challenge
    E. WHO-endorsed technologies are not available in high TB-burden countries

    A → Incorrect because it is true. According to paragraph seven, "… WHO-endorsed technologies (such as line-probe assays and liquid cultures) … are limited to centralized or reference laboratories"
    B → Incorrect because it is true According to paragraph seven, "… even in settings where the prevalence of Hr-TB is the highest, starting a quinolone-containing regimen empirically requires caution …"
    C → Incorrect because it is true. According to paragraph seven, "… WHO-endorsed technologies (such as line-probe assays and liquid cultures) … are limited to centralized or reference laboratories"
    D → Incorrect because it is true. According to paragraph seven, "… high-TB-burden countries will struggle to routinely implement these new guidelines for Hr-TB because easy access to isoniazid-resistance testing is a challenge"
    E → Correct because it is false. In paragraph seven, the author mentions that WHO-endorsed technologies *are* available in high-TB countries, but are not easily accessible because they are limited to centralized or reference laboratories. Therefore this answer choice is false

42. Which of the following is NOT a burden that patients with DR-TB experience?
    A. Societal
    B. Financial
    C. Physical
    D. Social
    E. Mental

    According to the last paragraph, "Beyond technologies and guidelines, we need to acknowledge the human impact of DR-TB, which imposes a tremendous physical, mental, financial, and social burden on patients"

43. Which of the following words best describes the author's tone throughout the passage?
    A. Persuasive
    B. Scornful
    C. Cynical
    D. Skeptical
    E. Accusatory

    A → Correct. Throughout the passage, the author presents evidence that supports his/her argument that universal drug-susceptibility testing is an essential component of providing quality TB care and preventing drug resistance
    B → Incorrect. The author does not express dislike, disrespect, or contempt throughout the entire passage
    C → Incorrect. The author does not express a distrust of human sincerity or integrity throughout the passage
    D → Incorrect. Although the author mentions some doubts regarding national surveillance systems and the new WHO guidelines, the passage is not skeptical in its entirety
    E → Incorrect. The author does not suggest that a particular subject is guilty or should be blamed for the DR-TB problem

44. What is the purpose of the first paragraph?
    A. To explain the mechanism of drug resistance
    B. To critique the use of novel technologies to achieve universal drug-susceptibility testing
    C. To explain how the issue of DR-TB came to be
    D. To convey the urgency of fighting Hr-TB
    E. To introduce the role of the World Health Organization (WHO)

    A → Incorrect. The author does not mention the mechanism behind drug resistance anywhere in the passage
    B → Incorrect. This is the purpose of paragraph two
    C → Correct. The author is trying to convince us that the DR-TB problem arose from sheer ignorance: "… this knowledge did not necessarily lead to testing for isoniazid-resistant, rifampicin-susceptible TB (Hr-TB) or to the use of special drug regimens … Simply put, we chose to ignore the problem."
    D → Incorrect. This is the purpose of paragraph three

E → Incorrect. The author does not mention the World Health Organization until paragraph six

45. What percentage of new tuberculosis cases are isoniazid-resistant and rifampicin-susceptible?
    A. 95%
    B. 11.4%
    C. 10.7%
    D. 7.4%
    E. 27.2%

According to paragraph three, "… on average—7.4% (95% CI 6.5–8.4) of new cases and 11.4% (9.4–13.4) of previously treated patients have Hr-TB"

46. Which of the following institutions was not involved in the release of the new WHO recommendations for Hr-TB?
    A. European Respiratory Society
    B. Infectious Disease Society of America
    C. Centers for Disease Control and Prevention
    D. American Thoracic Society
    E. Doctors of Thoracic Surgery

According to paragraph six, "This recommendation is reflected in the updated guideline for DR-TB jointly released in 2019 by the American Thoracic Society, Centers for Disease Control and Prevention, European Respiratory Society, and Infectious Disease Society of America …"

47. If isoniazid resistance is not detected, new patients are managed as if they had Hr-TB.

    Rifampicin resistance is commonly used as a proxy for multidrug-resistant (MDR)-TB.
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

According to paragraph five, "From a clinical standpoint, if isoniazid resistance is not detected, new patients are managed as if they had pansusceptible TB …". Therefore the first statement is false.

According to paragraph five, "… most research and policy efforts so far have been focused solely on rifampicin resistance as a proxy for multidrug-resistant (MDR)-TB". Therefore the second statement is true.

48. Which of the following values could be the overall prevalence of isoniazid resistance?
    A. 10%
    B. 15%
    C. 30%
    D. 35%
    E. 50%

According to paragraph three, "The overall prevalence of isoniazid resistance (with or without concomitant rifampicin resistance) ranged between 10.7% (9.6–11.9) and 27.2% (24.6–29.9) depending on the treatment history …". 15% is the only option between 10.7% and 27.2%, therefore it is the correct answer choice

49. Rank TB, MDR-TB, and Hr-TB in order of least drug-resistant to most drug-resistant
    A. Hr-TB < MDR-TB < TB
    B. TB < MDR-TB < Hr-TB
    C. TB < Hr-TB < MDR-TB
    D. MDR-TB < Hr-TB < TB
    E. Hr-TB < TB < MDR-TB

According to the first paragraph, Hr-TB is TB that is both isoniazid-resistant and rifampicin-susceptible. According to paragraph five, Hr-TB can develop into MDR-TB if further resistance is acquired. Therefore answer choice C) is correct

50. Why would a deeper examination of the genotypic diversity of isoniazid resistance be beneficial for TB treatment?
    A. Sequence data will uncover the full range of mutations associated with drug resistance
    B. Treatment guidelines are currently based on low-quality evidence
    C. Mutations in katG and inhA will be detected
    D. Genotype data is required for the creation of new antibiotics
    E. Genome editing can be used to reverse drug resistance in many strains of TB

According to the second last paragraph, "Importantly, a deeper examination of the genotypic diversity of isoniazid resistance would be of great benefit to inform treatment guidelines that are currently based on low-quality evidence"

FULL-LENGTH 2 MEDIUM DIFFICULTY

SCORE CONVERSION SCALE

Biology		Chemistry		PAT		RCT	
Percent →	DAT Score	Percent →	DAT Score	Percent →	DAT Score	Percent →	DAT Score
1–5%	0	1–5%	0	1–5%	0	1–5%	0
5–10%	1–3	5–10%	1–3	5–10%	1–3	5–10%	1–3
10–15%	3–5	10–15%	3–5	10–15%	3–5	10–15%	3–5
15–20%	5–8	15–20%	5–8	15–20%	5–8	15–20%	5–8
20–25%	8–11	20–25%	8–11	20–25%	8–11	20–25%	8–11
25–30%	12	25–30%	12	25–30%	11–14	25–30%	12
30–35%	13	30–35%	13	30–35%	15	30–35%	13
35–40%	14	35–40%	14	35–40%	16	35–40%	14
40–45%	15	40–45%	15	40–45%	17	40–45%	15
45–50%	16	45–50%	16	45–50%	18	45–50%	16
50–55%	17	50–55%	17	50–55%	19	50–55%	17
55–60%	18	55–60%	18	55–60%	20	55–60%	18
60–65%	20	60–65%	20	60–65%	21	60–65%	19
65–70%	22	65–70%	22	65–70%	23	65–70%	20
70–75%	23	70–75%	23	70–75%	24	70–75%	21
75–80%	24	75–80%	24	75–80%	25	75–80%	22
80–85%	26	80–85%	26	80–85%	27	80–85%	24
85–90%	28	85–90%	28	85–90%	28	85–90%	26
90–95%	29	90–95%	29	90–95%	29	90–95%	28
95–100%	30	95–100%	30	95–100%	30	95–100%	30

FULL-LENGTH 3 MEDIUM DIFFICULTY

SURVEY OF THE NATURAL SCIENCES

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Survey of Natural Sciences:

1. Each item is a question and/or incomplete statement followed by possible answers or completions. Read the item, decide which answer choice is the best, and bubble in the corresponding circle on the answer sheet
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 60 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. **DO NOT TURN PAST THE STOP PAGE AND ON TO THE NEXT SECTION UNTIL INSTRUCTED**
6. At the end of this section, the answer sheet is collected. The booklet remains at your table for use during the next section

TIME LIMIT:
60 minutes

TEST NAME:
SNS

TEST NUMBER:
03

This is a DAT simulation.

This section is composed of 70 questions:
Biology (1-40) and General Chemistry (41-70)

1. The attachment of oxygen to one of the four active sites of hemoglobin increases their affinity for other oxygen molecules. Which of the following best describes this phenomenon?
   A. Induced-fit model
   B. Competitive inhibition
   C. Cooperativity
   D. Noncompetitive inhibition
   E. Allosteric regulation

2. Which of the following animal phyla does NOT have a coelom?
   A. Chordata
   B. Echinodermata
   C. Arthropoda
   D. Platyhelminths
   E. Annelida

3. Which of the following hormonal changes triggers menstruation?
   A. Decrease in progesterone
   B. Decrease in follicle stimulating hormone
   C. Increase in estrogen
   D. Increase in leutenizing hormone
   E. Decrease in estrogen

4. Which of the following muscle tissues is mismatched with its feature?
   A. Cardiac – striated
   B. Smooth – involuntary control
   C. Skeletal – multinucleate
   D. Cardiac – syncytium of cells
   E. Smooth – mononucleate

5. The number of 10 to 20 year-olds in an urban city is extremely low, compared to the number of the number of 70 to 80 year-olds. Which of the following terms most accurately describes this population?
   A. Expansive
   B. Stationary
   C. Constrictive
   D. Logarithmic
   E. Type I

6. Which of the following chemical bonds are predominant in proteins?
   A. Glycosidic links
   B. Peptide bonds
   C. Ester bonds
   D. Disulphide bridges
   E. Phosphodiester bonds

7. New species can arise from non-disjunction, spontaneous mutation, or behavioural isolation. These are all examples of which of the following?
   A. Prezygotic isolation
   B. Postzygotic isolation
   C. Genetic drift
   D. Sympatric speciation
   E. Allopatric speciation

8. Which of the following structures is NOT part of the middle ear?
   A. Incus
   B. Eustachian tube
   C. Semicircular canals
   D. Tympanic membrane
   E. Stapes

9. Type I and II pneumocytes are derived from which embryonic structure?
   A. Intervertebral disks
   B. Endoderm
   C. Somites
   D. Ectoderm
   E. Mesoderm

10. Which of the following is NOT a parasympathetic response?
    A. Pupil constriction
    B. Decreased heart rate
    C. Increased digestion
    D. Relaxed urinary bladder
    E. Decreased glycolysis

11. The population of wolves in Banff National Park experienced a severe decline in 1950 due to a rabies epidemic. After this decline, major changes were noticed in the ecosystem. The wolves can thus be classified as which of the following?
    A. A dominant species
    B. An ecosystem engineer
    C. An umbrella species
    D. A keystone species
    E. A primary producer

12. Which of the following is NOT a form of post-transcriptional regulation?
    A. Ubiquitin tagging
    B. miRNA interference
    C. Alternative splicing
    D. RNA degradation
    E. Poly-A tail

13. If the percentage of cholesterol in a plasma membrane is decreased, which of the following consequences would occur?
    A. Increase in permeability at low temperatures
    B. Decrease in fluidity at high temperatures
    C. Increase in fluidity at low temperatures
    D. Increase in fluidity at high temperatures
    E. Atherosclerosis

14. Which of the following structures is the common passageway for food, fluids, and air?
    A. Esophagus
    B. Pharynx
    C. Trachea
    D. Larynx
    E. Epiglottis

15. The coral snake is highly venomous and has a distinctive black, red, and yellow pattern. This pattern is also found on the harmless scarlet king snake, an unrelated species. This is an example of which of the following?
    A. Behavioural defence
    B. Camouflage
    C. Mullarian mimicry
    D. Resource partitioning
    E. Batesian mimicry

16. If a tissue biopsy sample is stored in distilled water, what would occur to the cells?
    A. Nothing
    B. Plasmolysis
    C. Cytolysis
    D. Hydrolysis
    E. Cytokinesis

17. After the discovery of cancer, a 70 year old woman undergoes a parathyroidectomy (removal of the parathyroid glands). Which of the following is she at an increased risk for?
    A. Osteoporosis
    B. Increased blood calcium
    C. Goiter formation
    D. Decreased calcium resorption
    E. Osteomalacia

18. During fertilization in mammals, polyspermy is prevented by the following mechanism:
    A. Acrosome reaction
    B. Electrical block
    C. Cleavage
    D. Cortical reaction
    E. LH surge

19. The ancient Earth's reducing atmosphere was converted into an oxidative one thanks to:
    A. Methanogens
    B. Nitrifying bacteria
    C. Spirochetes
    D. Cyanobacteria
    E. Dinoflagellates

20. An unidentified strain of bacteria is cultured in a test tube. After incubation, the mixture appears to have a uniform concentration of bacteria throughout. This strain can be classified as:
    A. Microaerophile
    B. Obligate anaerobe
    C. Aerotolerant
    D. Obligate aerobe
    E. Facultative anaerobe

21. Which of the following metabolic processes occurs in the cytosol?
    A. Pyruvate oxidation
    B. Electron transport chain
    C. Citric acid cycle
    D. Calvin cycle
    E. Lactic acid fermentation

22. A congenital disorder results in the absence of sweat glands. Which of the following structures may be responsible for this developmental defect?
    A. Mesoderm
    B. Ectoderm
    C. Blastopore
    D. Epiderm
    E. Endoderm

23. Which of the following plant categories is NOT a bryophyte or lycophyte?
    A. Hornworts
    B. Liverworts
    C. Ferns
    D. Flat mosses
    E. Club mosses

24. Which of the following clinical signs is consistent with respiratory acidosis?
    A. Swollen bronchioles
    B. Decreased respiratory rate
    C. Increased heart rate
    D. Increased respiratory rate
    E. Decreased heart rate

25. Which of the following terrestrial biomes is characterized by moderate temperatures and the dominance of deciduous trees?
    A. Chaparral
    B. Temperate forest
    C. Boreal forest
    D. Tropical forest
    E. Savanna

26. Which of the following plant hormones promotes the shedding of leaves?
    A. Abscisic acid
    B. Gibberellin
    C. Cytokinin
    D. Ethylene
    E. Auxin

27. An individual with the genotype AABbcc is crossed with an individual with the genotype AaBBCc. What is the probability that their offspring will have the genotype AABBcc?
    A. $\frac{1}{2}$
    B. $\frac{1}{4}$
    C. $\frac{1}{8}$
    D. $\frac{1}{16}$
    E. $\frac{1}{32}$

28. Which of the following statements regarding mitochondria is INCORRECT?
    A. Contain a double lipid bilayer
    B. Found in all cells
    C. Replicate independently
    D. Abundant in myocytes
    E. Found in the neck of spermatozoa

29. Which of the following correctly describes the role of microfilaments within the cell?
    A. Dividing the cytoplasm during cytokinesis
    B. Mediating the transport of organelles
    C. Separating the chromosomes during anaphase
    D. Providing structural support
    E. Attaching cells to the extracellular matrix

30. In C4 photosynthesis, carbon dioxide is fixed into _ by the _ enzyme and transported to _ cells
    A. Malate; RuBisCO; mesophyll
    B. Oxaloacetate; PEP carboxylase; mesophyll
    C. Malate; RuBisCO; bundle sheath
    D. Oxaloacetate; PEP carboxylase; bundle sheath
    E. Malate; PEP carboxylase; bundle sheath

31. Acetylcholine triggers the release of _ from the _
    A. Na^+; sarcoplasmic reticulum
    B. Na^+; T-tubules
    C. Ca^{2+}; sarcoplasmic reticulum
    D. Ca^{2+}; T-tubules
    E. Ca^{2+}; sarcolemma

32. What is the ratio of aneuploid gametes resulting from nondisjunction during meiosis I vs II?
    A. 0.5
    B. 1
    C. 1.5
    D. 2
    E. 4

33. A species of spiders has varying sizes of red markings. Those with larger markings are better able to camouflage against tomatoes, while those with smaller markings are better able to hide in shaded areas. Over time, which of the following is most likely to occur?
    A. Stabilizing selection
    B. Directional selection
    C. Disruptive selection
    D. Frequency-dependent selection
    E. Sexual selection

34. Which of the following cell junctions allows action potential propagation in cardiomyocytes?
    A. Gap junctions
    B. Desmosomes
    C. Plasmodesmata
    D. Adherens junctions
    E. Tight junctions

35. Which of the following embryonic components develops into the placenta?
    A. Amnion
    B. Embryoblasts
    C. Allantois
    D. Chorion
    E. Epiblasts

36. Insulin stimulates glucose ____ and is produced by ____ cells in the pancreatic islets
    A. Release; alpha
    B. Absorption; alpha
    C. Release; beta
    D. Absorption; beta
    E. Absorption; delta

37. Which of the following is NOT a function of the liver?
    A. Blood filtration
    B. Bile production
    C. Cholecystokinin secretion
    D. Bilirubin secretion
    E. Gluconeogenesis

38. What is the function of topoisomerase during DNA replication?
    A. Separate double-stranded DNA
    B. Create temporary double-stranded breaks
    C. Prevent the annealing of separated DNA
    D. Replace RNA primers with DNA
    E. Bind DNA polymerase III to DNA

39. An increase in angiotensin II will result in:
    A. Vasodilation of blood vessels
    B. Decreased aldosterone production
    C. Increased Na^+ resorption in the proximal convoluted tubules
    D. Decreased antidiuretic hormone production
    E. Decreased Na^+ resorption in the distal convoluted tubules

40. Which of the following events occurs in meiosis but not mitosis?
    A. Attachment of spindle fibres to the kinetochore
    B. Splitting of sister chromatids
    C. Cleavage furrow formation
    D. Splitting of homologous chromosomes
    E. Alignment of centromeres at the metaphase plate

41. List the following elements in order of increasing atomic radius: F, Cu, Al, Rb, Ca
    A. Al < F < Cu < Ca < Rb
    B. F < Al < Ca < Cu < Rb
    C. Rb < Ca < Cu < Al < F
    D. F < Al < Cu < Ca < Rb
    E. F < Ca < Cu < Al < Rb

42. 150 J is used to heat a 5 g sample of aluminium from 20°C to 50°C. What is the specific heat capacity in J/g°C?
    A. 0.4
    B. 1
    C. 1.5
    D. 2
    E. 2.5

43. A chemical reaction with a negative change in enthalpy and entropy will be:
    A. Non-spontaneous at all temperatures
    B. Spontaneous at low temperatures
    C. Spontaneous at high temperatures
    D. Spontaneous at all temperatures
    E. Entropically driven

44. Which of the following statements is correct regarding the redox reaction shown below?

$$2Fe_2O_{3(s)} + 3C_{(s)} \rightarrow 4Fe_{(s)} + 3CO_{2(g)}$$

A. Fe_2O_3 is being oxidized
B. CO_2 is the oxidizing agent
C. This is a disproportionation reaction
D. Fe_2O_3 is the oxidizing agent
E. C is being reduced

45. Which of the following forms of radioactive decay has no effect on both mass and atomic number?

A. Alpha decay
B. Beta positive decay
C. Electron capture
D. Beta negative decay
E. Gamma decay

46. 20 g of NaCl is dissolved in 100 g of water. What is the molality of the resulting solution?

A. $\dfrac{20}{(58)(100)}$
B. $\dfrac{20}{(58)(0.100)}$
C. $\dfrac{(58)(0.100)}{20}$
D. $\dfrac{20}{(14)(0.100)}$
E. $\dfrac{(58)(100)}{20}$

47. If CH_3NH_2 is a weak base, which of the following equations represents the equilibrium constant expression for CH_3NH_2 in aqueous solution?

A. $K_b = \dfrac{[CH_3NH_2]}{[CH_3NH_3^+][OH^-]}$
B. $K_b = \dfrac{[CH_3NH_3^+]}{[CH_3NH_2][OH^-]}$
C. $K_b = \dfrac{[CH_3NH_2][H_3O^+]}{[CH_3NH_3^+]}$
D. $K_b = \dfrac{[CH_3NH_3^+][OH^-]}{[CH_3NH_2]}$
E. $K_b = \dfrac{[CH_4NH_2^+][OH^-]}{[CH_3NH_2]}$

48. Considering the following reaction, how many litres of nitrogen gas are generated from the reaction of 3 mol of oxygen gas and 6 mol of ammonia gas under STP conditions?

$$O_{2(g)} + NH_{3(g)} \rightarrow H_2O_{(l)} + N_{2(g)}$$

A. 11.2 L
B. 22.4 L
C. 44.8 L
D. 67.2 L
E. 89.6 L

49. Which of the following statements is true for the process of sublimation?

A. $\Delta H = 0$; $\Delta S > 0$
B. $\Delta H < 0$; $\Delta S < 0$
C. $\Delta H > 0$; $\Delta S > 0$
D. $\Delta H > 0$; $\Delta S < 0$
E. $\Delta H < 0$; $\Delta S > 0$

50. A sample of iron oxide contains 56/88% iron by weight. What is the simplest formula for this compound?
    A. FeO
    B. FeO_2
    C. Fe_3O_4
    D. Fe_4O_5
    E. Fe_5O_6

51. Which of the following changes will NOT shift the equilibrium reaction shown below to the products side?

$$CaO_{(s)} + H_2O_{(l)} \rightleftharpoons Ca(OH)_{2(s)} \quad \Delta H = 114\ \text{kJ/mol}$$

    A. Adding more CaO
    B. Increasing pressure
    C. Increasing temperature
    D. Decreasing pressure
    E. Decreasing temperature

52. Which of the following statements correctly describes Dalton's law?
    A. Pressure and volume are inversely proportional under isothermal conditions
    B. The partial pressure of an individual gas equals total pressure times percent weight
    C. Moles is proportional to volume under isothermal and isobaric conditions
    D. The total pressure of a gas mixture equals the sum of partial pressures
    E. Volume and temperature are proportional under isobaric conditions

53. What is the molecular geometry of H_2SO_4 in AXE notation?
    A. AX_3
    B. AX_4
    C. AX_3E
    D. AX_2E_2
    E. AX_5

54. Which set of coefficients would balance the following reaction?

$$Ba_3N_2 + H_2O \rightarrow Ba(OH)_2 + NH_3$$

    A. 1, 4, 2, 2
    B. 1, 3, 3, 2
    C. 2, 3, 6, 1
    D. 2, 3, 6, 2
    E. 1, 6, 3, 2

55. If a neutral isotope of uranium has an atomic mass of 240, how many neutrons does it contain?
    A. 56
    B. 92
    C. 146
    D. 148
    E. 332

56. An unknown compound has the empirical formula CH_2O. If the molar mass was determined to be 90 g/mol, what is the molecular formula?
    A. $C_6H_{12}O_6$
    B. CH_2O
    C. C_3H_6O
    D. $C_3H_6O_3$
    E. $C_2H_4O_2$

57. A gaseous mixture containing 2 g of hydrogen and 4 g of helium has a total pressure of 200 kPa. What is the pressure of helium alone?
    A. 50 kPa
    B. 100 kPa
    C. 150kPa
    D. 175 kPa
    E. 200 kPa

58. What is the concentration of I^- in a saturated solution of AgI, which has a K_{sp} of 9×10^{-2}?
    A. 8.1×10^{-3} M
    B. 9×10^{-2} M
    C. 3×10^{-1} M
    D. 1.5 M
    E. 2 M

59. Which of the following statements best describes a Lewis base?
    A. Donates protons
    B. Accepts protons
    C. Releases hydroxide
    D. Donates electrons
    E. Accepts electrons

60. 56 grams of calcium oxide (CaO) are added to 92 grams of ethanol (C_2H_5OH). Which of the following is expected to occur?
    A. Vapour pressure increases by $\frac{1}{2}$
    B. Vapour pressure increases by $\frac{2}{3}$
    C. Vapour pressure remains the same
    D. Vapour pressure decreases by $\frac{2}{3}$
    E. Vapour pressure decreases by $\frac{1}{3}$

61. Which of the following statements regarding electrochemical cells is CORRECT?
    A. Reduction occurs at the anode
    B. Voltaic cells have a negative ΔG
    C. The salt bridge conducts electrons from anode to cathode
    D. Anions of the electrolyte flow to the cathode
    E. The cathode is positively charged in an electrolytic cell

62. A dental amalgam is composed of 40% silver and 60% tin by mass. What is the mole percentage of silver within this mixture?
    A. $\frac{0.37}{0.87}$
    B. $\frac{0.87}{0.37}$
    C. $\frac{0.34}{0.87}$
    D. $\frac{0.87}{0.34}$
    E. 0.37

63. Which of the following statements regarding metals and non-metals is INCORRECT?
    A. Metals are lustrous
    B. Non-metals are brittle in the solid state
    C. Metals oxides form acidic solutions in water
    D. Non-metals tend to form anions
    E. Calcium is a metal

64. The following table contains the empirical initial rates for the reaction:

$$3Cl_2 + 2Fe \rightleftharpoons 2FeCl_3$$

What is the correct rate law?

Trial	$[Cl_2]$	[Fe]	Initial Rate
1	0.7 M	0.7 M	2.5×10^{-2} M/s
2	1.4 M	0.7 M	1.0×10^{-1} M/s
3	0.7 M	2.1 M	2.25×10^{-1} M/s

    A. $r = k[Cl][Fe]$
    B. $r = k[Cl][Fe]^2$
    C. $r = k[Cl][Fe]^3$
    D. $r = k[Cl]^2[Fe]^2$
    E. $r = k[Cl]^3[Fe]$

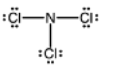
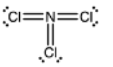
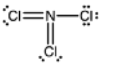
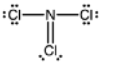
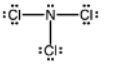
65. Which of the following compounds would have the highest boiling point?
    A. CH_4
    B. $C_{10}H_{24}$
    C. C_2H_4
    D. C_3H_8
    E. C_2H_6

66. The calculated yield for a synthesis reaction is 50 grams of $C_9H_8O_4$. Conducting the actual experiment resulted in only 48 grams. What is the percentage yield and percentage error for this experiment, respectively?
    A. 48%; 52%
    B. 92%; 8%
    C. 8%; 92%
    D. 96%; 4%
    E. 4%; 96%

67. Which of the following rate laws describes a second-order reaction?
    A. $r = k$
    B. $r = k[A]^3$
    C. r = k[A][B]
    D. $r = k[A][B]^2$
    E. $r = k[A]^2[B]^2$

68. What is the osmotic pressure exerted by a 2 molar solution of NaCl at 25°C?
    A. (298)(8.3)(4) kPa
    B. (298)(0.082)(4) kPa
    C. (273)(8.3)(4) kPa
    D. (273)(0.082)(4) kPa
    E. (298)(8.3)(2) kPa

69. Which of the following reactions is balanced?
    A. $Zn + 2HCl \rightarrow ZnCl_2 + H_2$
    B. $Zn + HCl \rightarrow ZnCl_2 + H_2$
    C. $2Zn + 4HCl \rightarrow 2ZnCl_2 + H_2$
    D. $Zn + 4HCl \rightarrow 4ZnCl_2 + H_2$
    E. $2Zn + HCl \rightarrow 2ZnCl_2 + H_2$

70. What is the correct lewis structure for NCl_3?
    A. 
    B. 
    C. 
    D. 
    E. 

STOP

You have completed the SNS section of the DAT.
You will receive a 10 min break before the next section.

FULL-LENGTH 3 MEDIUM DIFFICULTY

PERCEPTUAL ABILITY TEST

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Perceptual Ability Test:

1. Each item is a question requiring perceptual skills. This section contains six sub-sections. Read the specific instructions before starting each sub-section. Decide which answer choice is correct and bubble in the corresponding circle on the answer sheet. **Do not stop after each subsection; continue to answer all 90 questions**
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 60 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. **DO NOT TURN PAST THE STOP PAGE AND ON TO THE NEXT SECTION UNTIL INSTRUCTED**
6. At the end of this section, the answer sheet is collected. The booklet remains at your table for use during the next section

TIME LIMIT:
60 minutes

TEST NAME:
PAT

TEST NUMBER:
03

This is a DAT simulation.

PART 1

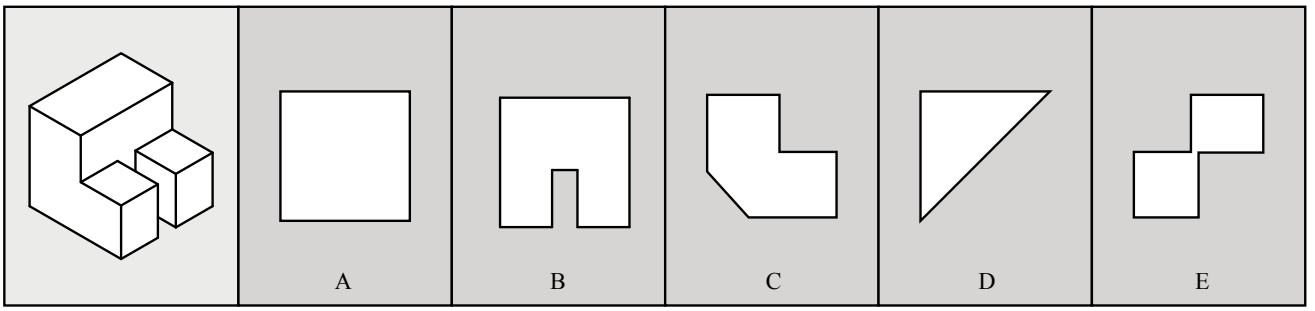
For questions 1 to 15, the test contains questions similar to the example shown below. A three-dimensional object is shown in the light-coloured box on the left. Various two-dimensional answer choices are shown on the right, in dark-coloured boxes.

In each question, your task is to visualize how the three-dimensional object would look from all sides. Then from the answer choices, you must choose a two-dimensional keyhole which would allow the three-dimensional object to pass through. Finally, bubble in the corresponding circle on your answer sheet.

The rules are as follows:

1. Before passing through the keyhole, the object may be rotated in any direction
2. Once the object starts passing through the keyhole, it cannot be rotated
3. Both the object and the keyhole are drawn to scale. They should have the same dimensions
4. There are no irregularities in the hidden parts of the objects

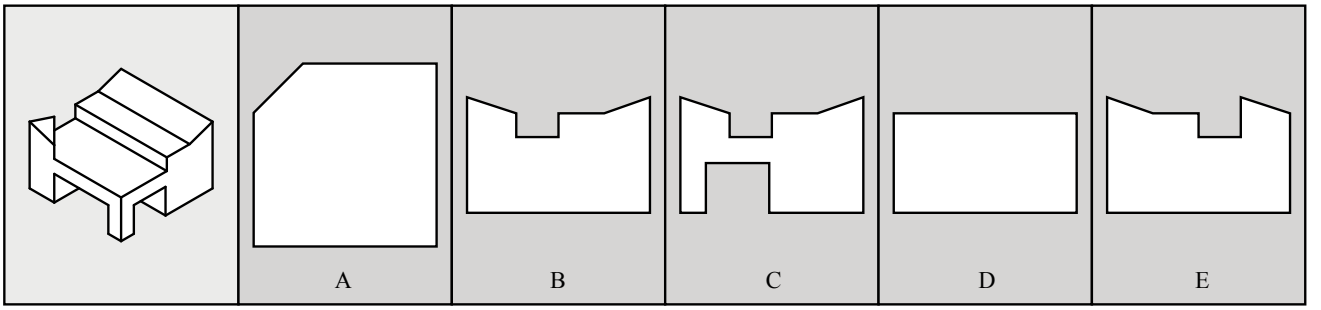
Example Question (Do NOT mark the answer to this example on your answer sheet)



The correct answer is B because the object would pass through this keyhole if the bottom or top side was rotated and inserted first

Please proceed to the questions

1.



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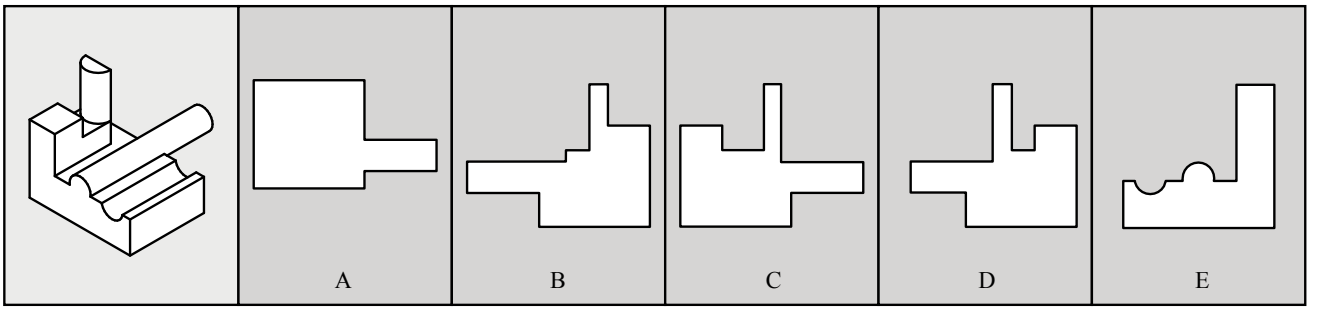

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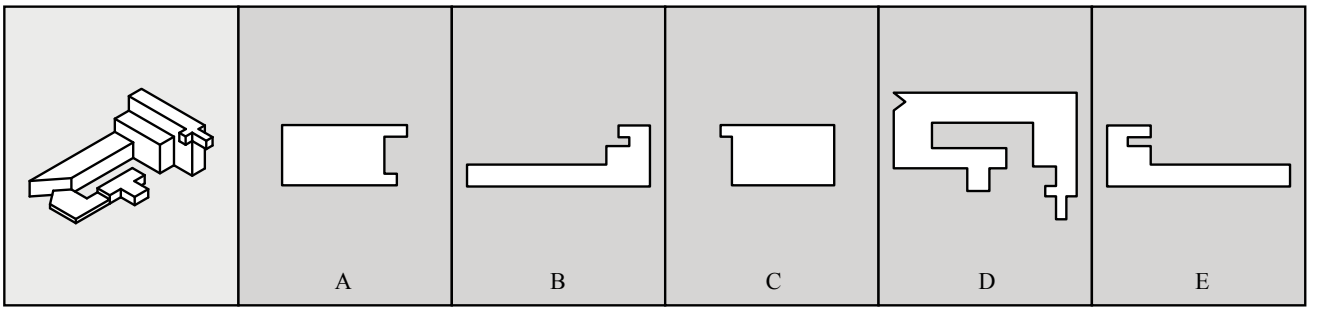

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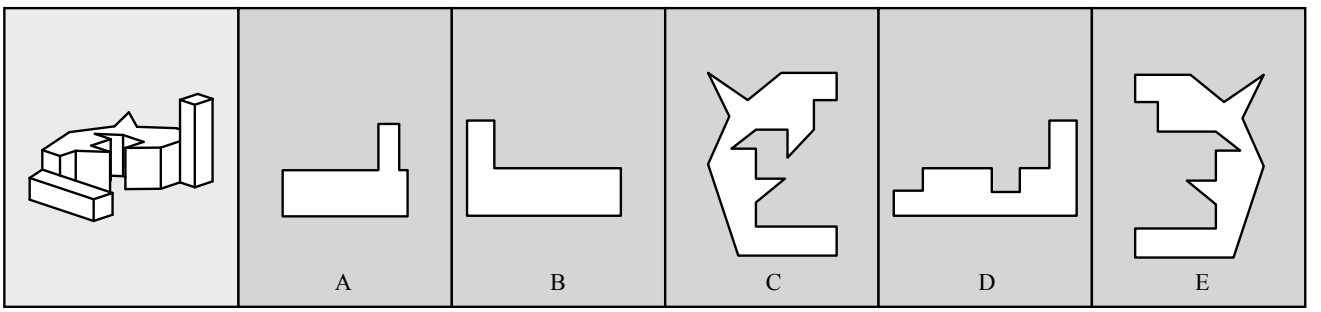

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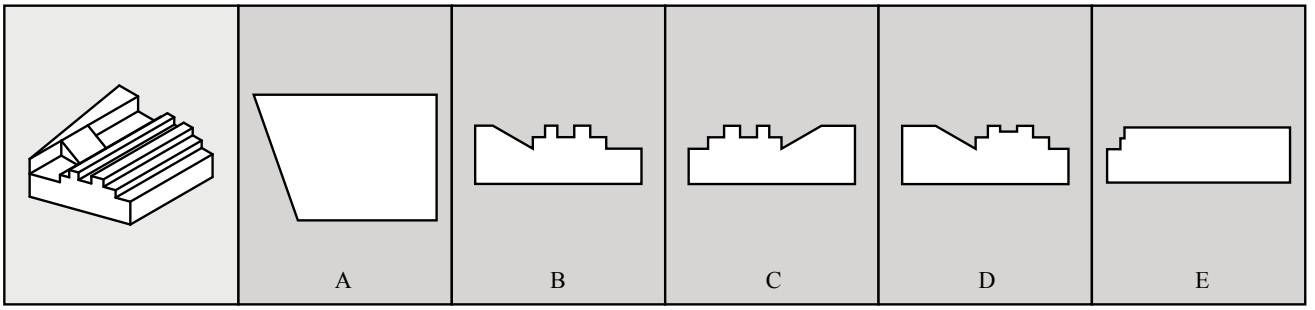

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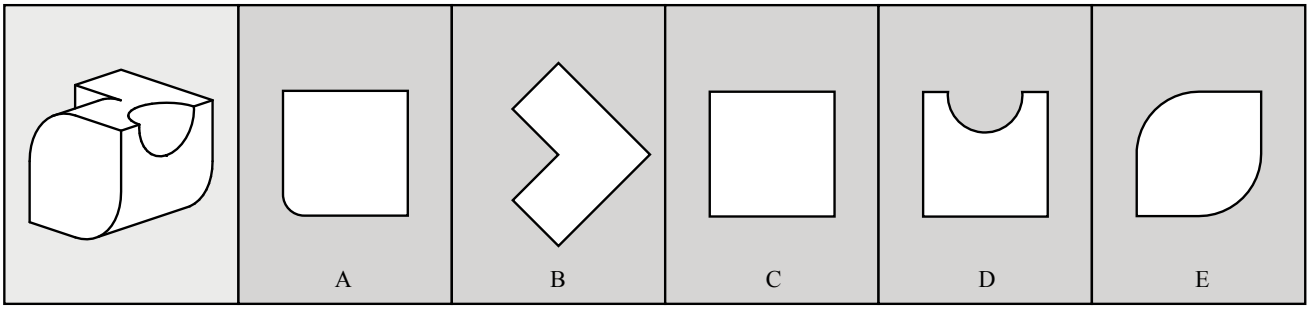

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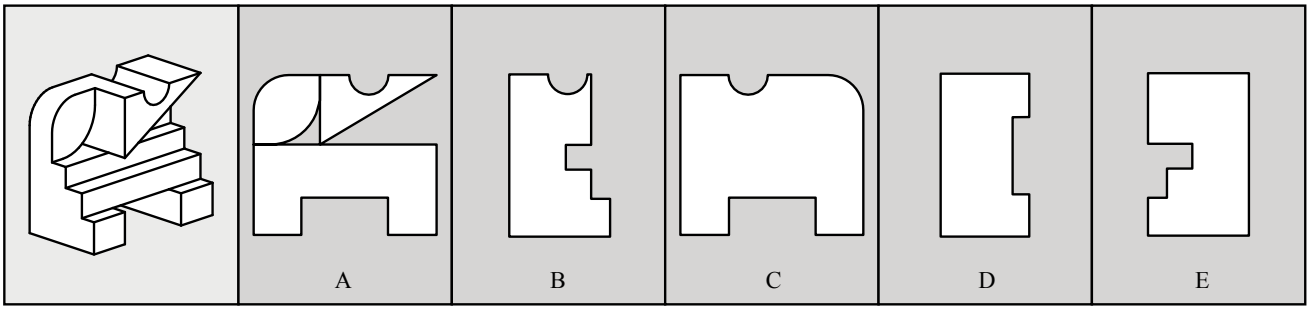

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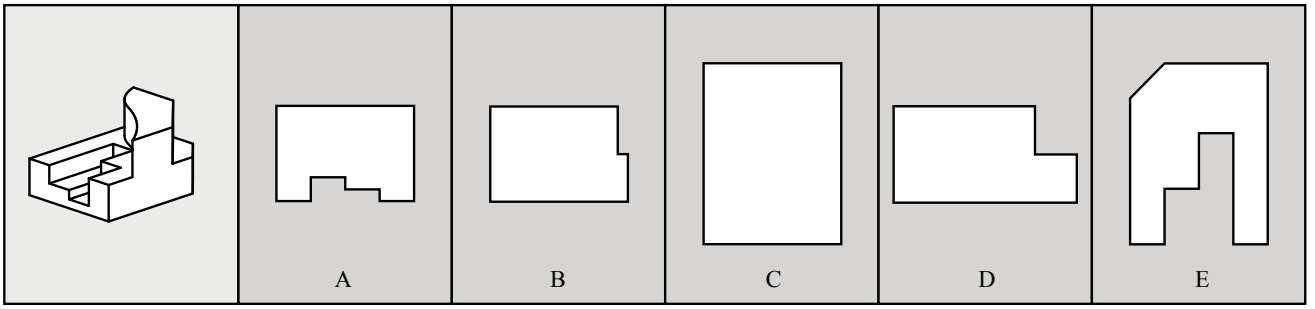
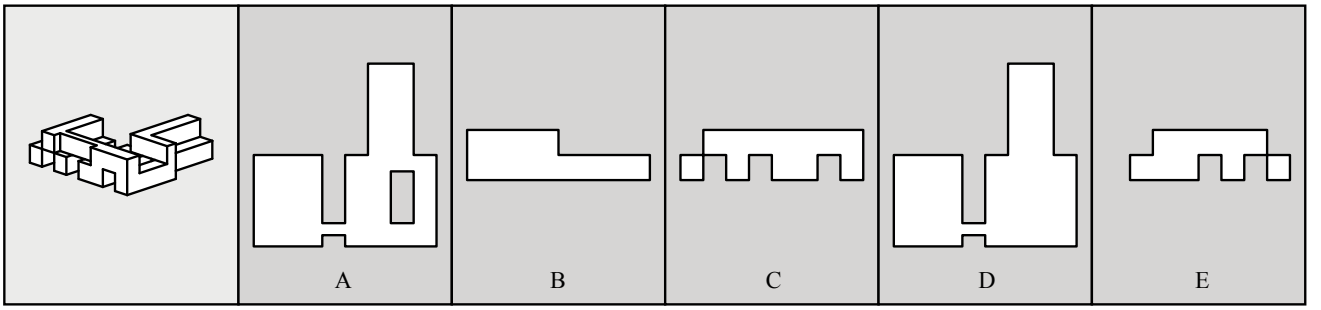


9.



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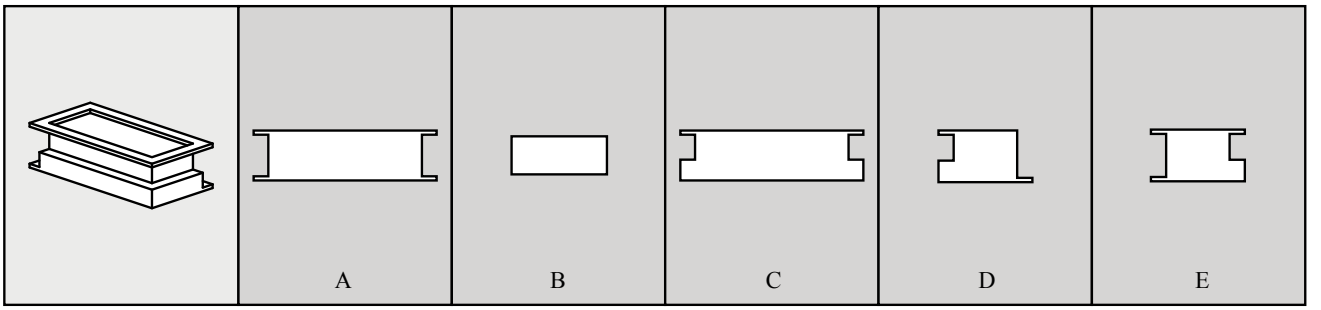

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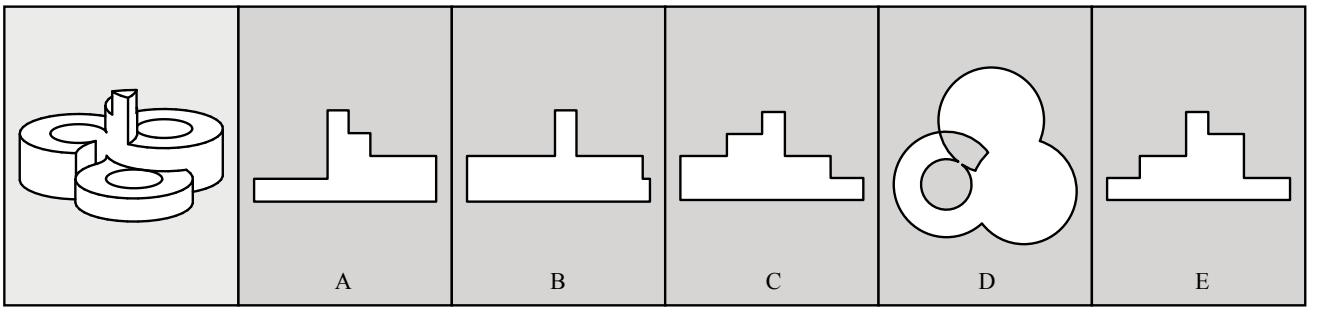
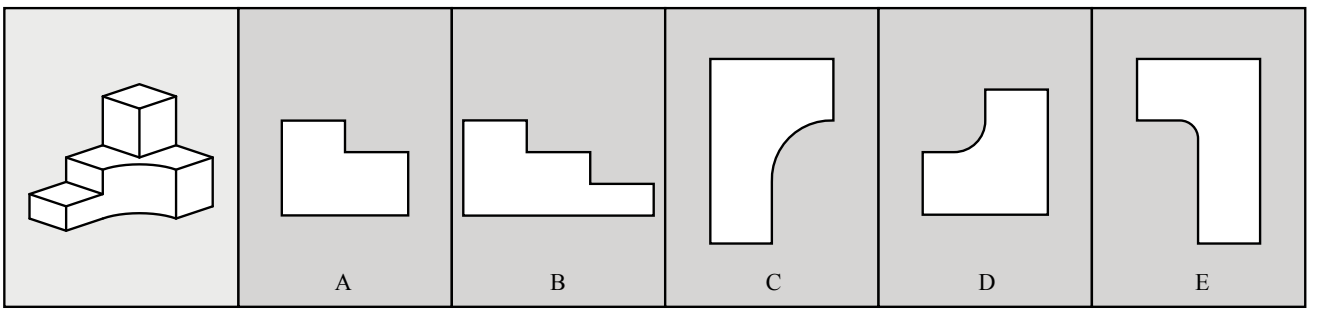
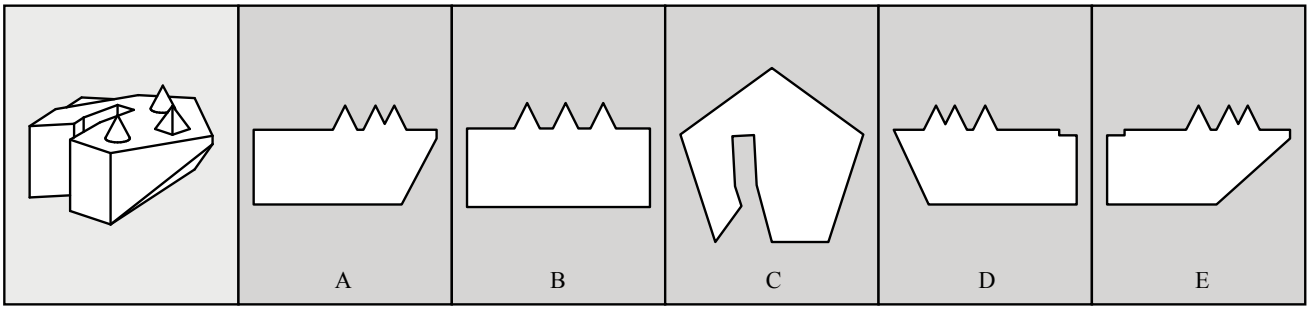


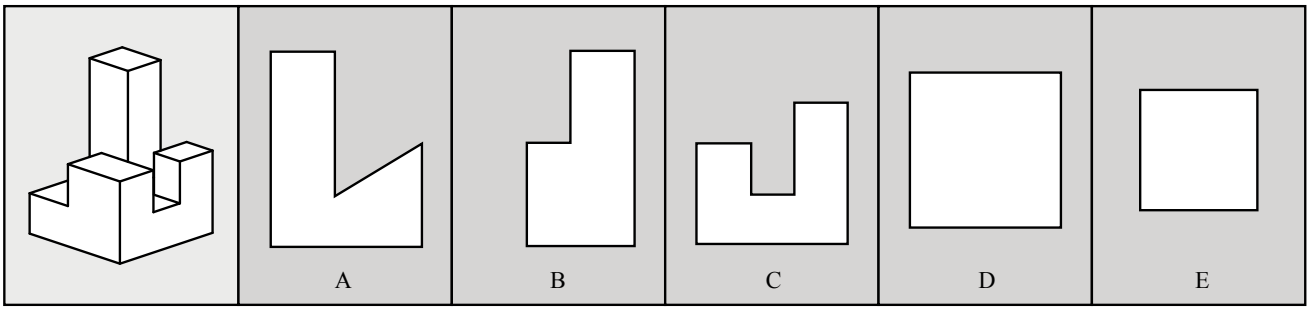
12.



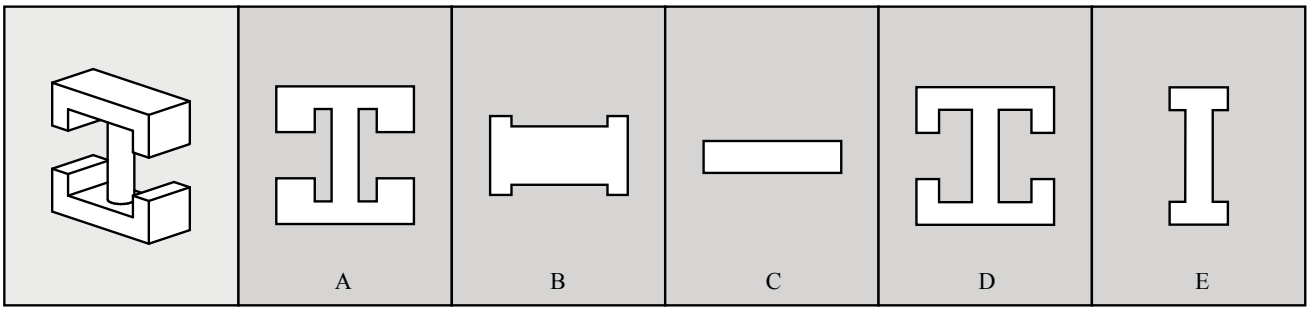
13.



14.

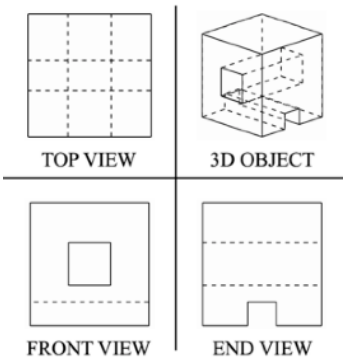


15.



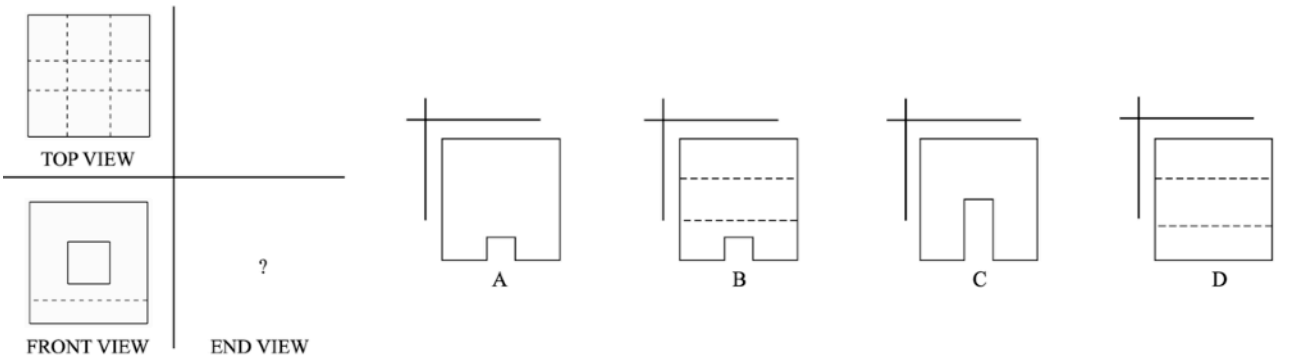
PART 2

For questions 16 to 30, the test contains questions similar to the example shown below. The top, front, and end projections of a three-dimensional object are shown. Edges that are obscured by parts of the object are shown as dotted lines, while edges that can be directly seen are shown as solid lines.



In each question, one of the three projections will be missing. Your task is to choose the projection that would complete the set of three projections in a manner consistent with the three-dimensional object (not shown).

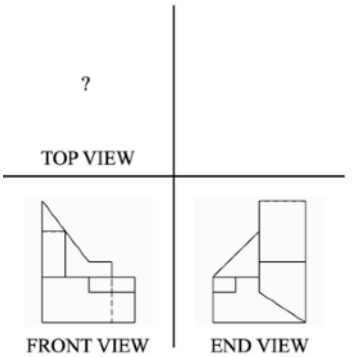
Example Question (Do NOT mark the answer to this example on your answer sheet)

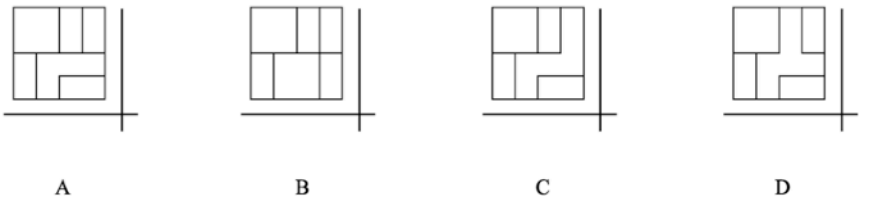


The correct answer is B because the object should have a rectangular tunnel at the bottom running left-to-right, and another square tunnel running front-to-back.

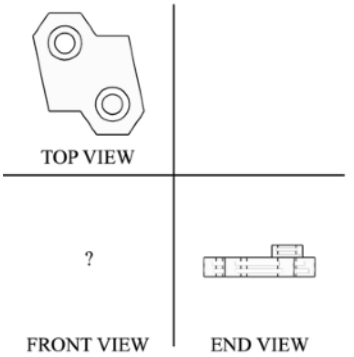
Please proceed to the questions

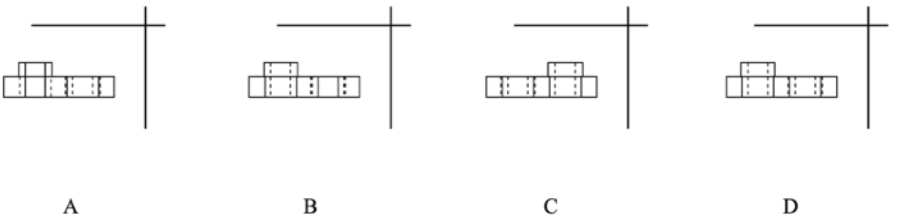
16. Choose the correct TOP VIEW



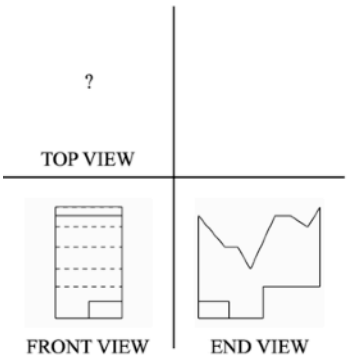


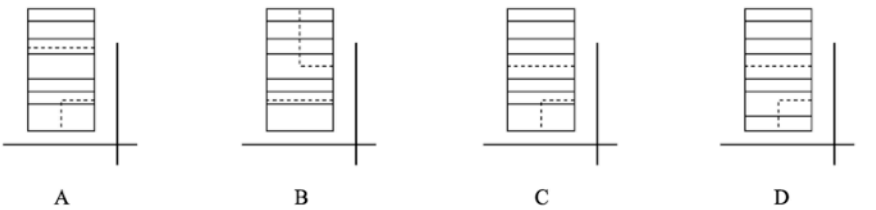
17. Choose the correct FRONT VIEW



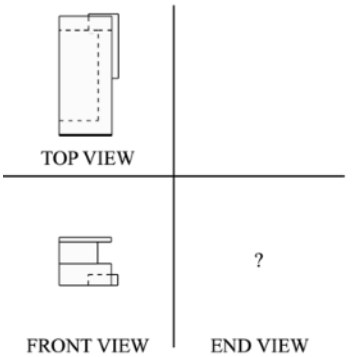


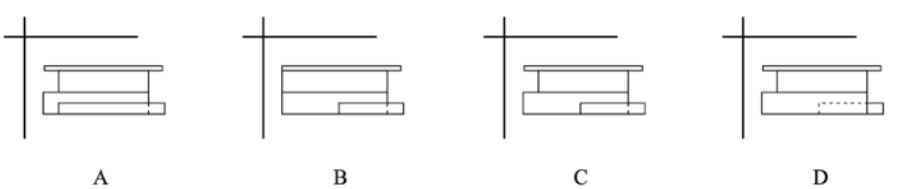
18. Choose the correct TOP VIEW



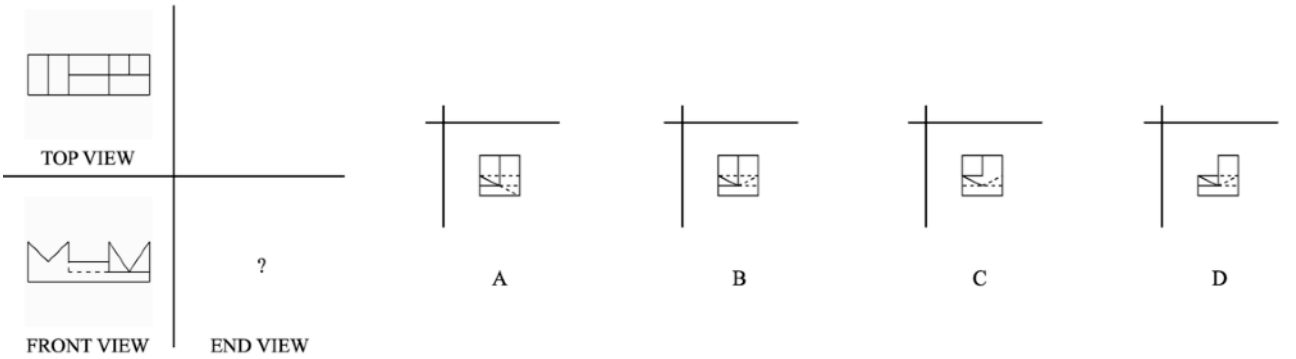


19. Choose the correct END VIEW

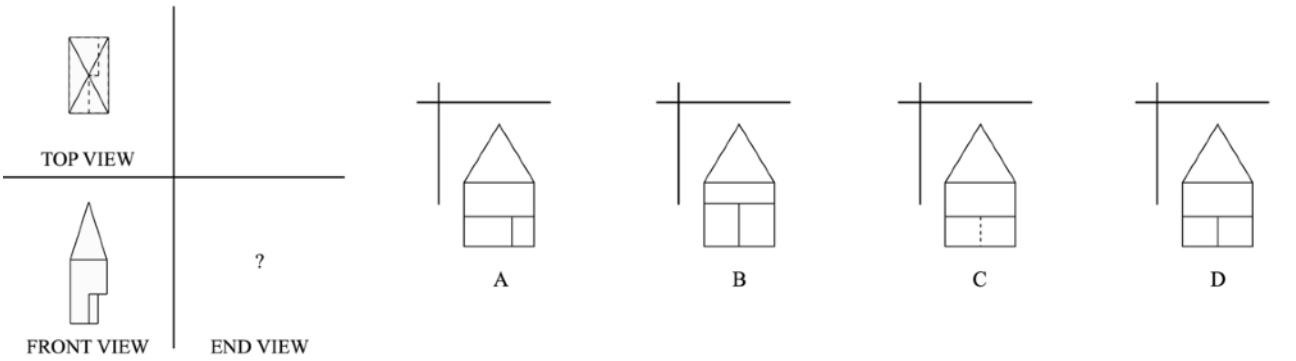




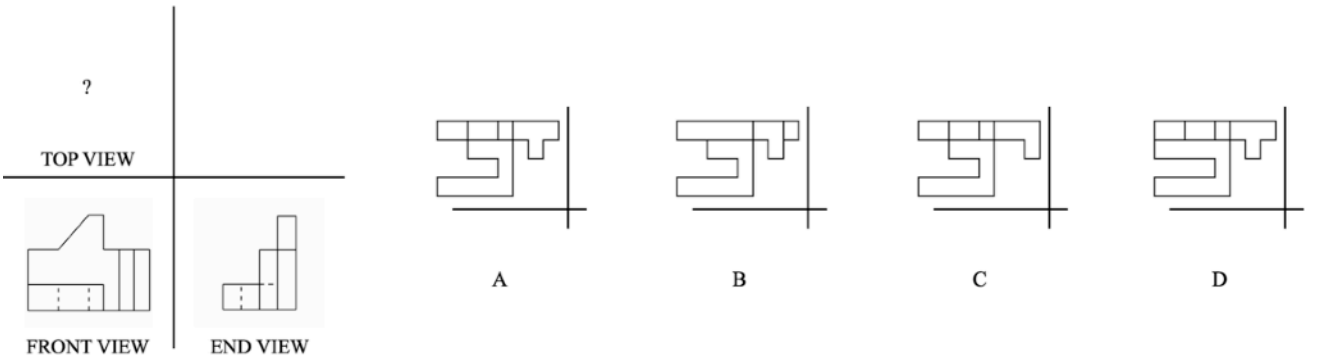
20. Choose the correct END VIEW



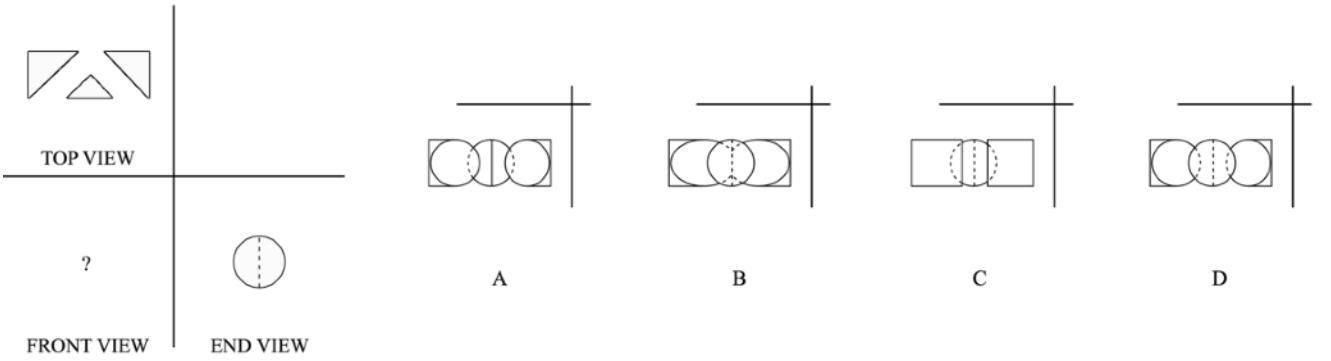
21. Choose the correct END VIEW



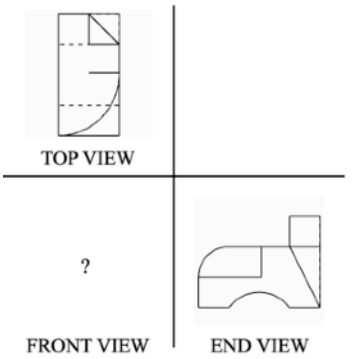
22. Choose the correct TOP VIEW

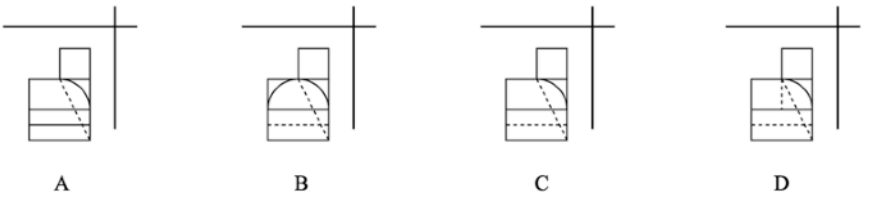


23. Choose the correct FRONT VIEW

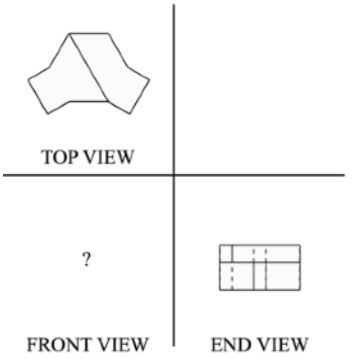


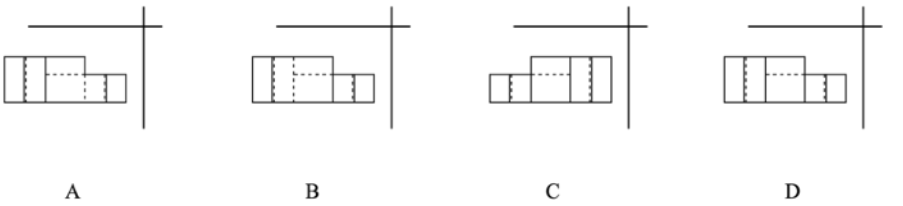
24. Choose the correct FRONT VIEW



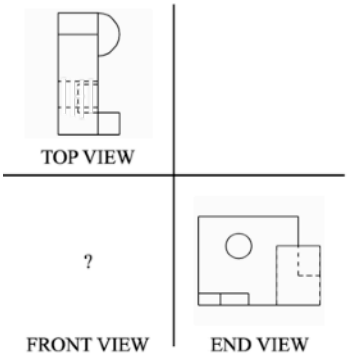


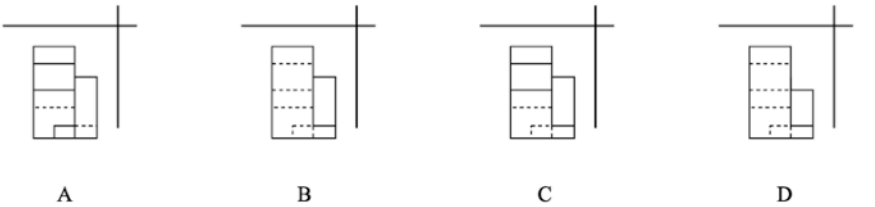
25. Choose the correct FRONT VIEW



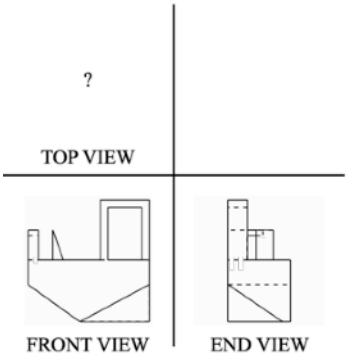


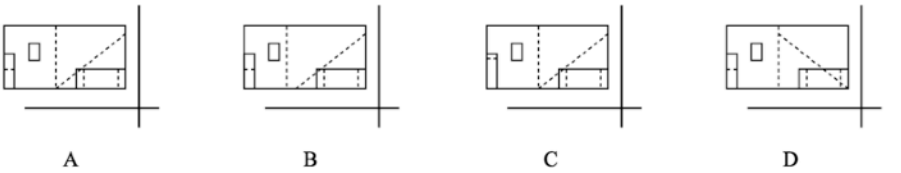
26. Choose the correct FRONT VIEW



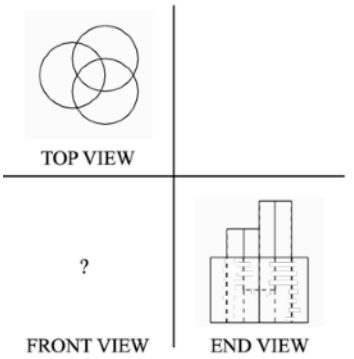


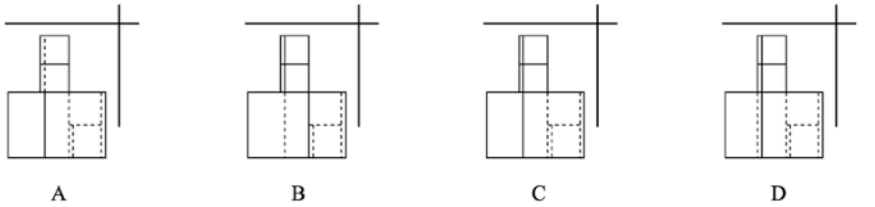
27. Choose the correct TOP VIEW



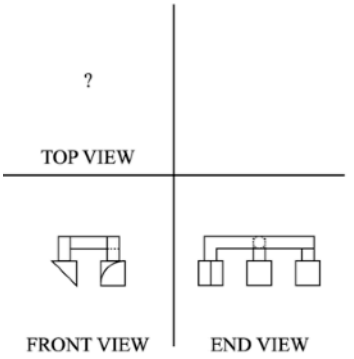


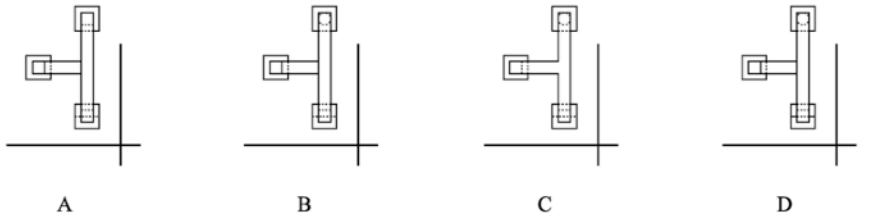
28. Choose the correct FRONT VIEW



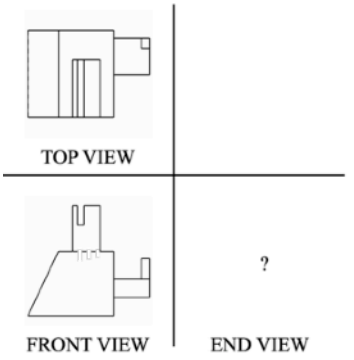


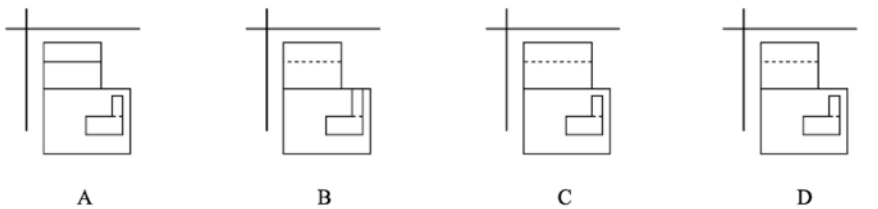
29. Choose the correct TOP VIEW





30. Choose the correct END VIEW

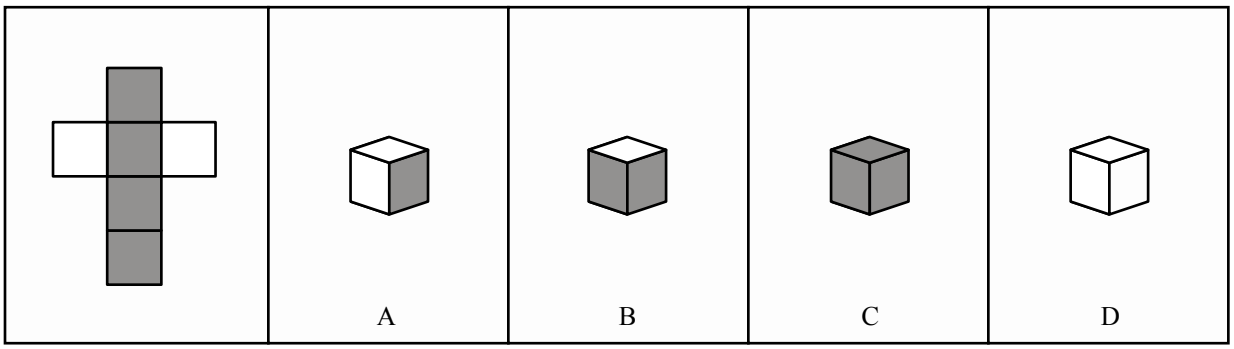




PART 6

For questions 76 to 90, the test contains two-dimensional patterns similar to the example shown below. This pattern is folded into the page, forming a three-dimensional figure. Your task is to mentally fold the two-dimensional patterns and select the correct three-dimensional figure out of the four presented.

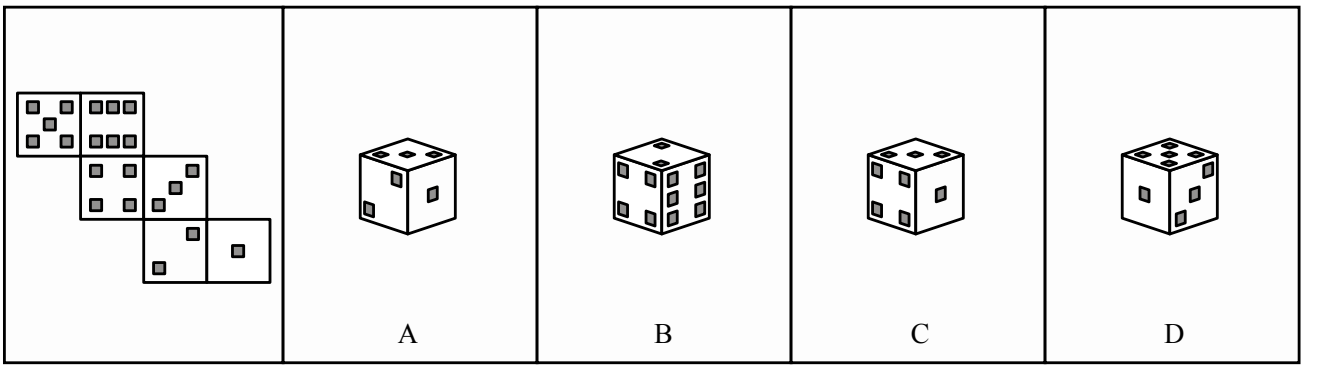
Example Question (Do NOT mark the answer to this example on your answer sheet)



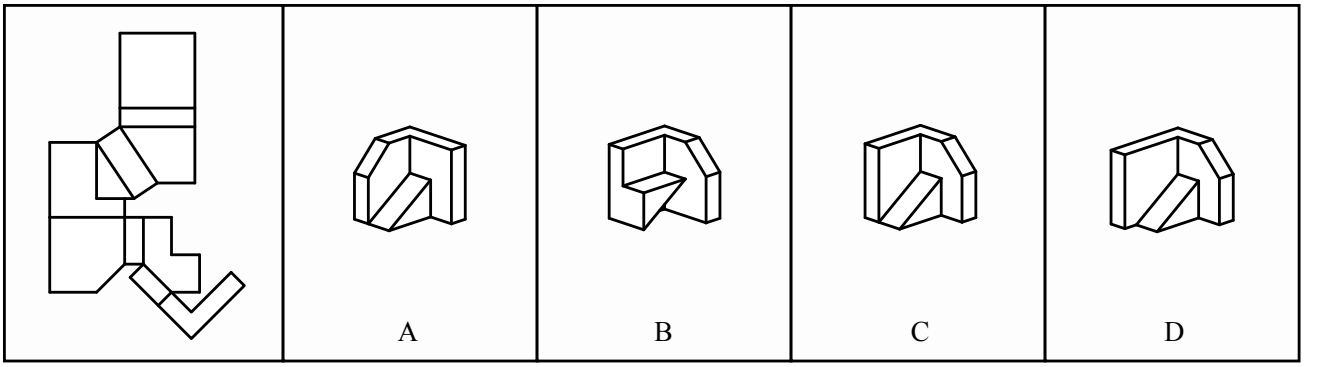
The correct answer is B, since it represents both the correct shape and pattern of shaded faces in the folded three-dimensional figure. There should be four shaded sides that exist side-by-side, and two unshaded sides on opposite ends of the cube.

Please proceed to the questions

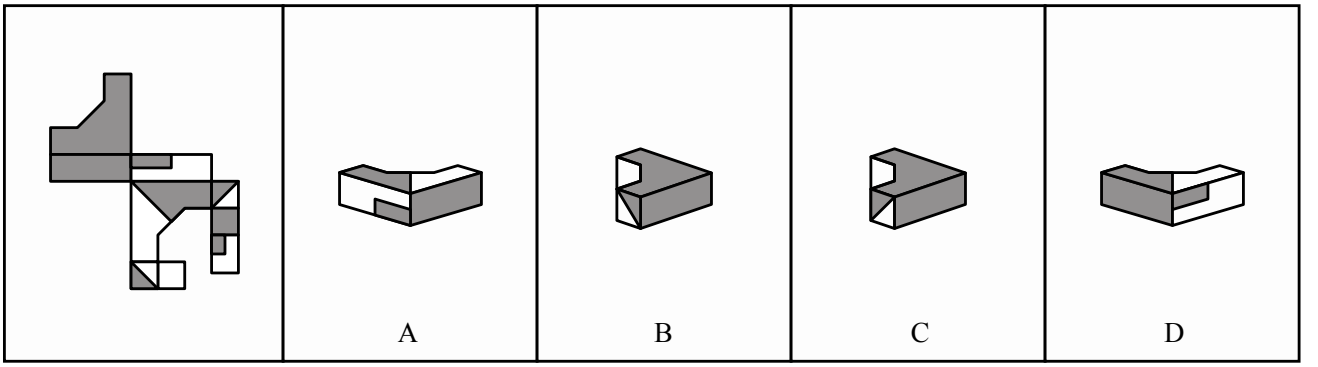
76.



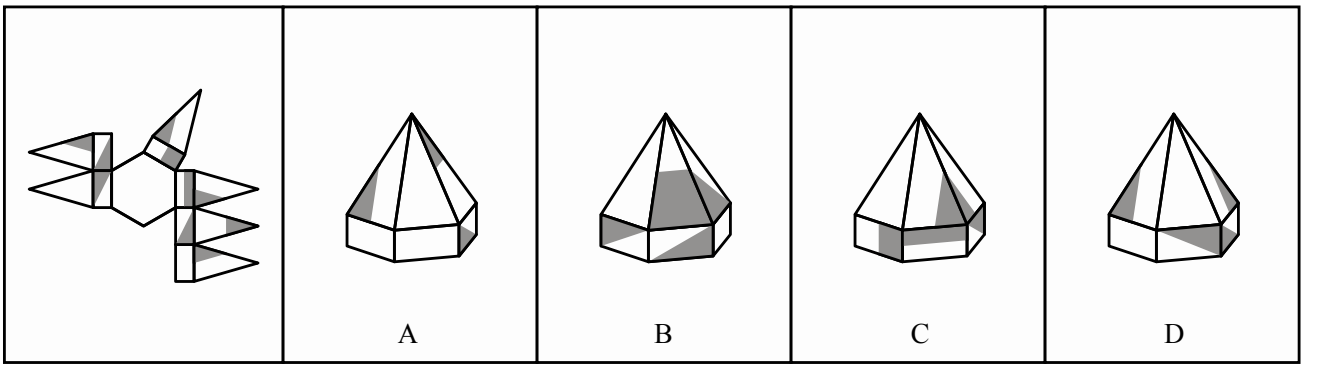
77.



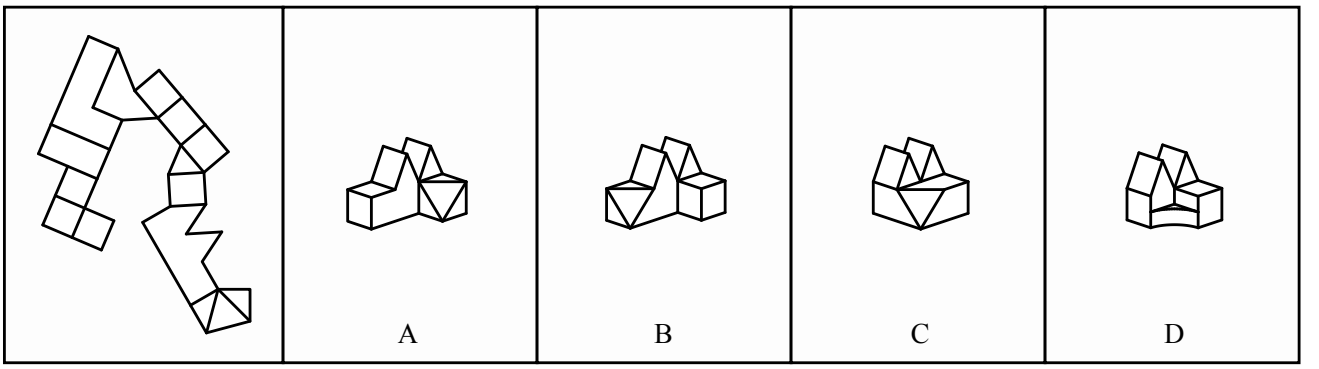
78.



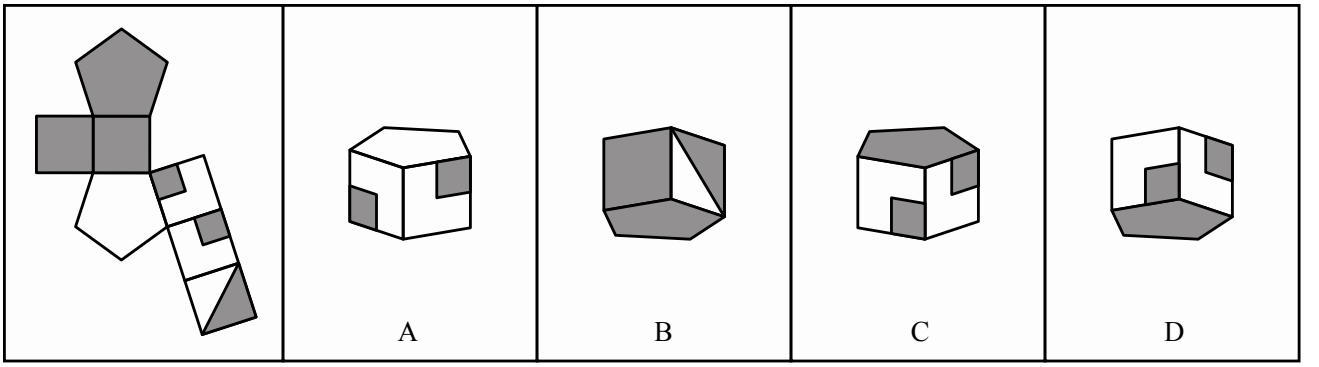
79.



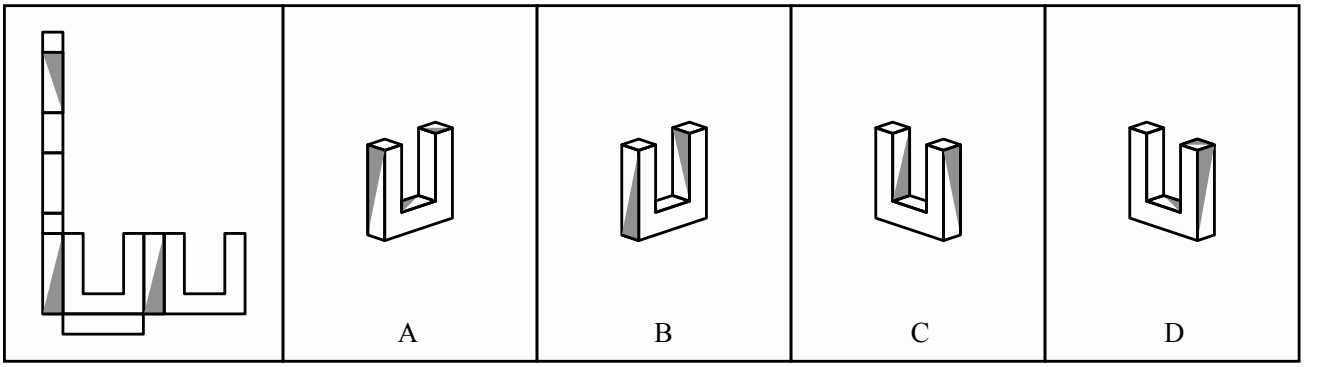
80.



81.



82.



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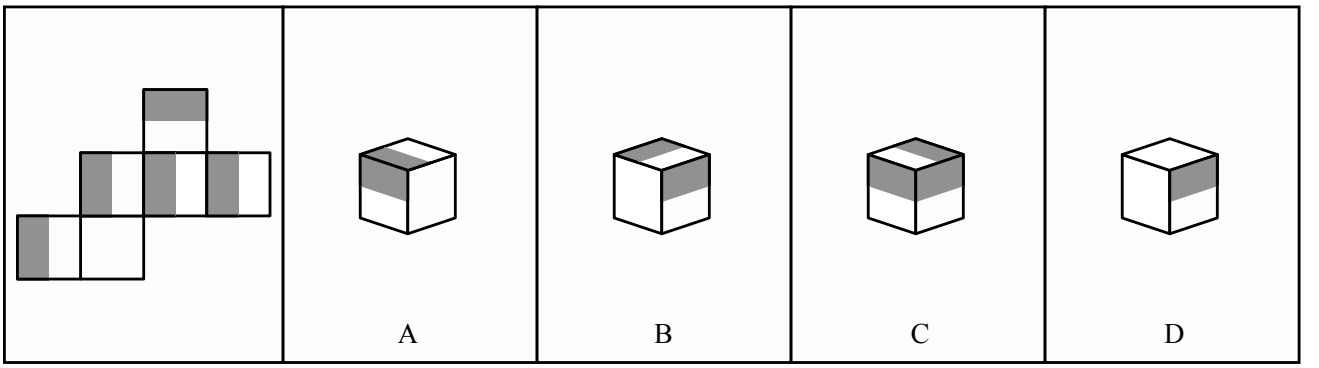

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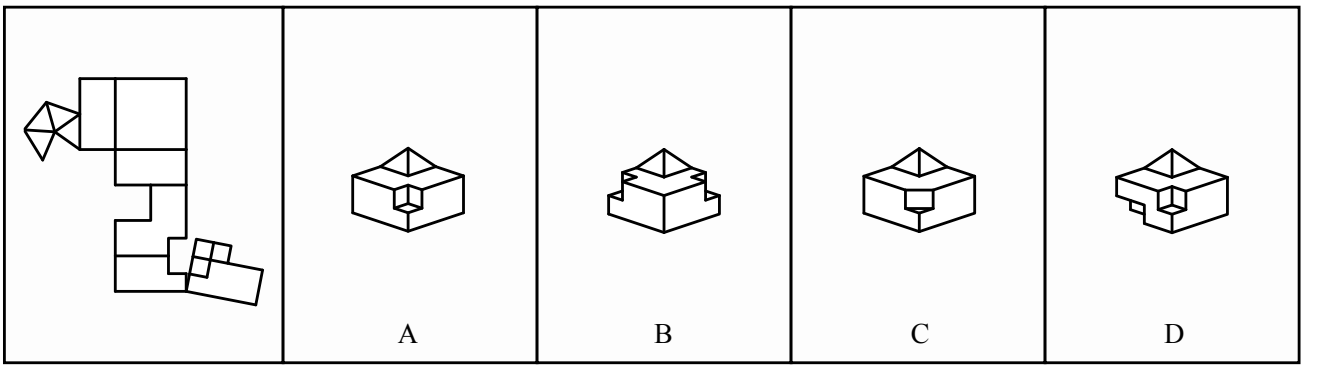

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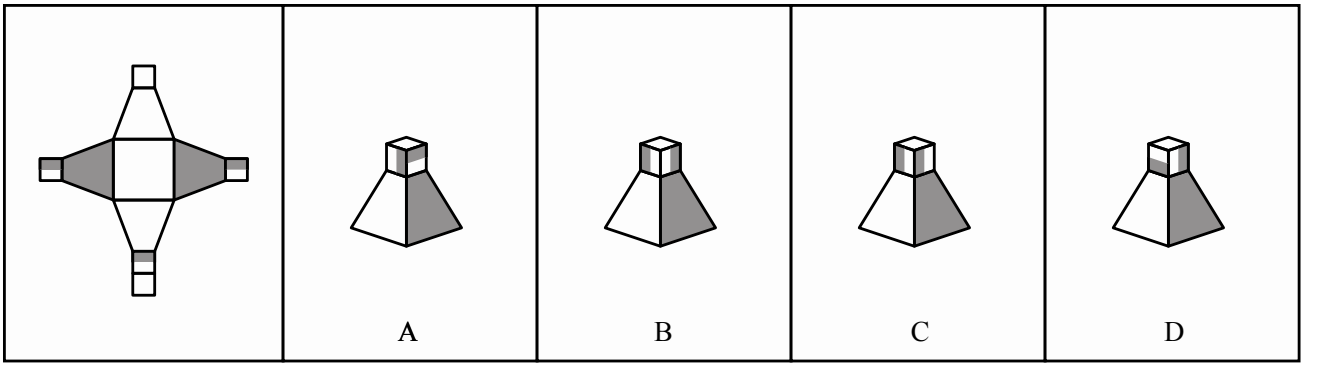

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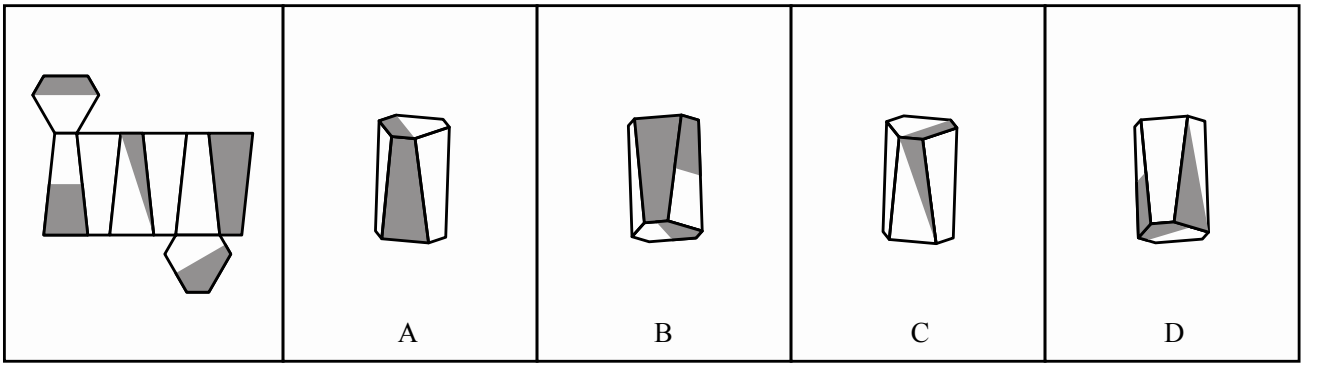

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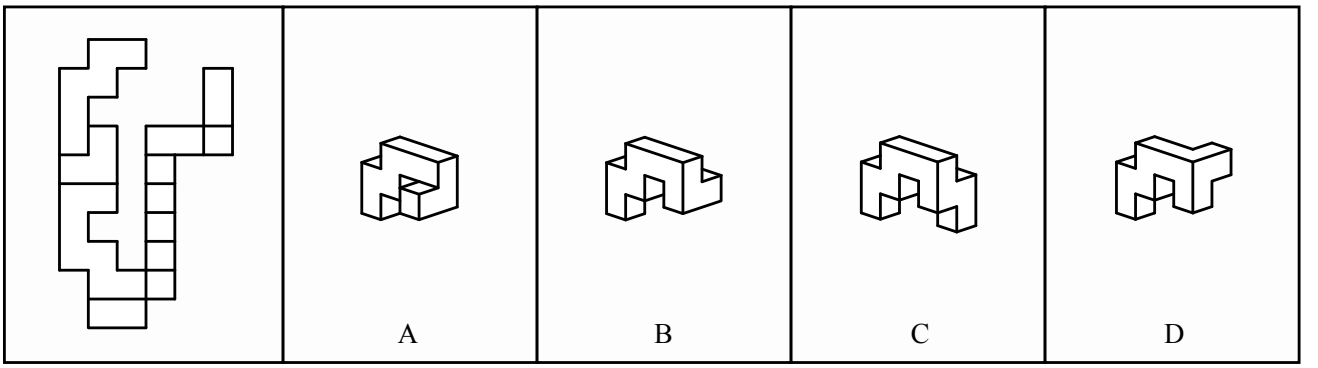

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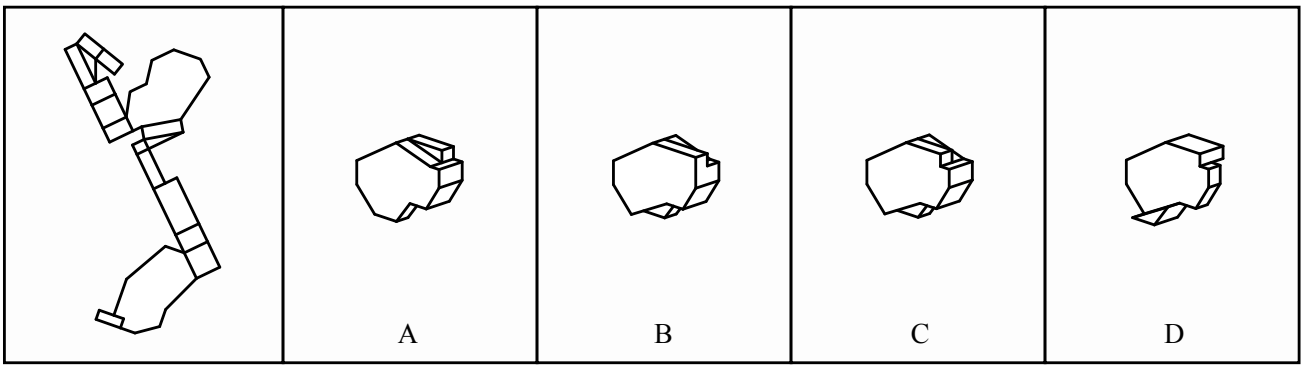

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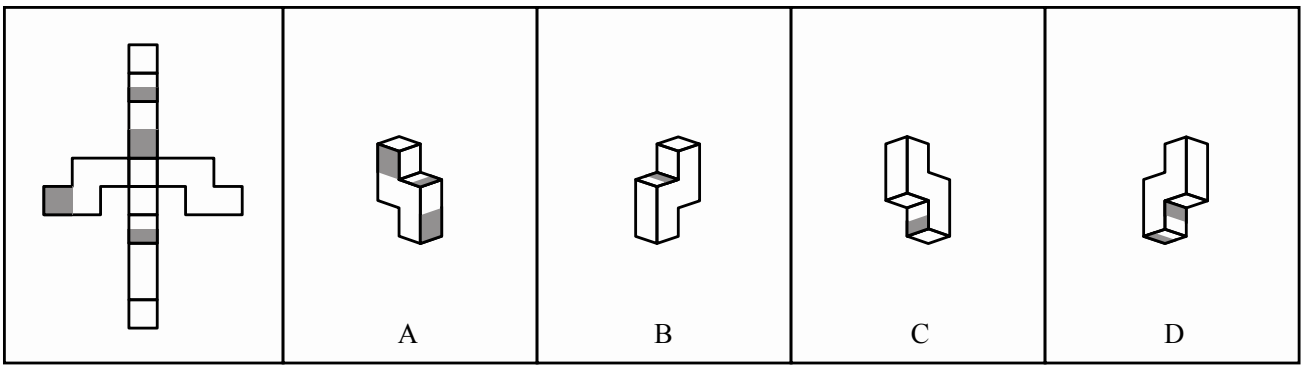

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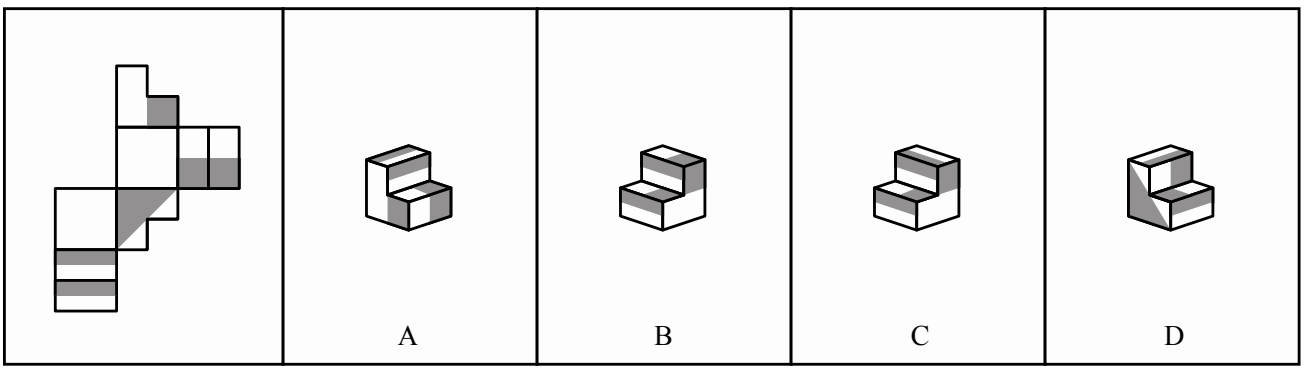


STOP

You have completed the PAT section of the DAT.
You will receive a 10 min break before the next section.

FULL-LENGTH 3 MEDIUM DIFFICULTY

READING COMPREHENSION TEST

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Reading Comprehension Test:

1. This test will evaluate your reading comprehension skills. It is composed of three passages. Reach each passage carefully, then proceed to the corresponding questions. Decide which of the presented choices best answers/completes the question/statement. Bubble in the appropriate answer choice on the answer sheet
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 50 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. At the end of this section, the answer sheet is collected and the Dental Aptitude Test simulation is now complete

TIME LIMIT:
50 minutes

TEST NAME:
RCT

TEST NUMBER:
03

This is a DAT simulation.

Passage 1

Devil Facial Tumour Disease

Devil facial tumour disease (DFTD) is an aggressive ulcerative cancer affecting Tasmanian devils (*Sarcophilus harrisii*), the largest species of carnivorous marsupial in the world. The disease is particularly well known for being transmissible via the allogenic exchange of cells during intraspecies fighting, which implicates biting behaviour. DFTD is highly lethal, with death occurring usually within six months of inoculation due to organ failure, secondary infection, or starvation. Between 1996 and 2015, DFTD has significantly impacted the Tasmanian devil species, decreasing population by 95% and making it officially recognized as an endangered species. However, the disease has had many complex and varied implications beyond the devil itself. Australia's ecologic, economic, and public health industries have all been impacted by the prevalence of DFTD. Three key aspects of this disease are transmission, global impact, and preservation.

In 1996, wildlife photographer Christo Baars set out to capture images of the iconic Tasmanian devil. Unintentionally, the photographer observed several devils with faces severely disfigured by large neoplasms – these photographs were the first known incidence of DFTD. Subsequently, many more devils were found with the same pattern of lesions, which often were lethal. Early scientists hypothesized that agricultural pesticides, organic chemicals, or retroviruses were responsible. However, in 2006, a devil that had escaped from a park was recaptured with bite marks. She later wounded a male, and both devils developed DFTD six months later. Evidently, the biting behaviour of devils was correlated to development of the disease. This particular case and many other epidemiological patterns of DFTD prompted cancer biologists to rethink the pathophysiology of cancer, ultimately producing the allograft theory of disease transmission.

The allograft theory was first proposed by A.M. Pearse et al. in a 2006 *Nature* paper. Pearse notes that in the late stages of DFTD, the tumours ulcerate, and fragments become easily dislodged during the devil's frequent fighting behaviour. The authors sampled jugular vein blood, bone marrow, skin, cancer tissue, and lymph nodes from a random mix of 11 wild and euthanized devils from across Tasmania. Cells were cultured and analyzed using G-banding, a cytogenetic technique that identifies chromosomal abnormalities by differentially staining euchromatin and heterochromatin in condensed chromosomes. The authors found that all of the 11 facial tumours analyzed consistently had the same chromosomal rearrangements (chr1 deletion, chrX deletion, chrY deletion, haploid chr6, chr1q deletion, and four unknown chromosomal fragments). The complex genotype and genetically identical nature of these neoplasms suggest that all 11 devils had the same tumour, which is inconsistent with human models of oncogenesis. Furthermore, a rare pericentric inversion detected in all cultures of one devil's normal tissue was absent in the facial tumour, suggesting the neoplasm did not arise from its own cells. This led scientists to hypothesize that DFTD is transmitted when cancer cells are passed directly between devils via biting behaviour.

Research in allograft theory has potential to not only improve management of DFTD, but many other conditions in companion animals and even humans. Unlike other transmissible tumours such as human papillomavirus (HPV), DFTD is non-viral. The only other non-viral transmissible cancer is canine transmissible venereal tumour (CTVT), which effects the genitalia of dogs and is sexually transmitted. DFTD is a significantly more recent disease and is invariably more lethal than CTVT, so the urgent need to develop therapies for devils may actuate the advancement of CTVT research by association. A.M. Pearse et al. suggest that the transmission mechanism of CTVT in dogs shares many features of allograft theory. Furthermore, both DFTD and CTVT have the potential to serve as animal models for post-organ-transplant cancer metastasis in humans, in which latent tumours from a donor are able to re-enter a proliferative state thanks to the recipient's immunocompromised condition. Additionally, DFTD is known for its ability to evade immune detection via the absence of major histocompatibility complex (MHC) class I molecules and the production of immunosuppressive cytokines. This is similar to how many human cancers modulate the anti-tumour response by reducing their immunogenicity. Experimental immunotherapies or vaccines for DFTD can therefore be applied to research combatting post-transplant metastasis in

humans. The novelty of DFTD as a non-viral cancer transmissible via allograft has made it of great importance for health research. However, the disease also has significant economic, cultural, and environmental effects.

As early as 1830, the devil was treated as a pest by the agricultural industry and culled in large numbers. In fact, Tasmanian devils have a very high degree of genetic similarity because of a population bottleneck during the 1900s that resulted in widespread inbreeding. This is a contributing factor to DFTD's high transmissibility between individuals and low immunogenicity, as discussed earlier. Farmers incorrectly attributed their livestock losses to packs of devils hunting weak sheep. However, it is now known that devils actually have a net positive effect on the ecological niche by exhibiting scavenging behaviour that helps clear away decomposing carcasses and roadkill that could spread disease. By removing reservoirs for zoonotic pathogens such as lymphocytic choriomeningitis virus and *Toxoplasma gondii*, devils reduce the transmission of both animal and human disease. Additionally, Tasmanian farmers benefit from the speed at which carcasses are eliminated, which makes it difficult for even insects to spread and cause harm to livestock. Ultimately, animal agriculture is a 1.53 billion-dollar (USD) industry that would significantly impact the Tasmanian economy even if livestock mortality were to increase marginally.

Another major economic effect of DFTD is on global tourism. From 2010-11, 8% of Australia's total export earnings were attributable to tourism. From 2014-15, tourism represented 3% of Australia's GDP, considerably higher than many countries including Canada (in which tourism accounts for only 1% of GDP). Tasmania's national parks and unique geography help make it the destination of choice for a significant portion (16%) of visitors to Australia. Animals such as the devil play a large role in creating this allure for foreign visitors, through both official representation and popular culture. It is the mascot of the Tasmanian tourism industry, National Parks and Wildlife Service, the former football team, and has even been adapted for a popular Warner Bros. cartoon series. The devil is a ubiquitous and iconic cultural symbol for the island state. Thus, in order for the tourism industry to be sustainable, care needs to be taken to protect the species from extinction. This is why research in DFTD prevention and management is not only an investment in the endangered animal, but also an investment in Australia's national interests and ultimately in the well-being of humans.

Another factor that the Tasmanian tourism industry is so dependent on is wildlife. The devil's position as a top predator in the ecosystem's food web means it is responsible for modulating the size of prey populations. Removal of the devil may lead to population explosions of herbivores such as the wombat, in turn leading to a top-down trophic cascade resulting in defoliation of their habitat. Because of this, these animals may then encroach onto human settlements, thus negatively effecting residential areas. Disruptions in Tasmania's ecosystems would be difficult to correct, since the island's fauna is isolated and distinct from that of mainland Australia. Therefore, the devil is demonstrated to have vast implications on Tasmania's ecology and its extinction would be a devastating hit to overall Tasmanian biodiversity.

Early efforts at controlling the DFTD epidemic involved field-level work such as the monitoring of disease propagation and the early trapping/culling of infected devils to reduce disease prevalence. On a legislative level, in 2003 the Tasmanian government established the Save the Tasmanian Devil Program (STDP), their official response to the threat of DFTD. STDP is responsible for the establishment of a disease-free "insurance" population on Marina Island, located off the east coast of Tasmania. The program aims to retain up to 95% of the wild population's genetic diversity. Devils that retire from the insurance population enter world-class zoos as "ambassadors" for conservation. Aside from captive breeding, the program has also led to the development of a diagnostic blood test capable of pre-clinical screening, using a biomarker-based approach similar to that of the human pharmaceutical industry. Oocyte vitrification has even been explored as a way to reduce loss of genetic diversity in the event of an extinction.

The line between human and animal medicine is becoming increasingly blurred in today's society, a trend exemplified by the 2015 vaccine breakthrough that resulted from the application of immunotherapy to DFTD. In the study, Kreiss *et al.*

inactivated 108 DTFD tumour cells via freeze/thawing or sonication. The cell suspension was paired with various adjuvants and injected subcutaneously into six devils according to various immunization schedules. After one year, two devils were challenged with a subcutaneous injection of viable tumour cells into the oral mucosa or cheek. Jugular blood was drawn 14 days before and after each immunization and analyzed for antibody response via flow cytometry, enzyme-linked immunosorbent assay (ELISA), and western blot. Cell-mediated immune response was detected using a radioactive chromium release assay. Results showed that a humoral immune response (increase in DFTD-specific antibodies) was detected after vaccine administration in five of the six devils, and cytotoxic responses similarly increased. One of the two challenged devils demonstrated short-term protection (1 year) against tumour inoculation. This study suggests that the devil's immune system can be trained using a vaccine to mount both a humoral and cell-mediated immune response against DFTD cells [30]. Since the majority of human cancer vaccines (Sipuleucel-T, BiovaxID, Oncophage, etc.) are therapeutic immunostimulants and not preventative agents, fabrication of the DFTD vaccine may serve as point of insight for scientists working on ways to proactively treat human cancers. Ultimately, innovations in human medicine can help us improve ecosystem health, and vice versa.

In summary, DFTD is a contagious cancer affecting Tasmanian devils that has a multitude of effects on the human condition. Research into the transmission of the disease has revolutionized the way cancer biologists conceptualize oncogenesis and has increased the motivation for scientists to develop therapies for CTVT and even human cancers. Historically, DFTD has had a significant positive impact in Australian ecology, tourism, farming, public health, and culture. Preservation responses for Tasmanian devils has led to the development of a novel prophylactic cancer vaccine, the theory of which may one day be applied to human cancers. DFTD is a fairly recent disease—the "patient zero" event causing the DFTD epidemic occurred sometime during the 21st century. Given that we are fortunate to be in this era of incredible medical advancement, this puts us in a unique and very promising position to eventually eradicate the disease and save the endangered devils from extinction.

1. The first case of DFTD was discovered by which of the following?
   A. A veterinarian
   B. An oncologist
   C. An Australian researcher
   D. A wildlife photographer
   E. A Tasmanian farmer

2. Which of the following correctly describes the allograft theory of disease transmission?
   A. DFTD is spread via sexual intercourse
   B. Pesticides and organic chemicals cause spontaneous DFTD
   C. DFTD is transmitted via retroviruses
   D. DFTD is transmitted via airborne droplets
   E. DFTD is transmitted via biting

3. Which of the following is NOT a potential cause of death in Tasmanian devils with DFTD?
   A. Starvation
   B. Organ failure
   C. Pulmonary embolism
   D. Secondary infection

4. How is DFTD different from HPV and CTVT, respectively?
   A. DFTD is bacterial; DFTD is not contagious
   B. DFTD is non-viral; DFTD is not sexually transmitted
   C. DFTD causes latent tumours; DFTD is not spread through allograft theory
   D. DFTD is non-viral; DFTD is far less lethal
   E. DFTD affects animals instead of humans; DFTD is not sexually transmitted

5. What scientific journal was the allograft theory of disease transmission first published in?
   A. Science
   B. The Lancet
   C. Nature
   D. The Journal of Infectious Diseases
   E. PLOS Pathogens

6. Tasmanian devils can reduce the transmission of disease by removing reservoirs for zoonotic pathogens such as canine transmissible venereal tumour (CTVT)
   A. Both the statement and reason are correct and related
   B. Both the statement and reason are correct but NOT related
   C. The statement is correct but the reason is NOT
   D. The statement is NOT correct, but the reason is correct
   E. NEITHER the statement NOR the reason is correct

7. What does the author describe as three key aspects of DFTD?
   A. Pathophysiology, transmission, social impact
   B. Transmission, pathophysiology, preservation
   C. Global impact, preservation, transmission
   D. Transmission, prevention, education
   E. Economy, ecology, public health

8. Which of the following chromosomal arrangements was NOT found in the 11 facial tumours from wild and euthanized devils?
   A. Chr1q duplication
   B. ChrX deletion
   C. Haploid Chr6
   D. ChrY deletion
   E. Chr1 deletion

9. During what year did Tasmanian devils experience a population bottleneck?
   A. 1996
   B. 2006
   C. 1830
   D. 1900
   E. 2001

10. How is DFTD similar to post-transplant metastasis?
    A. Both conditions are contagious
    B. In both situations, the cancer is able to bypass the immune system
    C. Both conditions are more common in immunocompromised patients
    D. In both situations, the cancer does not contain MHC I surface markers
    E. Both diseases have significant economic, cultural, and environmental effects

11. Which of the following statements would the author most likely agree with?
    A. The Tasmanian devil is an insignificant species for Australia's well-being
    B. Captive breeding is an effective strategy to preserve the devil species
    C. Killing infected devils is morally acceptable
    D. Tasmanian farmers were unknowingly harming themselves by killing the devils
    E. Scientists are unlikely to find a cure for DFTD

12. Which of the following lab techniques were NOT used in the study by Kreiss *et al.*?
    A. Western blotting
    B. ELISA
    C. Flow cytometry
    D. Sonication
    E. G-banding

13. Which of the following is NOT a human cancer vaccine?
    A. STDP-1
    B. BiovaxID
    C. Oncophage
    D. Sipuleucel-T

14. What is the main idea of the second last paragraph?
    A. Humoral and cell-mediated immune responses can be mediated by vaccines
    B. STDP, captive breeding, blood testing, and oocyte vitrification are some of the efforts made in controlling DFTD
    C. Influenza kills 10 times more animals than DFTD annually
    D. Advances in human and animal medicine can be used to inform each other
    E. Many principle in human and animal medicine are identical and interchangeable

15. Which of the following is NOT a positive outcome of DFTD's existence?
    A. Fabrication of a DFTD vaccine may provide insight for human cancer vaccines
    B. Increased motivation for the research and development of CTVT therapies
    C. Reduction of animal encroachment onto human settlements
    D. The disease revolutionized the way cancer biologists conceptualize oncogenesis
    E. Development of a novel prophylactic cancer vaccine

16. The first case of DFTD occurred in sometime during the 20th century.

    Evidence that suggested biting behaviour could transmit DFTD was first discovered in 2006.
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

17. What is the author's tone in the last paragraph?
    A. Impartial
    B. Satirical
    C. Sarcastic
    D. Optimistic
    E. Ambivalent

18. In which paragraph does the author discuss the history of the Tasmanian devil species?
    A. Paragraph two
    B. Paragraph three
    C. Paragraph four
    D. Paragraph five
    E. Paragraph six

19. In paragraph eight, why does the author use quotes around the words "insurance" and "ambassadors"?
    A. To indicate dislike or contempt for the words
    B. To suggest skepticism
    C. To indicate that they are not his/her own words
    D. To highlight the irony of the words
    E. To indicate that the words are too superfluous for the relatively mundane subject they describe

Passage 2

Antifluoridationists

Fluoride is a mineral that occurs naturally in most water supplies. Fluoridation is the adjustment of the natural fluoride concentration to about one part of fluoride to one million parts of water. Although fluoridation is safe and effective in preventing tooth decay, the scare tactics of misguided poisonmongers have deprived many communities of its benefits.

The history of fluoridation in the United States underlines its unique standing as a public health measure copied from a natural phenomenon. In the early 1900s, Dr. Frederick S. McKay began an almost 30-year search for the cause of the staining of teeth that was prevalent in Colorado, where he practiced dentistry. In his investigation, McKay found the condition common in other states, including Texas, where it was known as "Texas teeth." In 1928, he concluded that such teeth, although stained, showed "a singular absence of decay," and that both the staining and the decay resistance were caused by something in the water. In 1931, the "something" was identified as fluoride.

The Public Health Service then took over to determine precisely what amount of fluoride in the water would prevent decay without causing staining. Years of "shoe leather epidemiology" by Dr. H. Trendley Dean traced the dental status of 7,000 children who drank naturally fluoridated water in 21 cities in four states. In 1943, he reported that the ideal amount of fluoride was one part per million parts of water. This concentration was demonstrated to result in healthy, attractive teeth that had one-third as many cavities as might otherwise be expected—and no staining.

The next step was to determine whether water engineering could copy nature's amazing dental health benefit. At several test sites, the fluoride concentration of the public water supply was adjusted to one part per million. One such test was conducted in the neighbouring cities of Newburgh and Kingston, New York. First, the children in both cities were examined by dentists and physicians; then fluoride was added to Newburgh's water supply. After ten years, the children of Newburgh had 58% fewer decayed teeth than those of non-fluoridated Kingston. The greatest benefits were obtained by children who had drunk the fluoridated water since birth. Other studies showed that teeth made stronger by fluoride during childhood would remain permanently resistant to decay. As the evidence supporting fluoridation accrued, thousands of communities acted to obtain its benefits.

Recent data have shown that fluoridation has been reducing the incidence of cavities 20% to 40% in children and 15% to 35% in adults. The reduction is less than it used to be, probably due to improved dental hygiene and widespread use of fluoride toothpaste. Currently, more than 140 million Americans live in fluoridated communities. But 80 million others receive public water supplies that are not fluoridated—thanks largely to the efforts of poisonmongers.

The antifluoridationists' ("antis") basic technique is *the big lie*. Made infamous by Hitler, it is simple to use, yet surprisingly effective. It consists of claiming that fluoridation causes cancer, heart and kidney disease, and other serious ailments that people fear. The fact that there is no supporting evidence for such claims does not matter. The trick is to keep repeating them—because if something is said often enough, people tend to think there must be some truth to it.

A variation of the big lie is the *laundry list*. List enough "evils," and even if proponents can reply to some of them, they will never be able to cover the entire list. This technique is most effective in debates, letters to the editor, and television news reports. Another variation is the simple statement that fluoridation doesn't work. Although recent studies show less difference than there used to be in decay rates between fluoridated and non-fluoridated communities, the benefit is still substantial. In fact, the Public Health Service estimates that every dollar spent for community fluoridation saves about fifty dollars in dental bills.

A key factor in any anti campaign is the use of printed matter. Because of this, antis are very eager to have their views printed. Scientific journals will rarely publish them, but most local newspapers are willing to express minority viewpoints regardless of

whether facts support them. A few editors even welcome the controversy the antis generate—expecting that it will increase readership.

The aim of anti "documents" is to create the illusion of scientific controversy. Often they quote statements that are *out of date* or *out of context*. Quotes from obscure or hard-to-locate journals are often used. Another favoured tactic is to *misquote* a pro-fluoridation scientist, knowing that even if the scientist protests, the reply will not reach all those who read the original misquote.

Half-truths are another commonly used tactic. For example, saying that fluoride is a rat poison ignores the fact that poison is a matter of dose. Large amounts of many substances—even pure water—can poison people. But the trace amount of fluoride contained in fluoridated water will not harm anyone.

"*Experts*" are commonly quoted. It is possible to find someone with scientific credentials who is against just about anything. Most "experts" who speak out against fluoridation, however, are not legitimate experts on the subject. There are, of course, a few dentists and physicians who oppose fluoridation. Some of them object to fluoridation as a form of government intrusion, even though they know it is safe and effective.

The *innuendo* is another technique that has broad appeal because it can be used in a seemingly unemotional pitch. Some antis admit that fluoridation has been found safe "so far," but claim that its long-range effects have "not yet" been fully explored. *The waiting game* is a related gambit in which antis suggest that waiting a bit longer will help to resolve "doubt" about fluoridation's safety. No doubt, some antis will continue to use this argument for a few hundred more years.

A few antis have offered a "*reward*" for proving that fluoridation is safe. During the 1970s, a $100,000 offer required the pros to post a bond "to cover any costs which the offerers of the reward might incur if the proof is deemed invalid." The offer did not state who would judge the evidence, but it was safe to assume that the antis themselves would have appointed the judges. If a suit had been filed to collect the reward, the court might have ruled that the offer was a gambling bet that should not be enforced by a court. Such a suit would have required at least $25,000 for the bond and legal fees. Even if it had been won, however, there was no assurance that the money would have been recovered from the individuals who sponsored the reward. Most of them were elderly and scattered widely throughout the United States and Canada.

In conclusion, fluoridation is supported by libraries of articles that document its safety and effectiveness—more so than any other public health measure. It is supported by a variety of health, scientific, and civic groups that could hardly be expected to agree on any other single measure. If you live in a community with fluoridated water, consider yourself lucky. If you do not, don't let the poisonmongers scare you. Fluoridation is still a modern health miracle.

Adapted from *Fluoridation: Don't Let the Poisonmongers Scare You, 1993* by Bob Sprague, Mary Bernhardt, and Stephen Barrett, M.D. Reproduced with permission.

20. Which of the following describes a similarity between the citizens of Texas and Colorado?
    A. The teeth of people from Texas were stained, while the teeth of people from Colorado showed more decay
    B. The teeth of people from both Texas and Colorado showed no staining but more decay
    C. The teeth of people from Texas showed more decay, while the teeth of people from Colorado were stained
    D. The teeth of people from both Texas and Colorado showed no decay but were stained
    E. The teeth of people from both Texas and Colorado showed both staining and decay

21. The author describes Frederick S. McKay as practicing “shoe leather epidemiology”.

    Fluoridation has been shown to increase the incidence of cavities from 20 to 40%
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

22. What is the concentration of fluoridated tap water in parts per million?
    A. 1 ppm
    B. 2 ppm
    C. 3 ppm
    D. 10 ppm
    E. 20 ppm

23. Which of the following statements is the author LEAST likely to agree with?
    A. The fluoridation of water is an entirely man-made and artificial phenomenon
    B. Individuals who spread misinformation about fluoridation are a risk to public health
    C. There is an ideal concentration of fluorine
    D. Tap water fluoridation will actually save a community money in the long term
    E. The majority of Americans live in communities with fluoridated water

24. Which of the following diseases is NOT discussed by antifluoridationists in order to scare people?
    A. Kidney disease
    B. Cancer
    C. Alzheimer's disease
    D. Heart disease

25. What is the author's tone throughout the passage?
    A. Impartial
    B. Analytical
    C. Cynical
    D. Argumentative
    E. Solemn

26. In paragraph four, what is the author describing with the phrase "water engineering"?
    A. The underground infrastructure for water distribution in cities
    B. The filtration of heavy metals and other impurities from tap water
    C. The replacement of natural water with an artificial substitute
    D. The alteration of the chemical composition of tap water
    E. The construction of pumping facilities

27. Newburgh was the first city in New York to have artificially fluoridated tap water.

    Newspaper editors often allow antifluoridationists to publish articles in order to generate controversy
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

28. Which of the following best describes the "laundry list" tactic?
    A. Quote statements that are either out of date or out of context
    B. Quote people who claim to be experts
    C. Make a statement that conveys only part of the truth, in order to deliberately deceive
    D. Make a large number of arguments such that opponents are overwhelmed
    E. Make a fear-inducing statement that is blatantly false

29. During what year was fluoride found to be the chemical responsible for the "Texas teeth" phenomenon?
    A. 1900
    B. 1943
    C. 1931
    D. 1928
    E. 1970

30. Which of the following is NOT a reason why the author distrusts any "rewards" offered by antifluoridationists?
    A. It is unknown who would judge the evidence provided by profluoridationists
    B. An upfront payment is requested to cover "any costs associated if the evidence is deemed invalid"
    C. If a lawsuit is filed to collect the award, the courts would likely not enforce the offer
    D. There is no guarantee that any money would be recovered, since all antifluoridationists reside under American jurisdiction
    E. The cost of a potential lawsuit to collect the award would be at least $25,000

31. Which of the following techniques does the author expect antifluoridationists to use for years to come?
    A. Innuendo
    B. The big lie
    C. The laundry list
    D. The waiting game
    E. Half-truths

32. Anti-vaccine parents often argue that since the efficacy of a new vaccine have not yet been fully proven, we should not vaccinate our children. This falls under which of the following tactics?
    A. The big lie
    B. Half-truths
    C. The laundry list
    D. Innuendo
    E. Misquote

33. What is the purpose of this paragraph?
    A. To convince the reader that fluoridation is safe and has no side effects
    B. To educate the reader about the importance of fluoridation and how to recognize scare tactics used by antifluoridationists
    C. To inform the reader of the history of tap water fluoridation, as well as future plans
    D. To explain how antifluoridationists prevented widespread tap water fluoridation in America
    E. To illustrate the logistical and mechanical infrastructure behind tap water fluoridation

34. Which of the following groups is NOT mentioned by the author to be in agreement with profluoridationists?
    A. Scientific groups
    B. Civic groups
    C. Bureaucratic groups
    D. Health groups

Passage 3

Sexual Selection in Honeybees

Apis mellifera, commonly known as the European honeybee, is an economically important eusocial insect. Along with being responsible for products such as honey, beeswax, and bee propolis, *A. mellifera* is also used by many farmers to pollinate important food crops. Without honeybees, food production would be a lot more labour intensive.

Being eusocial, and practicing haplodiploidy, *A. mellifera* has a particularly unorthodox reproductive arrangement. Honeybee queens lay both fertilized and unfertilized eggs–fertilized eggs become female bees (A.K.A. workers) and unfertilized eggs become male bees (A.K.A. drones). So, all female honeybees–that is, queens and workers–are diploid, and drones are haploid. Only queens can mate with drones, and only queens can lay diploid eggs. Some workers are capable of laying eggs, but these are always haploid. So, in effect, only queen bees are capable of producing workers and new queen bees.

Why did this system evolve? And what does it mean for sexual selection in honeybees? According to Hamilton's kinship theory, evolution not only favours individual fitness, but also the inclusive fitness of an organism. Inclusive fitness is not just the fitness of an individual organism, but the fitness of its genetic material, whether it is carried by the organism or its relative. Hamilton's kinship theory is a powerful explanation for why altruistic behaviour may be evolutionarily favoured. Eusocial organisms could certainly be considered cases of extreme altruism–with the individual reproductive success of millions of workers sacrificed for the reproductive success of one, highly related queen. Haplodiploidy increases the degree of relatedness between workers, promoting eusocial behaviour. In ordinary diploid sexual reproduction, the degree of relatedness between siblings is 0.5, because there is a 50% chance that they will receive the same allele from the mother, and a 50% chance that they will receive the same allele from the father ($0.5 \times 0.5 + 0.5 \times 0.5 = 0.5$). However, between two worker bees sired by the same drone, the degree of relatedness is 0.75, because the likelihood of them getting the same allele from their haploid father is 100%, and the likelihood of getting the same allele from the queen is 50% ($1 \times 0.5 + 0.5 \times 0.5 = 0.75$). This increased relatedness is essential to worker cooperation in the hive, and artificially increasing genetic diversity has been shown to have detrimental effects on worker cooperation.

Apart from haplodiploidy, another unusual reproductive characteristic of *A. mellifera* is extreme polyandry. Polyandry is a mating system in which one female mates with multiple males. The mating behaviour of *A. mellifera* is as follows: drones aggregate in specific "congregation sites" before the arrival of queens. When the queens arrive for their nuptial flights, drones pursue them through the air in dense swarms of more than 100 individuals (called "drone comets"), mating rapidly during flight. Drones that have completed insemination die shortly afterwards. Queens have organs called lateral oviducts in which they store the sperm of many males, using it to fertilize eggs throughout the year.

Why do honeybees use this mating system? What are its evolutionary advantages? Well, one theory is that polyandry increases a hive's resistance to pathogens. By increasing the genetic diversity of a hive, polyandry decreases the likelihood that the entire hive is susceptible to one particular disease. This hypothesis was tested by Baer and Schmid-Hempel in 2001. The authors conducted an experiment in which they simulated polyandry in *Bombus terrestris*. They created hives of varying genetic diversity by artificially inseminating queens with different numbers of drones and drones of varying relatedness. Hives with the greatest genetic diversity had the greatest resistance to infection by *Crithidia bombi*, a common parasite. Hives with the maximum or minimum genetic diversity had the greatest reproductive fitness (when measured one mating season later). The authors concluded that genetic diversity did improve resistance to disease, but only after a threshold of diversity was past. Additionally, the increased genetic diversity decreased worker cooperation. These two factors resulted in a U–shaped distribution of fitness, with fitness being greatest at minimal genetic diversity, and after the threshold of diversity necessary for improved resistance was passed. The authors hypothesized that this distribution of fitness represented an evolutionary barrier to evolving polyandry—a barrier that *B. terrestris* had not crossed, but that *A. mellifera* had.

So, given that the fitness of a hive is not necessarily improved by queens being selective of drones, is there any evidence to support that it still happens? There is some evidence that cryptic female choice and sperm competition occurs in the lateral oviducts, but the research on this is far from conclusive. A 2003 study by Baer, Schmid-Hempel, Høeg, and Boomsma showed that sperm length correlated to drone body size, and that the variance of sperm lengths produced in drones was greater than the variance of sperm lengths found in the stored in the spermatheca of queens. These results suggested that sperm length could be a trait selected for, both by direct male-to-male competition, and by cryptic female choice. However, even if sperm length is a selected trait, it does not seem to favour some males over others. Research has found that all males that successfully mate have roughly equal representation in the patrilines of the hive. This supports the genetic scrambling hypothesis–that queens favour a strategy of maximum genetic diversity, without favouring any particular male.

In conclusion, common sense would perhaps dictate that honeybee queens would select the healthiest, most aggressive, or most flashy drones to mate with. However, the conditions of mating do not actually favour a particular drone morphology and, due to the genetic variation versus parasites hypothesis, queens do not benefit by being very selective of males, with the most advantageous behaviour being to maximize genetic diversity. So, *A. mellifera* exhibits a peculiar form of intersexual selection, in which queens don't select individual drones but rather, catalogues of genetic information.

35. The extinction of *Apis mellifera* would most likely lead to which of the following scenarios?
    A. The collapse of agricultural ecosystems
    B. The elimination of all honey, beeswax, and bee propolis products
    C. A decline in food production, due to a shortage of labour
    D. The extinction of many flowering plants
    E. The extinction of *Crithidia bombi*

36. Which of the following statements about Hamilton's kinship theory is correct?
    A. It explains why altruistic behaviour may be evolutionarily disfavoured
    B. Artificially decreasing genetic diversity has detrimental effects on worker cooperation
    C. It explains why altruistic behaviour may be evolutionarily favoured
    D. It is not just the fitness of an individual organism, but the fitness of its genetic material
    E. Evolution considers only individual fitness

37. Which of the following can NOT occur?
    A. Diploid queen mates with haploid drone and produces a new diploid worker
    B. Diploid queen produces a haploid drone
    C. Diploid worker produces a haploid drone
    D. Diploid worker mates with haploid drone and produces a diploid worker
    E. Diploid queen mates with haploid drone and produces a new diploid queen

38. Why is *Apis mellifera* polyandrous while *Bombus terrestris* is not?
    A. *Apis mellifera* has minimum genetic diversity
    B. *Apis mellifera* is more prone to infection by *Crithidia bombi*
    C. *Apis mellifera* has crossed an evolutionary barrier
    D. *Bombus terrestris* is a eusocial species
    E. *Bombus terrestris* does not practice haplodiploidy

39. What is a "drone comet"?
    A. A congregation of queen bees
    B. A swarm of male bees pursuing a queen
    C. A swarm of workers pursing a queen
    D. A swarm of drones pursuing a worker
    E. A congregation of workers

40. Polyandry is a mating system in which one male mates with multiple females.

    The genetic scrambling hypothesis states that queens favour maximum genetic diversity.
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

41. What tone is the passage written in?
    A. Argumentative
    B. Agnostic
    C. Informative
    D. Serious
    E. Cynical

42. The sperm length of *A. mellifera* is correlated to which of the following?
    A. Number of females mates
    B. Number of spermatheca
    C. Genetic Diversity
    D. Body weight
    E. Body size

43. What is the purpose of paragraph four?
    A. To explain the importance of honey bees
    B. To introduce the topic of polyandry
    C. To summarize the previous paragraph
    D. To introduce the topic of polygamy
    E. To critique evidence for mating behaviour

44. When was the study by Schmid-Hempel, Høeg, and Boomsma published?
    A. 2001
    B. 2002
    C. 2003
    D. 2004
    E. 2005

45. The degree of relatedness between siblings sired by the same drone is 0.5, because the likelihood of them getting the same allele from their haploid father is 100%, and the likelihood of getting the same allele from the queen is 50%
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

46. What is the main idea of paragraph six?
    A. The genetic scrambling hypothesis is convincing but not supported by research
    B. Cryptic female choice and sperm competition occurs in the lateral oviducts
    C. Genetic diversity can both increase or decrease evolutionary fitness
    D. Sperm length may be a selected trait, but females do not seem to favour some males over others based on the trait
    E. The variance of sperm lengths produced in drones is greater than the variance of sperm lengths found stored in queens

47. According to the author, what would "common sense" dictate as traits selected for by queens?
    A. Body size and sperm length
    B. Genetic diversity
    C. Health, aggression, and appearance
    D. Pollination and social abilities
    E. Flight patterns, aggression, and appearance

48. Which of the following is NOT true?
    A. Polyandry increases the hive's resistance to parasites and other pathogens
    B. Schmid-Hempel published at least two studies on the honeybee
    C. The degree of relatedness between siblings is 0.5 in diploid-diploid sexual reproduction
    D. Only queens can lay diploid eggs
    E. The nuptial flight of queens involve both drones and workers

49. What is a spermatheca?
    A. The site of sperm production in males
    B. The site of sperm storage in males
    C. The site of sperm storage in females
    D. The site of sperm lengthening in males
    E. A male insemination organ

50. According to paragraph three, what is the degree of relatedness between diploid siblings bred from two haploid parents?
    A. 0%
    B. 25%
    C. 50%
    D. 75%
    E. 100%

STOP

You have completed the RCT section of the DAT.
The exam is now over.

FULL-LENGTH 3 MEDIUM DIFFICULTY

SOLUTIONS

Survey of Natural Sciences

1. The attachment of oxygen to one of the four active sites of hemoglobin increases their affinity for other oxygen molecules. Which of the following best describes this phenomenon?
   A. Induced-fit model
   B. Competitive inhibition
   C. Cooperativity
   D. Noncompetitive inhibition
   E. Allosteric regulation

   A → Incorrect. The induced-fit model states that enzymes undergo a conformational change during binding, such that the active site becomes a more precise fit for the substrate
   B → Incorrect. Competitive inhibition occurs when an inhibitor binds to an enzyme at its active site, blocking the substrate
   C → Correct. Cooperativity describes how the binding of a substrate to one active site increases or decreases the substrate affinity of other active sites
   D → Incorrect. Noncompetitive inhibition occurs when an inhibitor binds to an enzyme at the allosteric site, changing the enzyme's conformation and preventing substrate binding
   E → Incorrect. Allosteric regulators are molecules that bind to an enzyme's allosteric site to inhibit or stimulate activity

2. Which of the following animal phyla does NOT have a coelom?
   A. Chordata
   B. Echinodermata
   C. Arthropoda
   D. Platyhelminths
   E. Annelida

   A coelom is a special cavity that develops from the mesoderm germ layer and protects the organs. Some animal phyla have them (called coelomates) while others do not (called acoelomates). The only five coelomate animal phyla are: chordata, arthropoda, annelida, mollusca, and echinodermata

3. Which of the following hormonal changes triggers menstruation?
   A. Decrease in progesterone
   B. Decrease in follicle stimulating hormone
   C. Increase in estrogen
   D. Increase in leutenizing hormone
   E. Decrease in estrogen

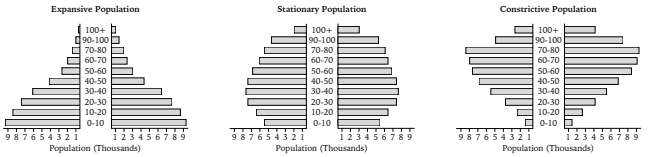
   A → Incorrect. Although progesterone does decrease during menstruation, the actual shedding of the endometrium is triggered by low estrogen
   B → Incorrect. The cause of menstruation is low estrogen. In fact, low estrogen and progesterone stimulates the hypothalamus to produce GnRH, thus *increasing* FSH levels
   C → Incorrect. Menstruation occurs when estrogen levels *decrease* due to atrophy of the corpus luteum
   D → Incorrect. If implantation does not occur, the *lack* of hCG and LH causes the corpus luteum to atrophy, resulting in decreasing estrogen levels that cause endometrial shedding
   E → Correct answer

4. Which of the following muscle tissues is mismatched with its feature?
   A. Cardiac – striated
   B. Smooth – involuntary control
   C. Skeletal – multinucleate
   D. Cardiac – syncytium of cells
   E. Smooth – mononucleate

   Cardiac muscle is composed of a chain of cells, joined via intercalated disks. Skeletal muscle is organized as a syncytium, which is a single cytoplasmic mass with several nuclei formed by the fusion of multiple cells. Smooth muscle is composed of individual torpedo-shaped cells

5. The number of 10 to 20 year-olds in an urban city is extremely low, compared to the number of the number of 70 to 80 year-olds. Which of the following terms most accurately describes this population?
   A. Expansive
   B. Stationary
   C. Constrictive
   D. Logarithmic
   E. Type I

An expansive population contains a high proportion of young individuals and a low proportion of elderly individuals. When graphed in a population pyramid, it resembles a pyramid. A stationary population contains a roughly equal proportion of young and elderly individuals. When graphed, it resembles a box. A constrictive population contains a low proportion of young individuals and a high proportion of elderly individuals. When graphed, it resembles an upside-down pyramid.



6. Which of the following chemical bonds are predominant in proteins?
   A. Glycosidic links
   B. Peptide bonds
   C. Ester bonds
   D. Disulphide bridges
   E. Phosphodiester bonds

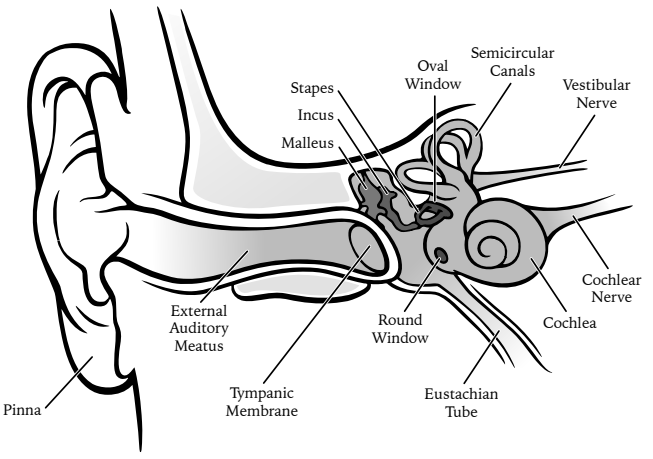
A → Incorrect. Glycosidic links connect carbohydrates
B → Correct answer. Peptide bonds connect amino acids into polypeptide chains, which are folded into proteins
C → Incorrect. Ester bonds are found predominantly in lipids
D → Incorrect. Although disulphide bridges may exist in the tertiary structure of proteins, they are far outnumbered by the quantity of peptide bonds in the primary structure
E → Incorrect. Phosphodiester bonds connect nucleotides

7. New species can arise from non-disjunction, spontaneous mutation, or behavioural isolation. These are all examples of which of the following?
   A. Prezygotic isolation
   B. Postzygotic isolation
   C. Genetic drift
   D. Sympatric speciation
   E. Allopatric speciation

A → Incorrect. Prezygotic isolation describes a reproductive incompatibility between two individuals that occurs before the formation of a zygote
B → Incorrect. Prezygotic isolation describes a reproductive incompatibility between two individuals that occurs after the formation of a zygote
C → Incorrect. Genetic drift is a change in a population's allele frequency due to random forces, often leading to the loss of biodiversity
D → Correct. Sympatric speciation describes the formation of new species within the same population, without the involvement of a geographic barrier or isolation. The examples listed in the question stem all satisfy this criteria
E → Incorrect. Allopatric speciation describes the formation of new species after the original population is separated by a geographic barrier and split into multiple isolated populations

8. Which of the following structures is NOT part of the middle ear?
   A. Incus
   B. Eustachian tube
   C. Semicircular canals
   D. Tympanic membrane
   E. Stapes

The semicircular canals are a component of the *inner* ear, along with the cochlea:



9. Type I and II pneumocytes are derived from which embryonic structure?
   A. Intervertebral disks
   B. Endoderm
   C. Somites
   D. Ectoderm
   E. Mesoderm

   A → Incorrect. The intervertebral disks are located between each vertebrae and are derived from the embryonic notochord
   B → Correct. The endoderm develops into the lungs, which contain type I and II pneumocytes
   C → Incorrect. Somites are repeating embryonic blocks that organize the segmented structures in vertebrates and gives rise to the bony vertebra
   D → Incorrect. The ectoderm develops into the nervous system, hair, nails, sweat glands, and epidermis
   E → Incorrect. The mesoderm develops into the musculoskeletal system, circulatory system, spleen, lymphatic system, notochord, genitourinary system, and dermis

10. Which of the following is NOT a parasympathetic response?
    A. Pupil constriction
    B. Decreased heart rate
    C. Increased digestion
    D. Relaxed urinary bladder
    E. Decreased glycolysis

    The sympathetic response can be thought of as "fight or flight" while the parasympathetic response is described as "rest and relaxation"

    A → Incorrect. Pupils constrict during the parasympathetic response because light is not needed for "rest and relaxation"
    B → Incorrect. Heart rate is lower during the parasympathetic response because extra blood does not need to be pumped to the muscles for "fight or flight"
    C → Incorrect. Digestion is increased during the parasympathetic response to stockpile nutrients in preparation for a "fight or flight" scenario
    D → Correct. The bladder is *constricted*, not *relaxed* during the parasympathetic response. This occurs simultaneously with the relaxation of the urinary sphincter, stimulating urination
    E → Incorrect. Glycolysis is decreased during the parasympathetic response because extra glucose is not needed to fuel muscles for "fight or flight"

11. The population of wolves in Banff National Park experienced a severe decline in 1950 due to a rabies epidemic. After this decline, major changes were noticed in the ecosystem. The wolves can thus be classified as which of the following?
    A. A dominant species
    B. An ecosystem engineer
    C. An umbrella species
    D. A keystone species
    E. A primary producer

    A → Incorrect. A dominant species is the most abundant or has the highest collective biomass out of all other species in its ecosystem
    B → Incorrect. An ecosystem engineer is a species that dramatically alters its environment (for example, beavers transform a forest into a flooded wetlands by building a dam)
    C → Incorrect. An umbrella species is not necessarily an ecologically important species, but rather one that is selected for conservation due to how they indirectly protect other species in an ecosystem
    D → Correct. A keystone species has an important ecological role and often disproportionally large effect on its ecosystem. The decline or removal of a keystone species will dramatically effect the populations of its predators, prey, and other species in the same food chain. This is the best answer
    E → Incorrect. Primary producers are autotrophic species that generate their own food from the sun's energy

12. Which of the following is NOT a form of post-transcriptional regulation?
    A. Ubiquitin tagging
    B. miRNA interference
    C. Alternative splicing
    D. RNA degradation
    E. Poly-A tail

    A → Correct. Ubiquitin tagging is a form of post-*translational* regulation in which a polyubiquitin chains are attached to proteins, marking them for destruction via a proteasome
    B → Incorrect because it is true. miRNA interference occurs when small single-stranded regulatory RNAs bind to a complimentary sequence in a RNA transcript, blocking translation by ribosomes
    C → Incorrect because it is true. Alternative splicing allows the production of different mRNAs from the same pre-mRNA, regulating which genes get translated
    D → Incorrect because it is true. RNA degradation prevents the transcript from being translated by ribosomes. This process can be accelerated by miRNAs
    E → Incorrect because it is true. Addition of a poly-A tail can be regulated to increase or decrease mRNA stability prior to translation by ribosomes

13. If the percentage of cholesterol in a plasma membrane is decreased, which of the following consequences would occur?
    A. Increase in permeability at low temperatures
    B. Decrease in fluidity at high temperatures
    C. Increase in fluidity at low temperatures
    D. Increase in fluidity at high temperatures
    E. Atherosclerosis

    Cholesterol acts as a membrane fluidity buffer. When temperature is high, cholesterol's intermolecular interactions makes the membrane less fluid. When temperature is low, cholesterol's steric hinderance makes the membrane more fluid. Therefore, if the percentage of cholesterol is decreased, we would expect fluidity to increase at high temperatures and decrease at low temperatures

    A → Incorrect. Membrane permeability is not affected
    B → Incorrect. Fluidity should increase at high temperatures
    C → Incorrect. Fluidity should decrease at low temperatures
    D → Correct answer
    E → Incorrect because atherosclerosis involves cholesterol buildup within the lumen of arteries, not lipid bilayers

14. Which of the following structures is the common passageway for food, fluids, and air?
    A. Esophagus
    B. Pharynx
    C. Trachea
    D. Larynx
    E. Epiglottis

    A → Incorrect. The esophagus transports food and fluids (not air) from the oral cavity to the stomach
    B → Correct. The pharynx is where the nasal and oral cavities join. Air then travels through the larynx while food and fluids travel down the esophagus
    C → Incorrect. The trachea transports air from the larynx to the bronchi. A flap called the epiglottis prevents food and fluids from entering the larynx and trachea
    D → Incorrect. The larynx transports air from the pharynx to the trachea. Vocal cords modulate the flow of exhaled air to produce speech. A flap called the epiglottis prevents food and fluids from entering the larynx and trachea
    E → Incorrect. The epiglottis is a flap of cartilage and tissue that prevents food and fluids from entering the larynx

15. The coral snake is highly venomous and has a distinctive black, red, and yellow pattern. This pattern is also found on the harmless scarlet king snake, an unrelated species. This is an example of which of the following?
    A. Behavioural defence
    B. Camouflage
    C. Mullarian mimicry
    D. Resource partitioning
    E. Batesian mimicry

    A → Incorrect. Behavioural defence is when an organism hides, plays dead, flees, herds, or uses distraction displays to escape from predators
    B → Incorrect. Camouflage is when an organism mimics the appearance of its environment to avoid predation or herbivory
    C → Incorrect. Mullerian mimicry is when two or more poisonous/repulsive species that have common predators resemble each other
    D → Incorrect. Resource partitioning is when several species occupy the same habitat but use resources in slightly different ways, thus creating their own niches and avoiding competition
    E → Correct. Batesian mimicry is when a harmless species resembles another poisonous/repulsive species

16. If a tissue biopsy sample is stored in distilled water, what would occur to the cells?
    A. Nothing
    B. Plasmolysis
    C. Cytolysis
    D. Hydrolysis
    E. Cytokinesis

    A → Incorrect. Since the cells contain more solvent than the distilled water, they have greater osmolarity and are in a hypotonic solution. The resulting net movement of water into the cell causes swelling and eventual bursting (cytolysis)
    B → Incorrect. Plasmolysis is the detachment of the cell membrane from the cell wall in a hypertonic solution
    C → Correct answer
    D → Incorrect. Hydrolysis is the breaking of a chemical bond via the introduction of a water molecule
    E → Incorrect. Cytokinesis is the splitting of cytoplasm that occurs at the end of mitosis

17. After the discovery of cancer, a 70 year old woman undergoes a parathyroidectomy (removal of the parathyroid glands). Which of the following is she at an increased risk for?
    A. Osteoporosis
    B. Increased blood calcium
    C. Goiter formation
    D. Decreased calcium resorption
    E. Osteomalacia

    A → Incorrect. Removal of the parathyroid gland would prevent the synthesis of parathyroid hormone (PTH). PTH increases blood calcium by stimulating osteoclasts to demineralize bone. Lack of PTH would result in lower osteoclast activity and less bone degradation
    B → Incorrect. Lack of PTH would result in lower blood calcium, due to decreased osteoclast activity
    C → Incorrect. Goitres are caused by high TSH levels. A lack of PTH would have no effect on TSH, thus a goiter is unlikely
    D → Correct. In addition to simulating osteoclasts, PTH also promotes calcium resorption in the kidneys and intestine. A lack of PTH would decrease calcium resorption
    E → Incorrect. Osteomalacia is an adult disease in which bone is weakened due to vitamin D deficiency

18. During fertilization in mammals, polyspermy is prevented by the following mechanism:
    A. Acrosome reaction
    B. Electrical block
    C. Cleavage
    D. Cortical reaction
    E. LH surge

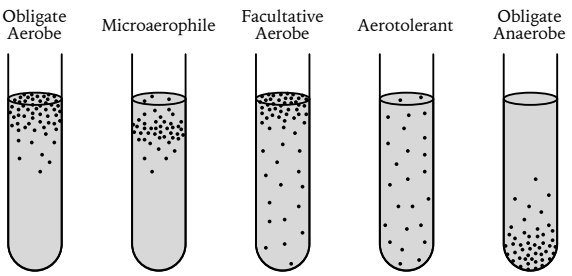
    A → Incorrect. The acrosome reaction is used by the sperm to penetrate the zona pellucida of the egg, and does not prevent polyspermy. During the acrosome reaction, proteolytic enzymes are released from the acrosome, a cap-shaped organelle in the sperm's head
    B → Incorrect. The electrical block (also known as the "fast block") occurs in non-mammals. During the electrical block, membrane fusion of the sperm and egg triggers oocyte depolarization, repelling any additional sperm
    C → Incorrect. Cleavage is a phase in early embryonic development and does not prevent polyspermy
    D → Correct. The cortical reaction is a polyspermy prevention mechanism that occurs in mammals. Membrane fusion of the sperm and egg triggers release of calcium ions from the oocyte endoplasmic reticulum. This in turn causes the release of cortical granules, which contain compounds that destroy sperm binding sites and hardens the zona pellucida
    E → Incorrect. The LH surge is a phase of the ovarian and menstrual cycle that triggers ovulation

19. The ancient Earth's reducing atmosphere was converted into an oxidative one thanks to:
    A. Methanogens
    B. Nitrifying bacteria
    C. Spirochetes
    D. Cyanobacteria
    E. Dinoflagellates

    A → Incorrect. Methanogens reduce carbon dioxide into methane gas, using hydrogen as a reducing agent
    B → Incorrect. Nitrifying bacteria oxidize ammonia into nitrites and nitrates in the soil
    C → Incorrect. Spirochetes are spiral bacteria that move in a corkscrew motion via an internal flagella
    D → Correct. Ancient cyanobacteria used photosynthesis to generate enough oxygen gas to transform the reducing atmosphere into an oxidative one
    E → Incorrect. Dinoflagellates are protists that evolved much later than bacteria

20. An unidentified strain of bacteria is cultured in a test tube. After incubation, the mixture appears to have a uniform concentration of bacteria throughout. This strain can be classified as:
    A. Microaerophile
    B. Obligate anaerobe
    C. Aerotolerant
    D. Obligate aerobe
    E. Facultative anaerobe

    A → Incorrect. Microaerophiles require oxygen but cannot tolerate high concentrations. No bacteria would be seen at the surface of the test tube
    B → Incorrect. Obligate anaerobes require oxygen to survive. No bacteria would be seen near the bottom of the test tube
    C → Correct. Aerotolerant organisms use fermentation but can tolerate oxygen. They can exist anywhere in the test tube
    D → Incorrect. Obligate anaerobes are poisoned by oxygen. No bacteria would be seen near the top of the test tube
    E → Incorrect. Facultative anaerobes use both aerobic respiration and fermentation but grow more efficiently using aerobic respiration. More bacteria would be seen near the top of the test tube



21. Which of the following metabolic processes occurs in the cytosol?
    A. Pyruvate oxidation
    B. Electron transport chain
    C. Citric acid cycle
    D. Calvin cycle
    E. Lactic acid fermentation

A → Incorrect. Pyruvate oxidation occurs in the mitochondrial matrix
B → Incorrect. The electron transport chain occurs at the inner mitochondrial membrane
C → Incorrect. The citric acid cycle occurs in the mitochondrial matrix
D → Incorrect. The Calvin cycle occurs in the stroma of the chloroplast
E → Correct answer

22. A congenital disorder results in the absence of sweat glands. Which of the following structures may be responsible for this developmental defect?
    A. Mesoderm
    B. Ectoderm
    C. Blastopore
    D. Epiderm
    E. Endoderm

A → Incorrect. The mesoderm develops into the musculoskeletal system, circulatory system, spleen, lymphatic system, notochord, genitourinary system, and dermis
B → Correct. The ectoderm develops into the nervous system, hair, nails, *sweat glands*, and epidermis
C → Incorrect. The blastopore is the opening to the archenteron, an embryonic gut
D → Incorrect. The epidermis is not a embryological structure
E → Incorrect. The endoderm develops into the pharynx, trachea and bronchi (epithelial parts), digestive system, liver, pancreas, bladder, lungs, thyroid, and parathyroid

23. Which of the following plant categories is NOT a bryophyte or lycophyte?
    A. Hornworts
    B. Liverworts
    C. Ferns
    D. Flat mosses
    E. Club mosses

Bryophyta is the only category of non-vascular plants. They have a very simple structure with not leaves, stems, roots or vasculature (xylem and phloem). Common examples of bryophytes include mosses, liverworts, and hornworts.

Lycophyta is one of the oldest lineages of vascular plants. Unlike bryophytes, they have specialized vascular tissue. Common examples of lycophytes include club mosses.

Pterophyta have specialized leaves called fronds. Young fronds are curled and called "fiddleheads" due to their shape. Ferns are pterophytes.

24. Which of the following clinical signs is consistent with respiratory acidosis?
    A. Swollen bronchioles
    B. Decreased respiratory rate
    C. Increased heart rate
    D. Increased respiratory rate
    E. Decreased heart rate

A → Incorrect. This is a sign of chronic bronchitis or asthma
B → Incorrect. High carbonic acids levels in blood would result in an equilibrium shift in the bicarbonate buffering system, producing more carbon dioxide. Therefore respiratory rate is expected to increase:

$$CO_2 + H_2O \overset{CA}{\rightleftharpoons} H_2CO_3 \rightleftharpoons HCO_3^- + H^+$$

C → Incorrect. Blood acidity does not influence heart rate
D → Correct answer
E → Incorrect. Blood acidity does not influence heart rate

25. Which of the following terrestrial biomes is characterized by moderate temperatures and the dominance of deciduous trees?
    A. Chaparral
    B. Temperate forest
    C. Boreal forest
    D. Tropical forest
    E. Savanna

A → Incorrect. A chaparral biome is characterized by rainy, cool winters and dry, warm summers. Shrubs and small trees dominate
B → Correct answer
C → Incorrect. A boreal forest or taiga biome is characterized by warm summers and snowfall during cold winters. Conifer trees dominate, with scattered shrubs
D → Incorrect. A tropical forest biome is characterized by high rainfall and high year-round temperatures
E → Incorrect. A savanna biome is characterized by warm year-round temperatures and forest fires. Trees and large shrubs are scattered while grasses dominate

26. Which of the following plant hormones promotes the shedding of leaves?

A. Abscisic acid
B. Gibberellin
C. Cytokinin
D. Ethylene
E. Auxin

A → Correct. Abscisic acid promotes the dormancy of seeds and abscission of leaves. It also inhibits growth and promotes stomatal closure in response to drought
B → Incorrect. Gibberellin promotes germination, shoot elongation, flowering, and fruit development
C → Incorrect. Cytokinin promotes cell division in the roots and shoots. It also slows down leaf death and abscission
D → Incorrect. Ethylene promotes the ripening of fruit
E → Incorrect. Auxin promotes cell elongation and is responsible for phototropism

27. An individual with the genotype AABbcc is crossed with an individual with the genotype AaBBCc. What is the probability that their offspring will have the genotype AABBcc?

A. $\frac{1}{2}$
B. $\frac{1}{4}$
C. $\frac{\boldsymbol{1}}{\boldsymbol{8}}$
D. $\frac{1}{16}$
E. $\frac{1}{32}$

Assuming independent assortment of alleles, we can consider the cross of each gene separately:

	A	A
A	AA	AA
a	Aa	Aa

	B	b
B	BB	Bb
B	BB	Bb

	c	c
C	Cc	Cc
c	cc	cc

$\%\ AA = \frac{1}{2}$ $\%\ BB = \frac{1}{2}$ $\%\ cc = \frac{1}{2}$

Using the multiplication rule, the combined probability of obtaining an AABBcc genotype is:

$$\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$$

28. Which of the following statements regarding mitochondria is INCORRECT?

A. Contain a double lipid bilayer
B. Found in all cells
C. Replicate independently
D. Abundant in myocytes
E. Found in the neck of spermatozoa

A → Incorrect because it is true. This double membrane forms the intermembrane space, where a high proton concentration is generated for the electron transport chain. It is also evidence for the endosymbiotic theory
B → Correct because it is false. Mitochondria and other membrane-bound organelles are not found in prokaryotes
C → Incorrect because it is true. Mitochondria and chloroplasts have their own DNA and replicate independently
D → Incorrect because it is true. Myocytes require extra ATP to power the contraction of sarcomeres
E → Incorrect because it is true. The neck of spermatozoa contain many mitochondria to power the flagellar tail

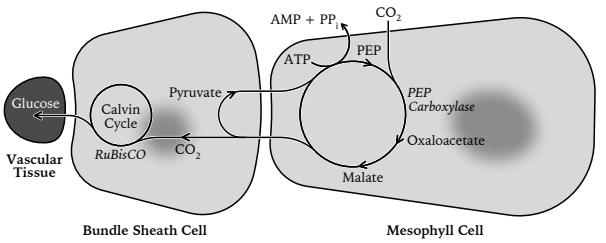
29. Which of the following correctly describes the role of microfilaments within the cell?

A. Dividing the cytoplasm during cytokinesis
B. Mediating the transport of organelles
C. Separating the chromosomes during anaphase
D. Providing structural support
E. Attaching cells to the extracellular matrix

A → Correct. Microfilaments are composed of actin protein and function in cytoplasm motility
B → Incorrect. This is the function of microtubules
C → Incorrect. This is the function of the mitotic spindle, which is composed of microtubules
D → Incorrect. This is the function of intermediate filaments such as keratin and nuclear lamins
E → Incorrect. This is the function of hemidesmosomes, which contain intermediate filaments

30. In C4 photosynthesis, carbon dioxide is fixed into _ by the _ enzyme and transported to _ cells
    A. Malate; RuBisCO; mesophyll
    B. Oxaloacetate; PEP carboxylase; mesophyll
    C. Malate; RuBisCO; bundle sheath
    D. Oxaloacetate; PEP carboxylase; bundle sheath
    E. Malate; PEP carboxylase; bundle sheath

C4 photosynthesis prevents photorespiration by spatially separating CO_2 fixation and the Calvin cycle into different cells of the leaf. In mesophyll cells, CO_2 is fixed into a four-carbon molecule called oxaloacetate, then transported to bundle sheath cells for the Calvin cycle. This fixation process is catalyzed by PEP carboxylase, which has specific affinity for CO_2, unlike RuBisCO



31. Acetylcholine triggers the release of _ from the _
    A. Na^+; sarcoplasmic reticulum
    B. Na^+; T-tubules
    C. Ca^{2+}; sarcoplasmic reticulum
    D. Ca^{2+}; T-tubules
    E. Ca^{2+}; sarcolemma

During synaptic transmission, an action potential reaches the presynaptic terminal of a motor neuron, causing the exocytosis of acetylcholine into the synaptic cleft. Acetylcholine then binds to nicotinic receptors located at the end plate of a muscle cell. This causes voltage-gated Na^+ channels to open, causing an action potential that is propagated down the T-tubules and to the sarcoplasmic reticulum. The sarcoplasmic reticulum releases Ca^{2+}, which triggers muscle contraction

32. What is the ratio of aneuploid gametes resulting from nondisjunction during meiosis I vs II?
    A. 0.5
    B. 1
    C. 1.5
    D. 2
    E. 4

If nondisjunction occurs during meiosis I, then all four gametes will be aneuploid—two with $n+1$ chromosomes and two with $n-1$. On the other hand, if nondisjunction occurs during meiosis II, only half of the gametes will be aneuploid —one with $n+1$ chromosomes and one with $n-1$. Therefore, the ratio of aneuploid gametes resulting from nondisjunction during meiosis I vs II is 4:2 = 2

33. A species of spiders has varying sizes of red markings. Those with larger markings are better able to camouflage against tomatoes, while those with smaller markings are better able to hide in shaded areas. Over time, which of the following is most likely to occur?
    A. Stabilizing selection
    B. Directional selection
    C. Disruptive selection
    D. Frequency-dependent selection
    E. Sexual selection

A → Incorrect. Stabilizing selection occurs when individuals with an average phenotype are favoured, reducing the frequency of extreme phenotypes
B → Incorrect. Directional selection occurs when individuals with one extreme phenotype are favoured, reducing the frequency of all other variations
C → Correct. Disruptive selection occurs when extreme phenotypes are favoured, reducing the frequency of the average phenotype
D → Incorrect. Frequency-dependent selection occurs when the fitness of a particular phenotype is dependent on the frequency of the phenotype within the population. Based on the question stem, the fitness of the spiders depends on the size of the markings, not the frequencies of the phenotypes
E → Incorrect. Sexual selection occurs when one sex has a preference for certain traits in the other sex

34. Which of the following cell junctions allows action potential propagation in cardiomyocytes?

A. Gap junctions
B. Desmosomes
C. Plasmodesmata
D. Adherens junctions
E. Tight junctions

A → Correct. Gap junctions form tunnels between cells, allowing the free flow of water and ions
B → Incorrect. Desmosomes are dot-shaped seals between cells, linking intermediate filaments
C → Incorrect. Plasmodesmata are a special type of gap junction found only in plant cells
D → Incorrect. Adherens junctions are dot-shaped seals between cells, linking actin filaments
E → Incorrect. Tight junctions form a continuous, water-tight seal between cells

35. Which of the following embryonic components develops into the placenta?

A. Amnion
B. Embryoblasts
C. Allantois
D. Chorion
E. Epiblasts

A → Incorrect. The amnion is the innermost extraembryonic membrane, which protects the developing embryo
B → Incorrect. Embryoblasts form a solid lump of cells called the inner cell mass, which develops into the embryo
C → Incorrect. The allantois develops into the umbilical chord in humans, and functions as a reservoir for nitrogenous waste in egg-laying amniotes
D → Correct. The chorion is the outermost extraembryonic membrane, which mediates implantation into the endometrium and develops into the placenta
E → Incorrect. Epiblasts form part of the bilaminar disk. The human embryo develops almost entirely from epiblasts

36. Insulin stimulates glucose ____ and is produced by ____ cells in the pancreatic islets

A. Release; alpha
B. Absorption; alpha
C. Release; beta
D. Absorption; beta
E. Absorption; delta

Insulin is produced by beta cells in the pancreatic islets and stimulates glucose absorption from blood into skeletal muscle and adipose tissue

Glucagon is produced by alpha cells in the pancreatic islets and stimulates glucose release from tissue into blood

Somatostatin is produced by delta cells in the pancreatic islets and inhibits insulin, glucagon, and growth hormone

37. Which of the following is NOT a function of the liver?

A. Blood filtration
B. Bile production
C. Cholecystokinin secretion
D. Bilirubin secretion
E. Gluconeogenesis

A → Incorrect because it is true. The liver detoxifies chemicals and drugs absorbed by the small intestines
B → Incorrect because it is true. The liver produces bile, which helps digest fats. Bile is stored in the gallbladder
C → Correct because it is false. Cholecystokinin is a hormone secreted by duodenal cells. It stimulates bile release
D → Incorrect because it is true. Bilirubin is a metabolic waste product of hemoglobin, which is filtered and excreted by the liver
E → Incorrect because it is true. The liver can produce glucose from non-carbohydrate precursors such as amino acids, glycerol, pyruvate, and lactate

38. What is the function of topoisomerase during DNA replication?

A. Separate double-stranded DNA
B. Create temporary double-stranded breaks
C. Prevent the annealing of separated DNA
D. Replace RNA primers with DNA
E. Bind DNA polymerase III to DNA

A → Incorrect. This is the function of helicase
B → Correct. Topoisomerase creates double-stranded breaks to prevent supercoiling
C → Incorrect. This is the function of single-stranded binding (SSB) proteins
D → Incorrect. This is the function of DNA polymerase I
E → Incorrect. This is the function of the sliding clamp

39. An increase in angiotensin II will result in:
    A. Vasodilation of blood vessels
    B. Decreased aldosterone production
    C. Increased Na^+ resorption in the proximal convoluted tubules
    D. Decreased antidiuretic hormone production
    E. Decreased Na^+ resorption in the distal convoluted tubules

    A → Incorrect. Angiotensin II triggers *vasoconstriction*
    B → Incorrect. Angiotensin II stimulates aldosterone production by the adrenal gland
    C → Correct answer
    D → Incorrect. Angiotensin II stimulates ADH production by the posterior pituitary gland
    E → Incorrect. Angiotensin II *increases* Na^+ resorption in the *proximal* convoluted tubules

40. Which of the following events occurs in meiosis but not mitosis?
    A. Attachment of spindle fibres to the kinetochore
    B. Splitting of sister chromatids
    C. Cleavage furrow formation
    D. Splitting of homologous chromosomes
    E. Alignment of centromeres at the metaphase plate

    All of the events listed in the answer choices occur in both meiosis and mitosis, except for D). Anaphase I of meiosis is the same as anaphase in mitosis except the *homologous chromosomes* are pulled apart, rather than sister chromatids

41. List the following elements in order of increasing atomic radius: F, Cu, Al, Rb, Ca
    A. Al < F < Cu < Ca < Rb
    B. F < Al < Ca < Cu < Rb
    C. Rb < Ca < Cu < Al < F
    D. F < Al < Cu < Ca < Rb
    E. F < Ca < Cu < Al < Rb

    Atomic radius decreases as you move from left to right on the periodic table because the number of protons in the nucleus increases. The positive charge of the protons pull the electrons closer together, decreasing atomic radius.

    On the other hand, atomic radius increases as you move from top to bottom on the periodic table because the number of electron shells increase, adding more "layers" on top of the nucleus.

    We can use this general periodic trend to rank our elements in the following order: F (closest to top right) < Al < Cu < Ca < Rb (closest to bottom left)

42. 150 J is used to heat a 5 g sample of aluminium from 20°C to 50°C. What is the specific heat capacity in J/g°C?
    A. 0.4
    B. 1
    C. 1.5
    D. 2
    E. 2.5

    Write out the heat transfer equation:

    $$q = m\,c\,\Delta T$$

    Rearrange for specific heat capacity:

    $$c = \frac{q}{m\,\Delta T}$$

    Substitute known values and solve:

    $$c = \frac{150\text{ J}}{(5\text{ g})(50°\text{C} - 20°\text{C})}$$

    $$c = \frac{150}{(5)(30)}$$

    $$c = \frac{150}{150} = 1$$

43. A chemical reaction with a negative change in enthalpy and entropy will be:
    A. Non-spontaneous at all temperatures
    B. Spontaneous at low temperatures
    C. Spontaneous at high temperatures
    D. Spontaneous at all temperatures
    E. Entropically driven

    A reaction is spontaneous when its change in Gibbs free energy (ΔG) is negative. ΔG is calculated via the equation:

    $$\Delta G = \Delta H - T\Delta S$$

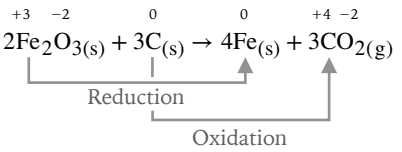
    Therefore, if ΔH and ΔS are both negative, temperature must be low in order for the positive entropy term ($T\Delta S$) to be smaller than the negative enthalpy term (ΔH) in magnitude. This reaction is thus enthalpically driven.

44. Which of the following statements is correct regarding the redox reaction shown below?

$$2Fe_2O_{3(s)} + 3C_{(s)} \rightarrow 4Fe_{(s)} + 3CO_{2(g)}$$

A. Fe_2O_3 is being oxidized
B. CO_2 is the oxidizing agent
C. This is a disproportionation reaction
D. Fe_2O_3 is the oxidizing agent
E. C is being reduced

First write out the oxidation states of each element and identify the half-reactions:



Since the oxidation state of Fe decreases, Fe_2O_3 is reduced and and thus an oxidizing agent. Since the oxidation state of C increases, C is oxidized and and thus a reducing agent. Answer choice B) is incorrect because CO_2 is a product, not a reactant. Answer C) is incorrect because a disproportionation reaction describes when oxidation and reduction occurs to the *same* reactant molecule.

45. Which of the following forms of radioactive decay has no effect on both mass and atomic number?

A. Alpha decay
B. Beta positive decay
C. Electron capture
D. Beta negative decay
E. Gamma decay

A → Incorrect. In alpha decay, a ${}^{4}_{2}He^{2+}$ particle is released from the nucleus. Mass decreases by 4, and the number of protons decreases by 2 ($A - 4$, $Z - 2$)
B → Incorrect. In beta positive decay, a proton decays into a neutron, releasing a positron and neutrino. Mass remains the same, but the number of protons decreases by 1 (A, $Z - 1$)
C → Incorrect. In electron capture, a proton and electron combine to form a neutron. Mass remains the same, but the number of protons decreases by 1 (A, $Z - 1$)
D → Incorrect. In beta negative decay, a neutron decays into a proton, releasing an electron and antineutrino. Mass remains the same, but number of protons increases by 1 (A, $Z + 1$)
E → Correct answer. In gamma decay, a γ particle is released (a high energy photon). This is the only form of radioactive decay in which the mass and number of protons remain the same (A, Z)

46. 20 g of NaCl is dissolved in 100 g of water. What is the molality of the resulting solution?

A. $\dfrac{20}{(58)(100)}$
B. $\dfrac{\boldsymbol{20}}{\boldsymbol{(58)(0.100)}}$
C. $\dfrac{(58)(0.100)}{20}$
D. $\dfrac{20}{(14)(0.100)}$
E. $\dfrac{(58)(100)}{20}$

Molality is defined as the number of moles of the solute divided by the number of kilograms of the solution.

First, we write out the formula for molality:

$$\text{Molality} = \frac{n_{solute}}{m_{solution}}$$

Next, we find the molar mass of NaCl:

$$MM_{NaCl} = 23 + 35 = 58 \text{ g/mol}$$

The number of mole of solute can then be represented as:

$$n_{solute} = \frac{20}{58}$$

Finally, substitute all known values into the formula for molality. Remember to convert the mass of the solvent (water) to kilograms:

$$\text{Molality} = \frac{20 \text{ g}}{(58 \text{ g/mol})(0.100 \text{ kg})}$$

47. If CH_3NH_2 is a weak base, which of the following equations represents the equilibrium constant expression for CH_3NH_2 in aqueous solution?

A. $K_b = \dfrac{[CH_3NH_2]}{[CH_3NH_3^+][OH^-]}$

B. $K_b = \dfrac{[CH_3NH_3^+]}{[CH_3NH_2][OH^-]}$

C. $K_b = \dfrac{[CH_3NH_2][H_3O^+]}{[CH_3NH_3^+]}$

D. $\boldsymbol{K_b = \dfrac{[CH_3NH_3^+][OH^-]}{[CH_3NH_2]}}$

E. $K_b = \dfrac{[CH_4NH_2^+][OH^-]}{[CH_3NH_2]}$

Weak bases partially dissociate in solution, forming the following generic equilibrium:

$$B + H_2O \rightleftharpoons HB^+ + OH^-$$

Applying this pattern to CH_3NH_2, we get the following equilibrium equation:

$$CH_3NH_2 + H_2O \rightleftharpoons CH_3NH_3^+ + OH^-$$

Note that the proton from H_2O is added to the amino group of CH_3NH_2 rather than the methyl group. The dissociation constant (K_b) is simply the equilibrium constant for the dissociation reaction of our weak base:

$$K_b = \frac{[CH_3NH_3^+][OH^-]}{[CH_3NH_2]}$$

The concentration of products is listed in the numerator, while the concentration of reactants is in the denominator. Note that the exponent of each term is 1, since the stoichiometric ratios of the equilibrium equation are all 1:1

48. Considering the following reaction, how many litres of nitrogen gas are generated from the reaction of 3 mol of oxygen gas and 6 mol of ammonia gas under STP conditions?

$$O_{2(g)} + NH_{3(g)} \rightarrow H_2O_{(l)} + N_{2(g)}$$

A. 11.2 L
B. 22.4 L
C. 44.8 L
D. 67.2 L
E. 89.6 L

First, balance the equation:

$$3O_{2(g)} + 4NH_{3(g)} \rightarrow 6H_2O_{(l)} + 2N_{2(g)}$$

To find the limiting reagent, we divide each reactant's molar value by its corresponding stoichiometric coefficient:

$$\text{quotient}_{O_2} = \frac{3\text{ mol}}{3} = 1$$

$$\text{quotient}_{NH_3} = \frac{6\text{ mol}}{4} = 1.5$$

O_2 has the lowest resulting quotient, so it is the limiting reagent. NH_3 is the excess reagent.

Next, use molar ratios to determine the amount of N_2 produced when the 1 mol of limiting reagent is consumed:

$$n_{N_2} = n_{O_2} \times \frac{2}{3} = 3\text{ mol} \times \frac{2}{3} = 2\text{ mol}$$

Since 1 mol of any gas occupies 22.4 L under STP conditions, therefore we can calculate the volume of N_2 produced:

$$V_{N_2} = 2\text{ mol} \times 22.4\text{ L/mol} = 44.8\text{ L}$$

49. Which of the following statements is true for the process of sublimation?

A. $\Delta H = 0; \Delta S > 0$
B. $\Delta H < 0; \Delta S < 0$
C. $\Delta H > 0; \Delta S > 0$
D. $\Delta H > 0; \Delta S < 0$
E. $\Delta H < 0; \Delta S > 0$

Sublimation is the change of phase from solid to gas, without a liquid intermediate.

A positive enthalpy change (ΔH) means the reaction releases heat (exothermic), while a negative ΔH means the reaction absorbs heat (endothermic). Since sublimation converts solids to gasses, it requires heat and therefore $\Delta H < 0$.

A positive entropy change (ΔS) means the reaction increases the amount of disorder in the system, while a negative ΔS means the reaction decreases disorder. Since sublimation creates more high-energy gas particles, it increases the amount of disorder and therefore $\Delta S > 0$

50. A sample of iron oxide contains 56/88% iron by weight. What is the simplest formula for this compound?

A. FeO
B. FeO_2
C. Fe_3O_4
D. Fe_4O_5
E. Fe_5O_6

First let's write out the formula for percent weight:

$$\text{Percent Weight} = \frac{m_{Fe}}{m_{FeO_2}}$$

The most efficient strategy for this question is validating each answer choice by trial and error:

Let's try answer choice A). We find the molar mass of Fe and FeO. Then, calculate percent weight:

$$\text{Percent Weight} = \frac{56\ \text{g/mol}}{56\ \text{g/mol} + 16\ \text{g/mol}} = \frac{56}{72}$$

This does not match the percent weight mentioned in the question stem. So let's try answer choice B):

$$\text{Percent Weight} = \frac{56\ \text{g/mol}}{56\ \text{g/mol} + (2)16\ \text{g/mol}} = \frac{56}{88}$$

This matches the percent weight given in the question stem. Therefore B) is the correct answer.

51. Which of the following changes will NOT shift the equilibrium reaction shown below to the products side?

$$CaO_{(s)} + H_2O_{(l)} \rightleftharpoons Ca(OH)_{2(s)} \quad \Delta H = 114\ \text{kJ/mol}$$

A. Adding more CaO
B. Increasing pressure
C. Increasing temperature
D. Decreasing pressure
E. Decreasing temperature

A → Incorrect. Increasing $[CaO_{(s)}]$ will shift the equilibrium to the right in an effort to reduce the additional $CaO_{(s)}$
B → Incorrect. Since this equilibrium does not involve gaseous species, we cannot predict the effect of pressure
C → Correct. Since ΔH is positive, this reaction generates heat. Increasing temperature will therefore shift the equilibrium to the left in an effort to consume the added heat
D → Incorrect. See explanation for answer choice B)
E → Incorrect. See explanation for answer choice C)

52. Which of the following statements correctly describes Dalton's law?

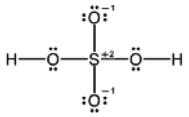
A. Pressure and volume are inversely proportional under isothermal conditions
B. The partial pressure of an individual gas equals total pressure times percent weight
C. Moles is proportional to volume under isothermal and isobaric conditions
D. The total pressure of a gas mixture equals the sum of partial pressures
E. Volume and temperature are proportional under isobaric conditions

A → Incorrect. This describes Boyle's law
B → Incorrect. The partial pressure of an individual gas equals total pressure times *mole fraction*, not percent weight
C → Incorrect. This describes Avogadro's law
D → Correct answer
E → Incorrect. This describes Charle's law

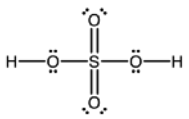
53. What is the molecular geometry of H_2SO_4 in AXE notation?

A. AX_3
B. AX_4
C. AX_3E
D. AX_2E_2
E. AX_5

H_2SO_4 has a total of $2(1) + 6 + 4(6) = 32$ valence electrons. Sulphur is the least electronegative non-hydrogen element, so we draw it as our central atom. Then, we connect the four oxygens to it via single bonds. The two hydrogens are bonded to two oxygens, forming a hydroxyl group. After completing octets of each surrounding atom, we have accounted for every valence electron:



However, sulphur has a +2 formal charge while two oxygens have a −1 formal charge. To minimize formal charges, we can form two double bonds:



Since sulphur is in the third row of the periodic table, it can have an expanded octet. This is the final lewis diagram for H_2SO_4. Since the central atom has four surrounding atoms and no lone pairs, this is an AX_4 configuration.

54. Which set of coefficients would balance the following reaction?

$$Ba_3N_2 + H_2O \rightarrow Ba(OH)_2 + NH_3$$

A. 1, 4, 2, 2
B. 1, 3, 3, 2
C. 2, 3, 6, 1
D. 2, 3, 6, 2
E. 1, 6, 3, 2

We begin by balancing Ba atoms. There are 3 on the left and 1 on the right, so we multiply $Ba(OH)_2$ by 3:

$Ba_3N_2 + H_2O \rightarrow \mathbf{3}Ba(OH)_2 + NH_3$

Next we balance the N atoms. There are 2 on the left and 1 on the right, so we multiply NH_3 by 2:

$Ba_3N_2 + H_2O \rightarrow 3Ba(OH)_2 + \mathbf{2}NH_3$

Then we balance the H atoms. There are 2 on the left and 12 on the right, so we multiply H_2O by 6:

$Ba_3N_2 + \mathbf{6}H_2O \rightarrow 3Ba(OH)_2 + 2NH_3$

Finally we balance the O atoms. There are 6 on the left and 6 on the right, so no coefficients need to be added:

$Ba_3N_2 + 6H_2O \rightarrow 3Ba(OH)_2 + 2NH_3$

55. If a neutral isotope of uranium has an atomic mass of 240, how many neutrons does it contain?

A. 56
B. 92
C. 146
D. 148
E. 332

The atomic mass number (A) of any element is equal to the sum of the atomic number (Z) and the number of neutrons. Z is equal to the number of protons. In a neutral atom, Z is also equal to the number of electrons. Since uranium has Z = 92, therefore it has 92 protons. This means that we can calculate the number of neutrons as follows:

$A = Z + \#\,\text{Neutrons}$

$\#\,\text{Neutrons} = A - Z$

$\#\,\text{Neutrons} = 240 - 92 = 148$

56. An unknown compound has the empirical formula CH_2O. If the molar mass was determined to be 90 g/mol, what is the molecular formula?

A. $C_6H_{12}O_6$
B. CH_2O
C. C_3H_6O
D. $C_3H_6O_3$
E. $C_2H_4O_2$

First we find the molar mass of the empirical formula:

$MM = 12(1) + 1(2) + 16(1) = 29$

Next, we find the ratio between the actual molar mass and the empirical formula molar mass:

$$\text{ratio} = \frac{90}{29} \approx 3$$

Finally, we multiply the subscripts of the empirical formula by this ratio:

$CH_2O \times 3 = C_3H_6O_3$

57. A gaseous mixture containing 2 g of hydrogen and 4 g of helium has a total pressure of 200 kPa. What is the pressure of helium alone?

A. 50 kPa
B. 100 kPa
C. 150kPa
D. 175 kPa
E. 200 kPa

First, convert masses to moles using molar mass:

$$n(H_2) = \frac{m(H_2)}{MM(H_2)} = \frac{2\text{ g}}{1\text{ g/mol}} = 2\text{ mol}$$

$$n(He) = \frac{m(He)}{MM(He)} = \frac{4\text{ g}}{4\text{ g/mol}} = 1\text{ mol}$$

Next, use Dalton's law to calculate the partial pressure of helium:

$P_{partial} = (P_{total})(X_{He})$

$$P_{partial} = (200\text{ kPa})(\frac{1\text{ mol}}{2\text{ mol}}) = 100\text{ kPa}$$

58. What is the concentration of I^- in a saturated solution of AgI, which has a K_{sp} of 9×10^{-2}?

A. 8.1×10^{-3} M
B. 9×10^{-2} M
C. 3×10^{-1} M
D. 1.5 M
E. 2 M

First, write out the dissociation equation and set up an ICE table with the known values:

$$AgI_{(s)} \rightleftharpoons Ag^+_{(aq)} + I^-_{(aq)}$$

I	0 M	0 M
C	$+x$	$+x$
E	x	x

Next, write out the equilibrium constant equation:

$$K_{sp} = [Ag^+_{(aq)}][I^-_{(aq)}]$$

Substitute known values and solve for x:

$$9\times10^{-2} = (x)(x)$$

$$x^2 = 9\times10^{-2}$$

$$x = \sqrt{9\times10^{-2}} = 3\times10^{-1}$$

59. Which of the following statements best describes a Lewis base?

A. Donates protons
B. Accepts protons
C. Releases hydroxide
D. Donates electrons
E. Accepts electrons

A → Incorrect. This is the definition of a Brønsted-Lowry acid
B → Incorrect. This is the definition of a Brønsted-Lowry base
C → Incorrect. This is the definition of an Arrhenius base
D → Correct answer
E → Incorrect. This is the definition of a Lewis acid

60. 56 grams of calcium oxide (CaO) are added to 92 grams of ethanol (C_2H_5OH). Which of the following is expected to occur?

A. Vapour pressure increases by $\frac{1}{2}$
B. Vapour pressure increases by $\frac{2}{3}$
C. Vapour pressure remains the same
D. Vapour pressure decreases by $\frac{2}{3}$
E. Vapour pressure decreases by $\frac{1}{3}$

Vapour pressure depression is a colligative property that describes the decrease in a solvent's vapour pressure after a solute is added. In this case, CaO is the solute and C_2H_5OH is the solvent. First, convert masses into moles:

$$n(\text{CaO}) = \frac{m(\text{CaO})}{MM(\text{CaO})} = \frac{56\text{ g}}{56\text{ g/mol}} = 1\text{ mol}$$

$$n(C_2H_5OH) = \frac{m(C_2H_5OH)}{MM(C_2H_5OH)} = \frac{92\text{ g}}{46\text{ g/mol}} = 2\text{ mol}$$

Next, write out the equation for vapour pressure depression (Raoult's law) and rearrange for the ratio between the vapour pressure of the solution and that of the solvent:

$$P_{solution} = P_{solvent} \times X_{solvent}$$

$$\frac{P_{solution}}{P_{solvent}} = X_{solvent}$$

Substitute known values and solve:

$$\frac{P_{solution}}{P_{solvent}} = \frac{2\text{ mol}}{1\text{ mol} + 2\text{ mol}} = \frac{2}{3}$$

61. Which of the following statements regarding electrochemical cells is CORRECT?

A. Reduction occurs at the anode
B. Voltaic cells have a negative ΔG
C. The salt bridge conducts electrons from anode to cathode
D. Anions of the electrolyte flow to the cathode
E. The cathode is positively charged in an electrolytic cell

A → Incorrect. Reduction always occurs at the cathode, while oxidation occurs at the anode. This can be memorized using the mnemonic "ANO-CPR". See chapter 15 - electrochemistry.
B → Correct answer. Galvanic/voltaic cells are spontaneous
C → Incorrect. A salt bridge is used to connect the electrolyte solutions of the anode and cathode, allowing a free flow of *ions* between the oxidation and reduction reactions. This prevents a buildup of charge on either side of the cell
D → Incorrect. Anions of the electrolyte always migrate to the anode while cations migrate to the cathode
E → Incorrect. In an electrolytic cell, the anode is positive and cathode is negative. This is the opposite for voltaic cells

62. A dental amalgam is composed of 40% silver and 60% tin by mass. What is the mole percentage of silver within this mixture?

A. $\dfrac{\boldsymbol{0.37}}{\boldsymbol{0.87}}$

B. $\dfrac{0.87}{0.37}$

C. $\dfrac{0.34}{0.87}$

D. $\dfrac{0.87}{0.34}$

E. 0.37

Let's assume that we have 100 g of the amalgam:

$m_{Ag} = (0.4)(100\text{ g}) = 40\text{ g}$

$m_{Sn} = (0.6)(100\text{ g}) = 60\text{ g}$

Now we convert masses to moles by dividing by molar mass:

$$m_{Ag} = \frac{40\text{ g}}{108\text{ g/mol}} = 0.37\text{ mol}$$

$$m_{Sn} = \frac{60\text{ g}}{119\text{ g/mol}} = 0.50\text{ mol}$$

Finally, we calculate the mole percentage of silver:

$$\text{Mole \%} = \frac{0.37\text{ mol}}{0.37\text{ mol} + 0.50\text{ mol}}$$

$$\text{Mole \%} = \frac{0.37}{0.87}$$

63. Which of the following statements regarding metals and non-metals is INCORRECT?

A. Metals are lustrous

B. Non-metals are brittle in the solid state

C. Metals oxides form acidic solutions in water

D. Non-metals tend to form anions

E. Calcium is a metal

A → Incorrect because it is true. Metals are lustrous while non-metals are dull

B → Incorrect because it is true. Non-metals are brittle while metals are malleable and ductile

C → Correct because it is false. Metal oxides form basic solutions in water, while non-metal oxides form acidic solutions in water

D → Incorrect because it is true. Non-metals tend to gain electrons to form anions, while metals tend to lose electrons to form cations

E → Incorrect because it is true. Calcium is in the second column of the periodic table, and is therefore an alkaline earth metal

64. The following table contains the empirical initial rates for the reaction:

$$3Cl_2 + 2Fe \rightleftharpoons 2FeCl_3$$

What is the correct rate law?

Trial	$[Cl_2]$	[Fe]	Initial Rate
1	0.7 M	0.7 M	2.5×10^{-2} M/s
2	1.4 M	0.7 M	1.0×10^{-1} M/s
3	0.7 M	2.1 M	2.25×10^{-1} M/s

A. $r = k[Cl][Fe]$

B. $r = k[Cl][Fe]^2$

C. $r = k[Cl][Fe]^3$

D. $r = k[Cl]^2[Fe]^2$

E. $r = k[Cl]^3[Fe]$

Comparing trial 1 and 2, $[Cl_2]$ is doubled:

$$\frac{1.4\text{ M}}{0.7\text{ M}} = 2$$

The initial rate is quadrupled:

$$\frac{1.0\times10^{-1}\text{ M/s}}{2.5\times10^{-2}\text{ M/s}} = 4$$

Since $2^2 = 4$, therefore the reaction is second order with respect to Cl_2

Comparing trial 1 and 3, [Fe] is tripled:

$$\frac{2.1\text{ M}}{0.7\text{ M}} = 3$$

The initial rate is nine times greater:

$$\frac{2.25\times10^{-1}\text{ M/s}}{2.5\times10^{-2}\text{ M/s}} = 9$$

Since $3^2 = 9$, therefore the reaction is second order with respect to Fe

65. Which of the following compounds would have the highest boiling point?

A. CH_4
B. $C_{10}H_{24}$
C. C_2H_4
D. C_3H_8
E. C_2H_6

A compound's boiling point is determined by the strength of its intermolecular forces. The relative strengths of intermolecular and intramolecular forces are:

London Dispersion < Induced Dipole < Dipole-Dipole < Hydrogen Bond < Covalent Bond < Ionic Bond

Since the carbon-hydrogen bond is not polar, we only need to consider London dispersion forces. This force is due to the random distribution of electrons in a non-polar molecule, which allows a momentary polarization to occur, forming a transient dipole. These transient dipoles can induce the polarization of surrounding non-polar molecules, creating a short-lived attraction.

The greater a molecule's surface area, the easier it is to polarize. Therefore, most large molecules have stronger dispersion forces than smaller molecules. Looking at the answer choices, $C_{10}H_{24}$ is the largest compound. Therefore B) is the correct answer

66. The calculated yield for a synthesis reaction is 50 grams of $C_9H_8O_4$. Conducting the actual experiment resulted in only 48 grams. What is the percentage yield and percentage error for this experiment, respectively?

A. 48%; 52%
B. 92%; 8%
C. 8%; 92%
D. 96%; 4%
E. 4%; 96%

The calculation for percentage yield is:

$$\%\,\text{Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\,\%$$

$$\%\,\text{Yield} = \frac{48\text{ g}}{50\text{ g}} \times 100\,\% = 96\,\%$$

The calculation for percentage error is:

$$\%\,\text{Error} = \frac{\text{Approx Value} - \text{Exact Value}}{\text{Exact Value}} \times 100\,\%$$

$$\%\,\text{Error} = \frac{48\text{ g} - 50\text{ g}}{50\text{ g}} \times 100\,\% = 4\,\%$$

67. Which of the following rate laws describes a second-order reaction?

A. $r = k$
B. $r = k[\text{A}]^3$
C. $r = k[A][B]$
D. $r = k[\text{A}][\text{B}]^2$
E. $r = k[\text{A}]^2[\text{B}]^2$

The reaction order describes the relationship between reactant concentrations and the reaction rate. It is equal to the sum of exponents in a reaction's rate law. Therefore, the answer is $r = k[\text{A}][\text{B}]$

68. What is the osmotic pressure exerted by a 2 molar solution of NaCl at 25°C?

A. (298)(8.3)(4) kPa
B. (298)(0.082)(4) kPa
C. (273)(8.3)(4) kPa
D. (273)(0.082)(4) kPa
E. (298)(8.3)(2) kPa

Write out the formula for osmotic pressure:

$\Pi = TRiM$

Since NaCl is an ionic compound composed of two monoatomic ions, it has a van't Hoff factor of 2. Substitute the other known values and solve for Π:

$\Pi = (273 + 25\text{ K})(8.3\text{ L} \cdot \text{kPa} \cdot \text{K}^{-1} \cdot \text{mol}^{-1})(2)(2\text{ M})$

$\Pi = (298)(8.3)(4)\text{ kPa}$

69. Which of the following reactions is balanced?

A. $Zn + 2HCl \rightarrow ZnCl_2 + H_2$
B. $Zn + HCl \rightarrow ZnCl_2 + H_2$
C. $2Zn + 4HCl \rightarrow 2ZnCl_2 + H_2$
D. $Zn + 4HCl \rightarrow 4ZnCl_2 + H_2$
E. $2Zn + HCl \rightarrow 2ZnCl_2 + H_2$

We begin by balancing the Zn atoms. There is 1 on the right and 1 on the left, so the coefficients are already balanced:

$Zn + HCl \rightarrow ZnCl_2 + H_2$

Next we balance the Cl atoms. There are 2 on the right and 1 on the left, so multiply HCl by 2:

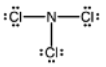
$Zn + \mathbf{2}HCl \rightarrow ZnCl_2 + H_2$

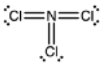
Finally, we balance the H atoms. There are 2 on the left and 2 on the right, so the coefficients are already balanced:

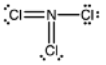
$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

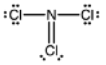
Therefore the correct answer is A)

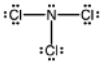
70. What is the correct lewis structure for NCl_3?

A. 

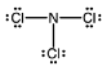
B. 

C. 

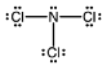
D. 

E. 

NCl_3 has a total of $5 + 3(7) = 26$ valence electrons. Nitrogen is the least electronegative element, so it is the central atom:



After we connect the three chlorines to nitrogen via single bonds, we are left with two remaining electrons. Therefore nitrogen has one lone pair:



All octets are complete and there are no formal charges, so this is the final lewis structure

Solutions – Perceptual Ability Test

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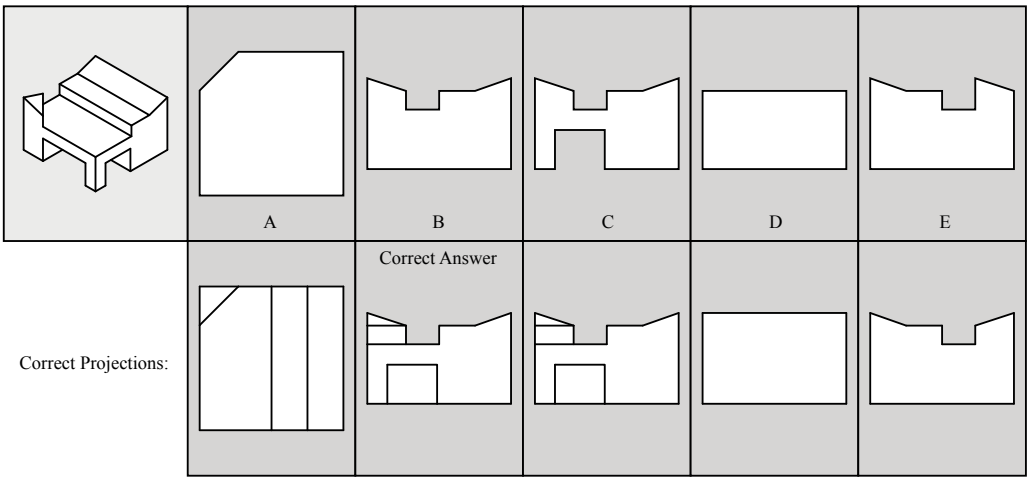

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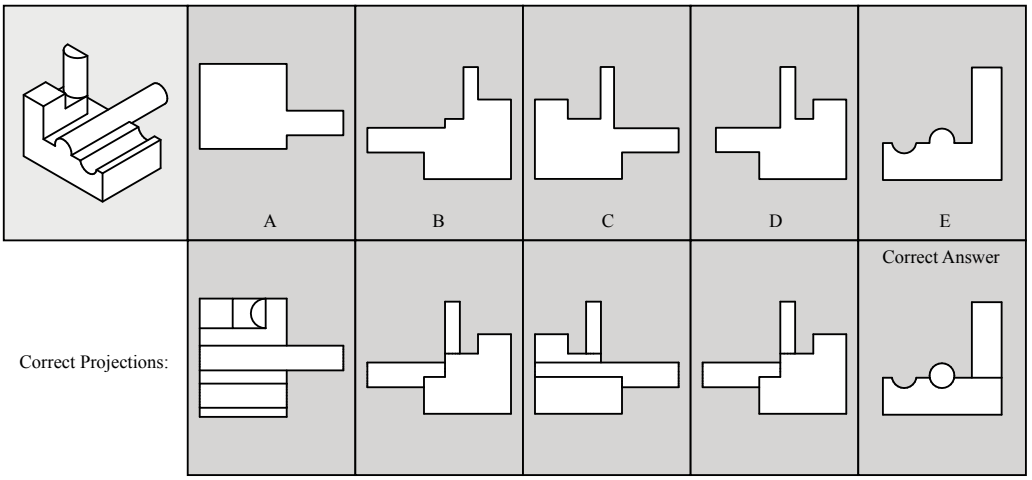

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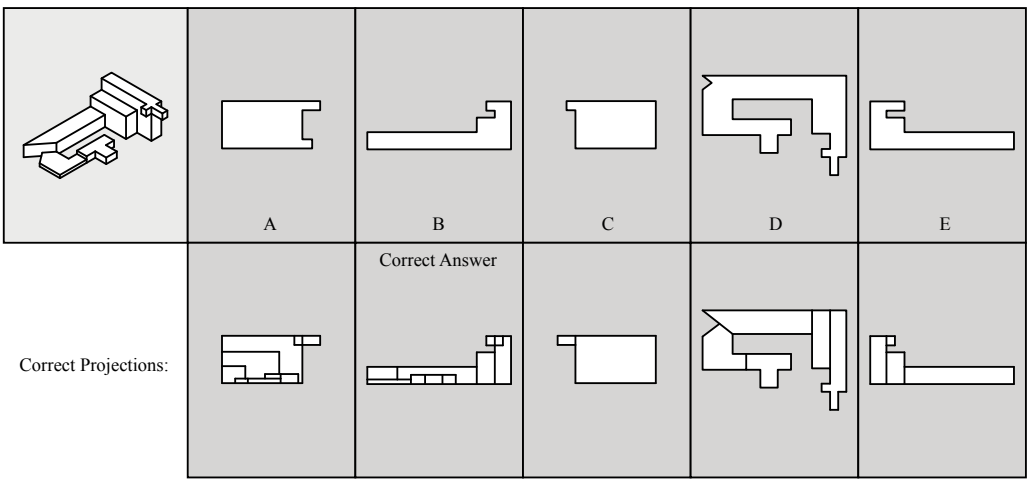

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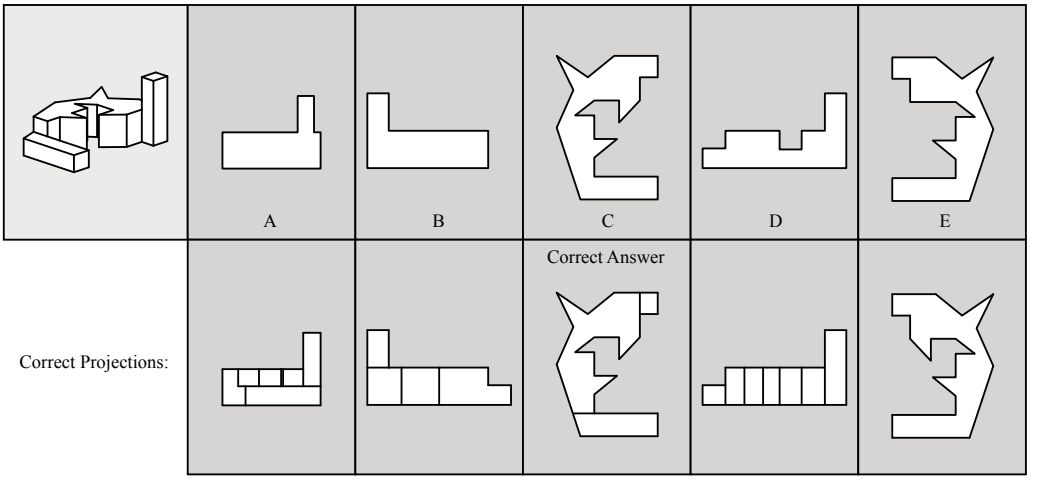
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Correct Answer
Correct Projections:

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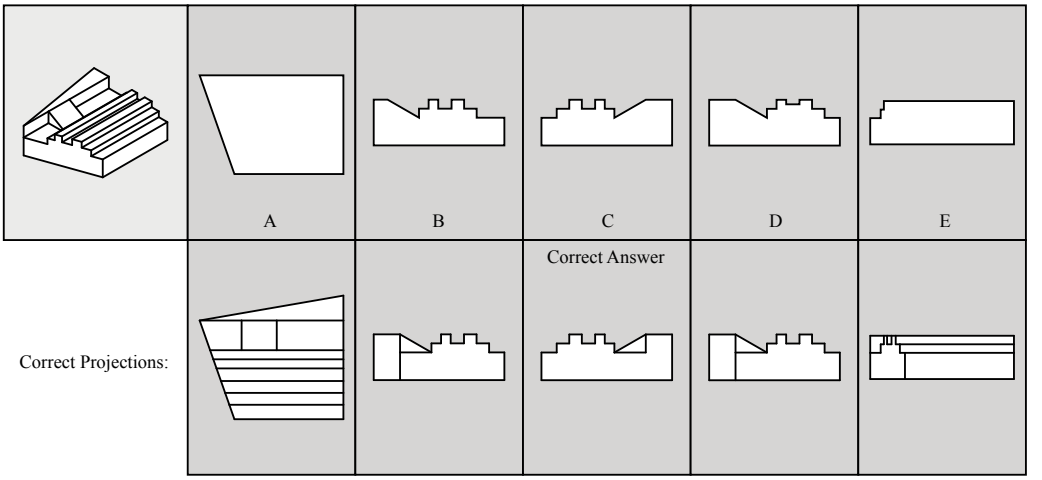
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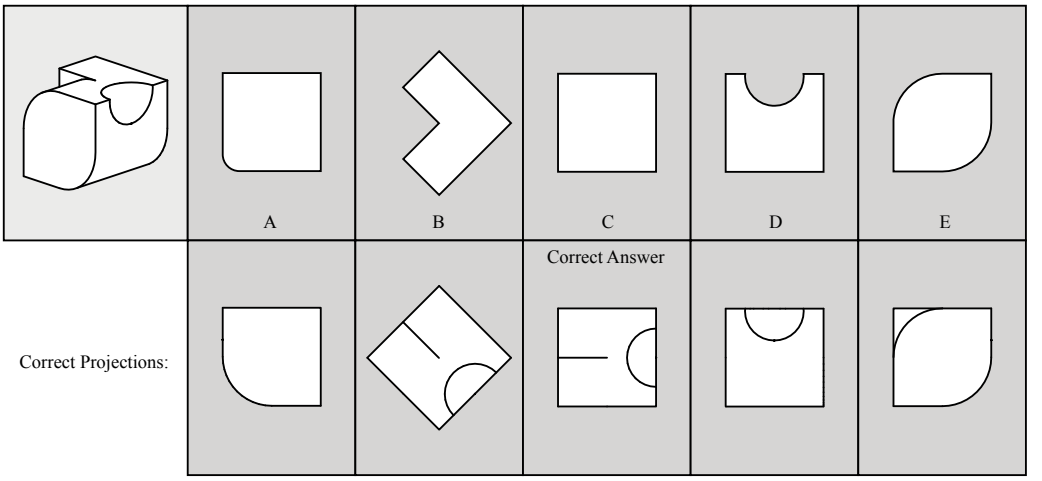
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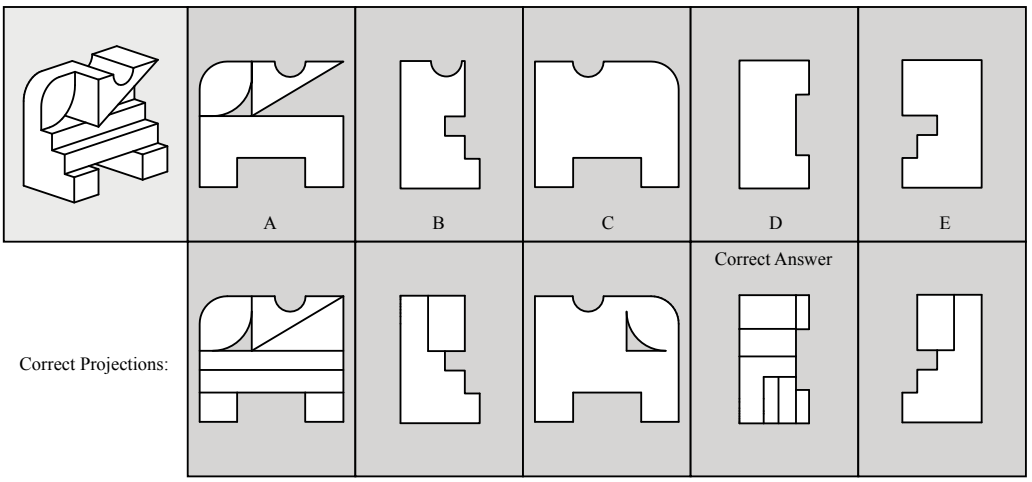
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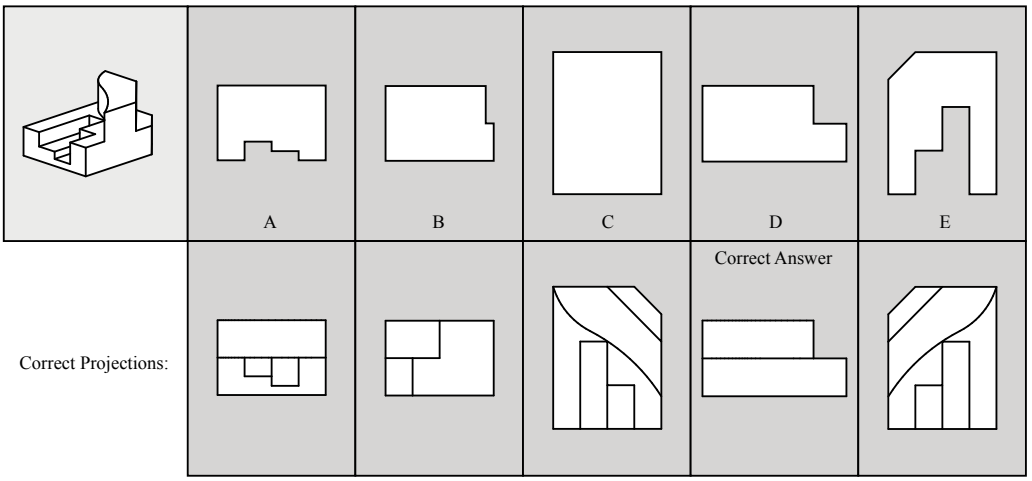
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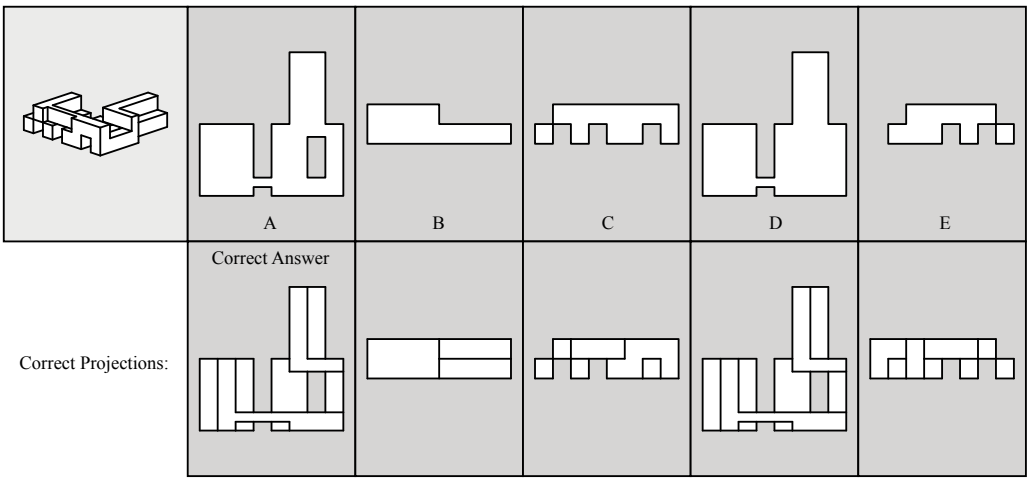
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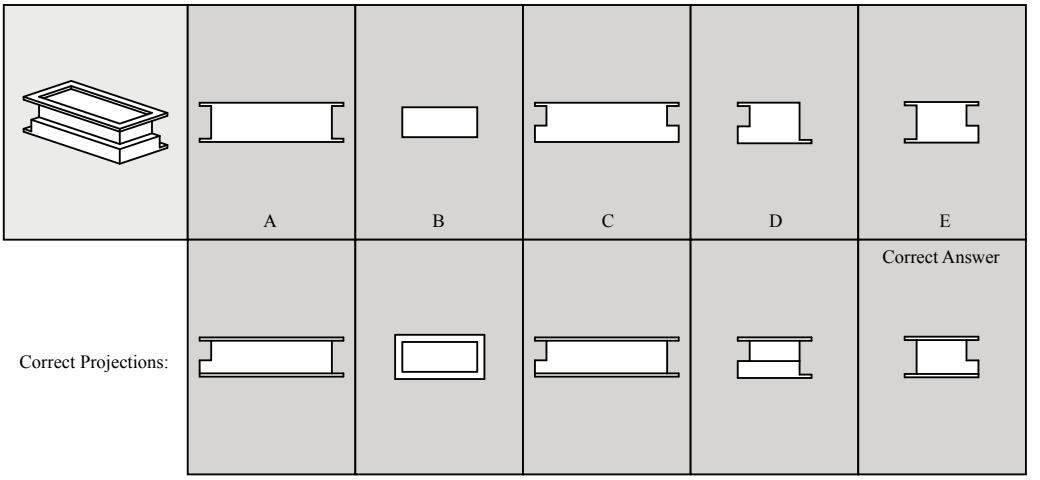
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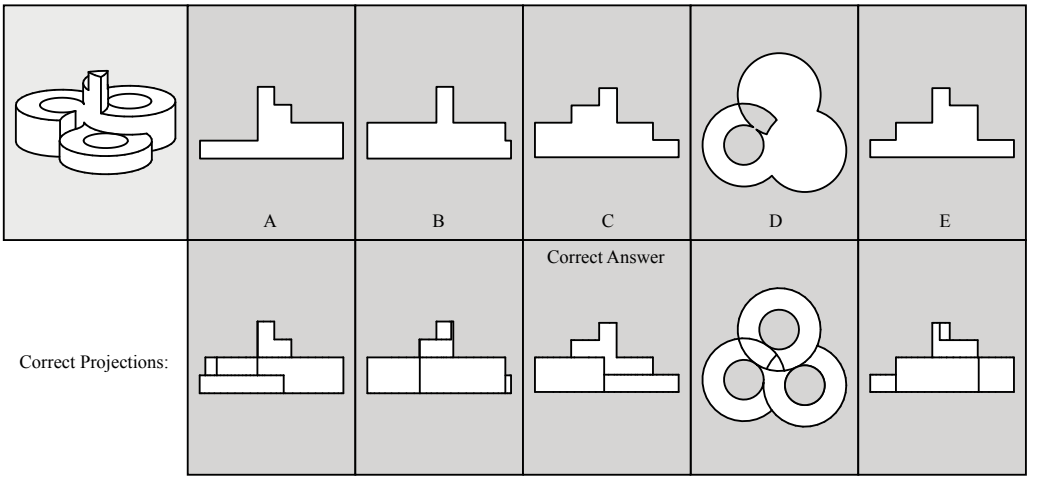
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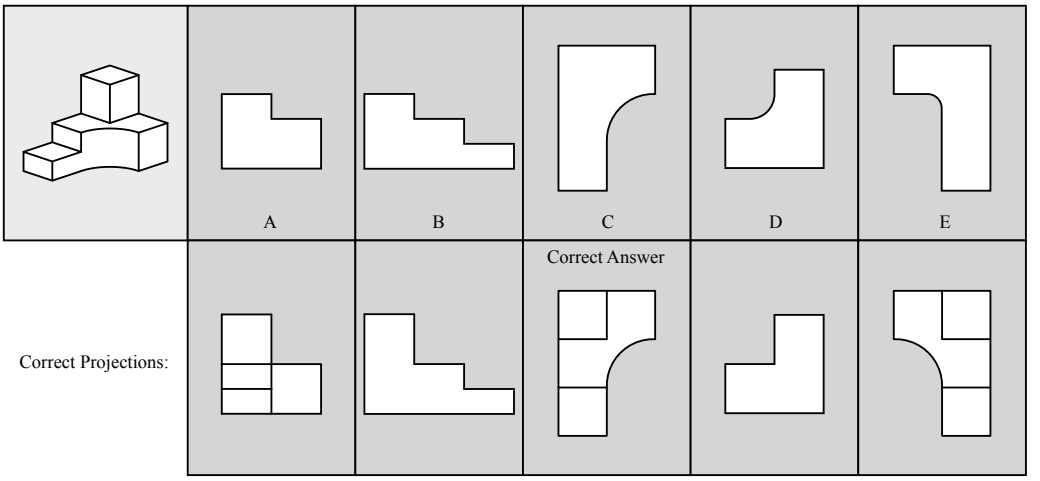
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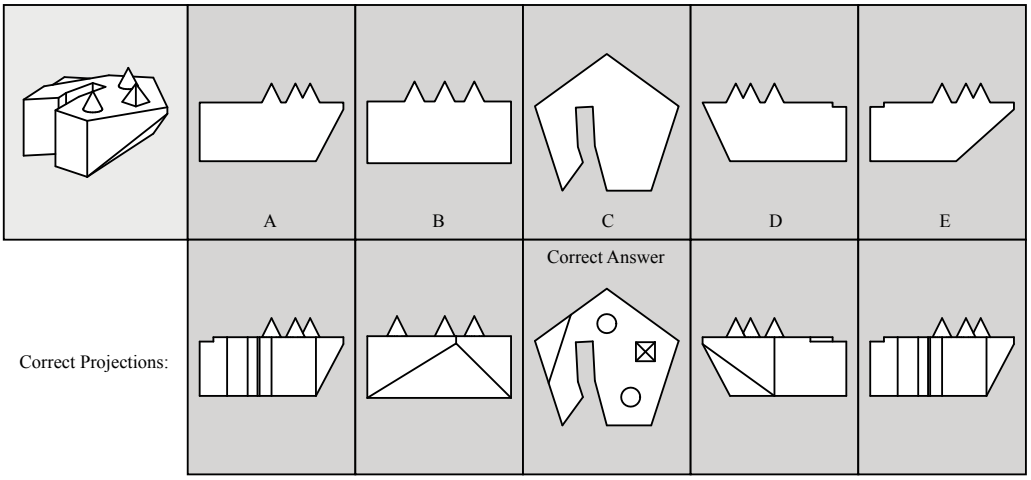
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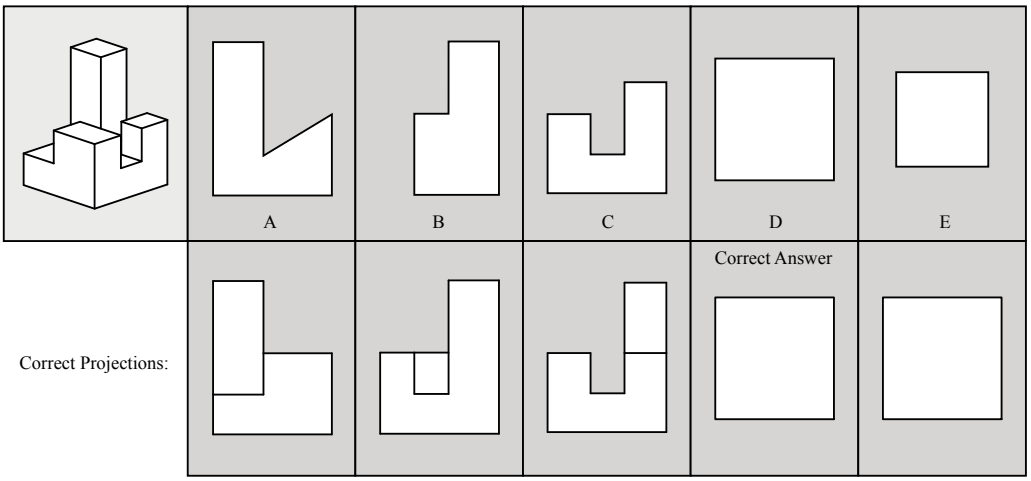
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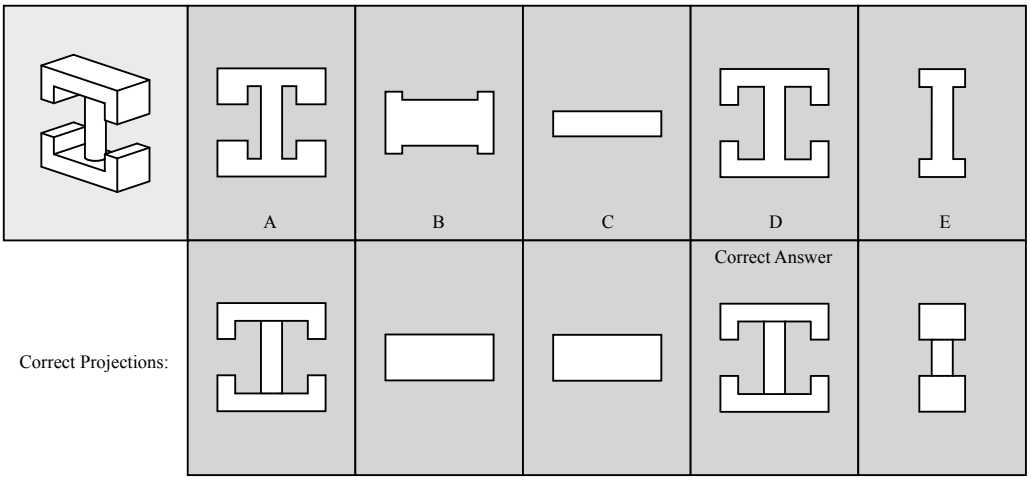
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Correct Answer
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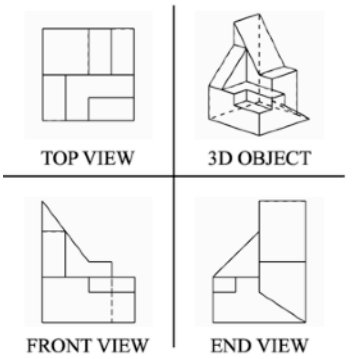
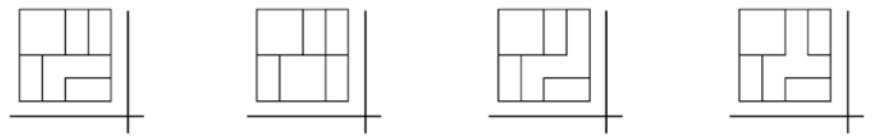
16. Choose the correct TOP VIEW





A

Correct Answer

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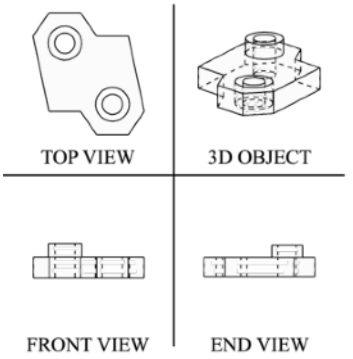
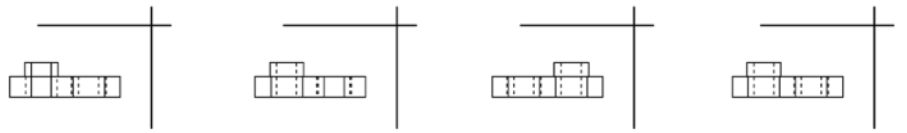
17. Choose the correct FRONT VIEW

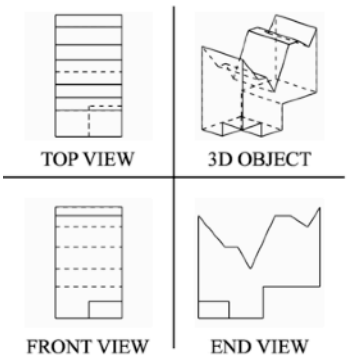


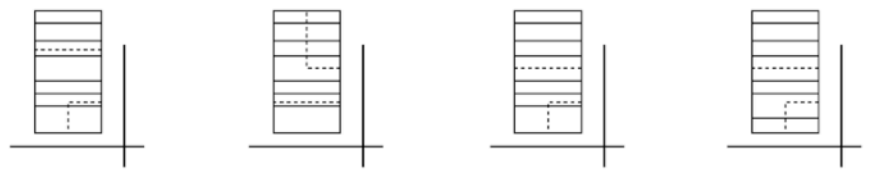


A B C D

Correct Answer

18. Choose the correct TOP VIEW

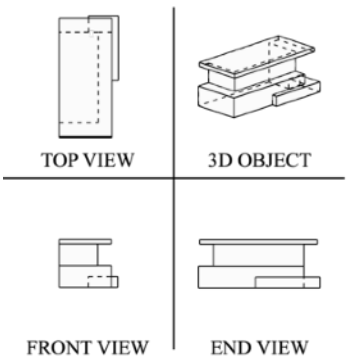


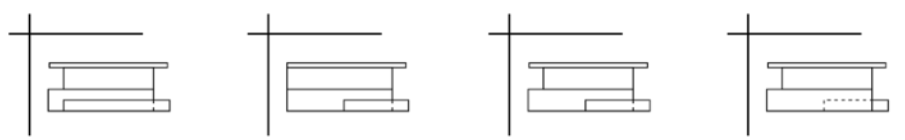


A B C D

Correct Answer

19. Choose the correct END VIEW

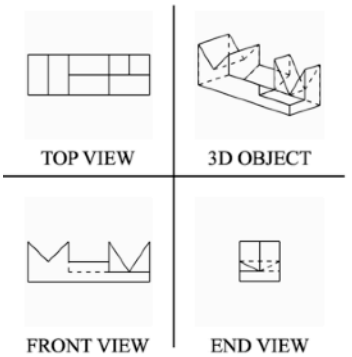


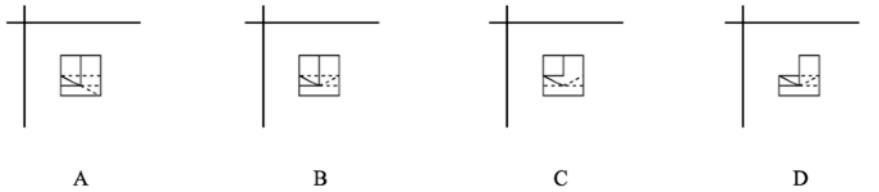


A B C D

Correct Answer

20. Choose the correct END VIEW





Correct Answer

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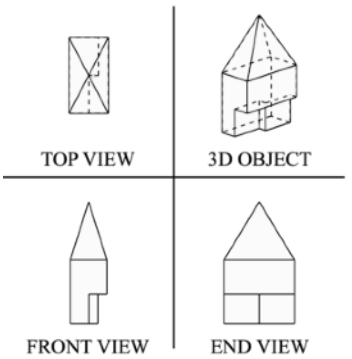

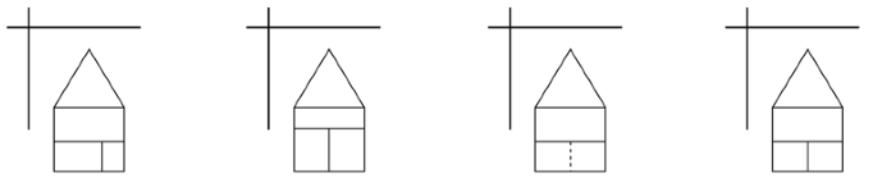

Correct Answer

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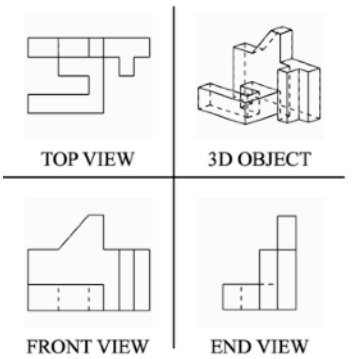

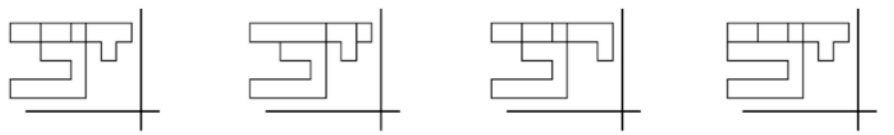

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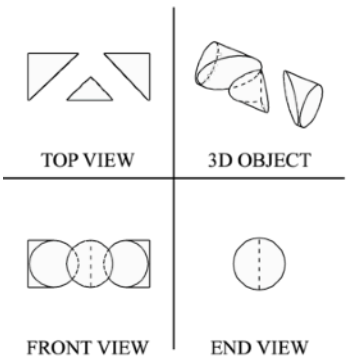

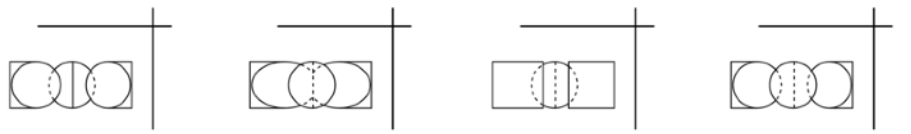

Correct Answer

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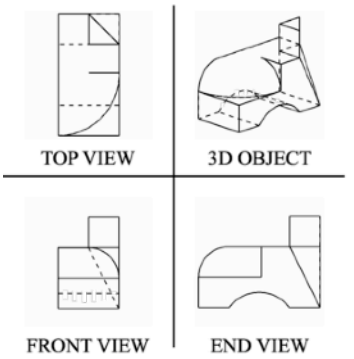

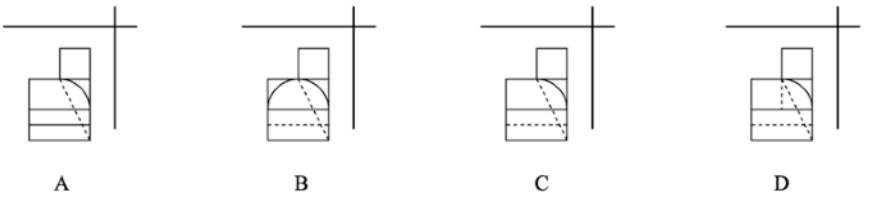

Correct Answer

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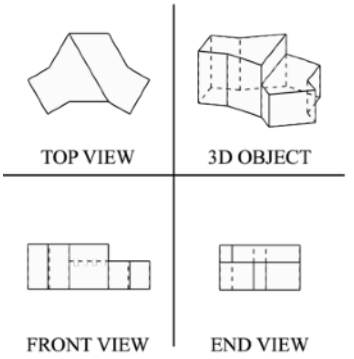

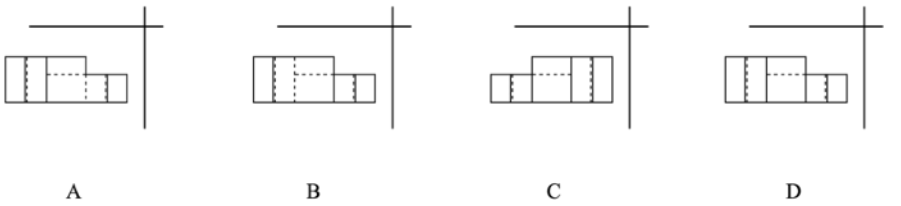

Correct Answer

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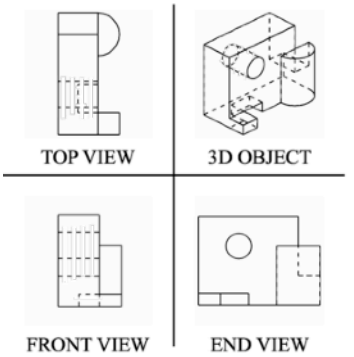



Correct Answer

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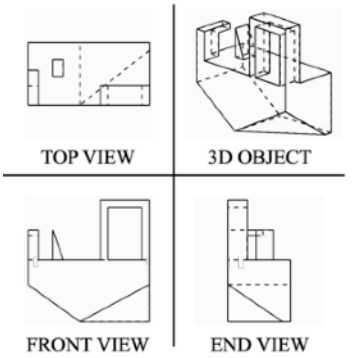

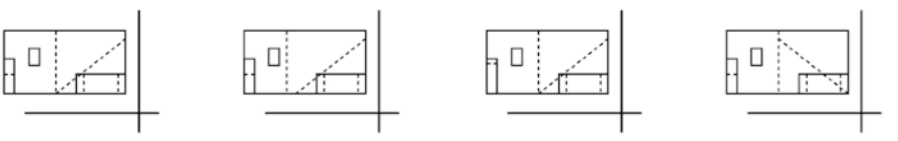

Correct Answer

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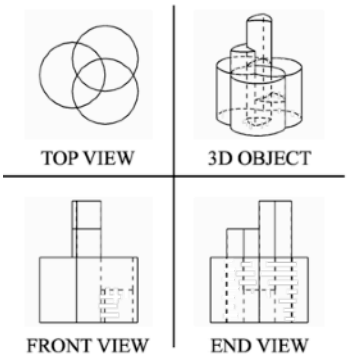

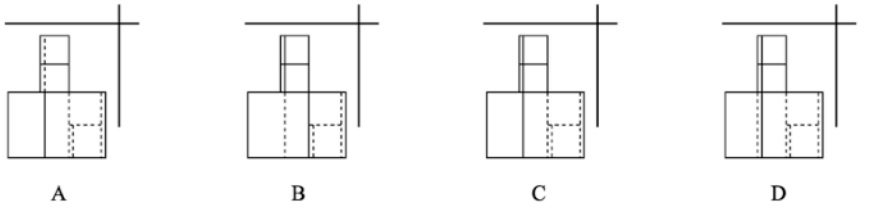

Correct Answer

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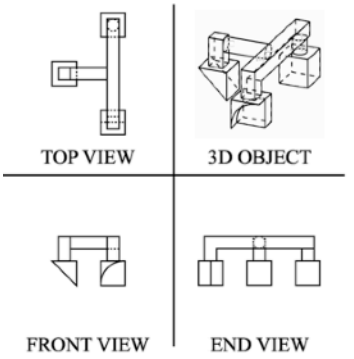

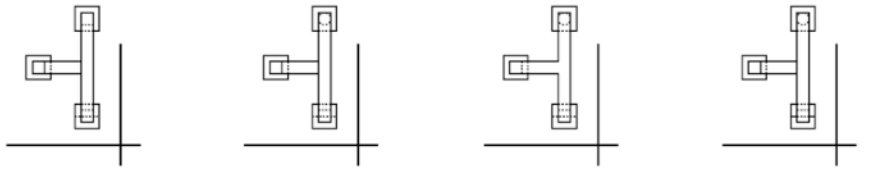

Correct Answer

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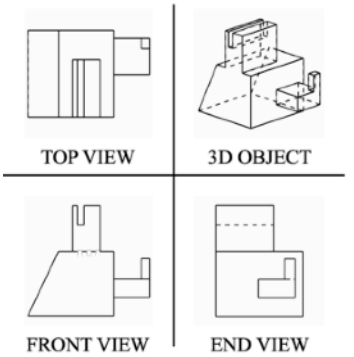

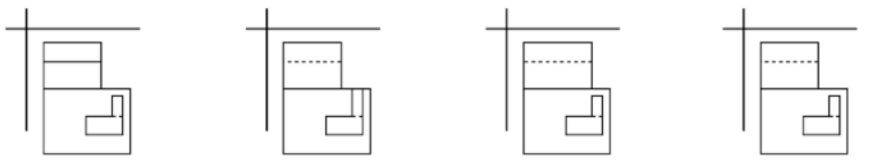

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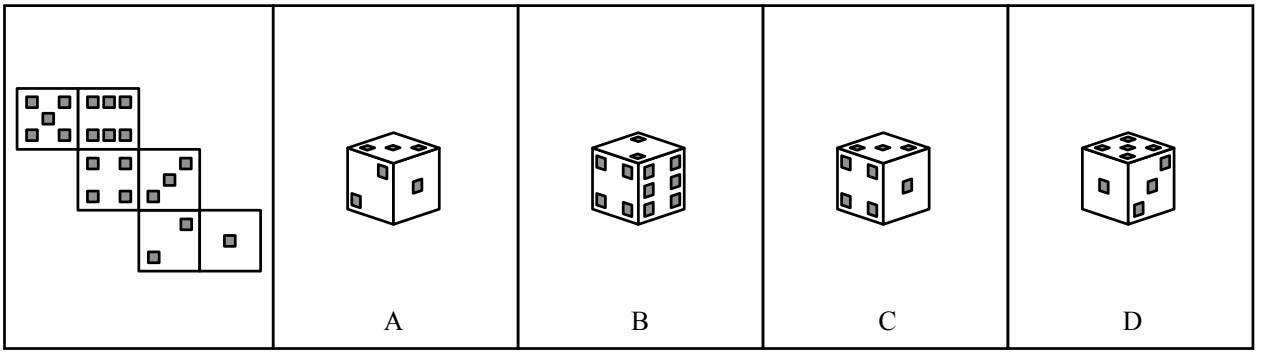

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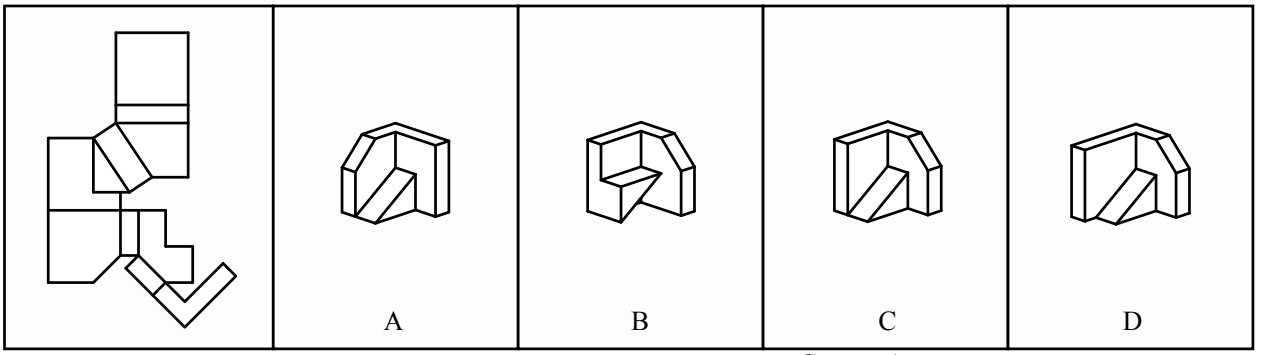

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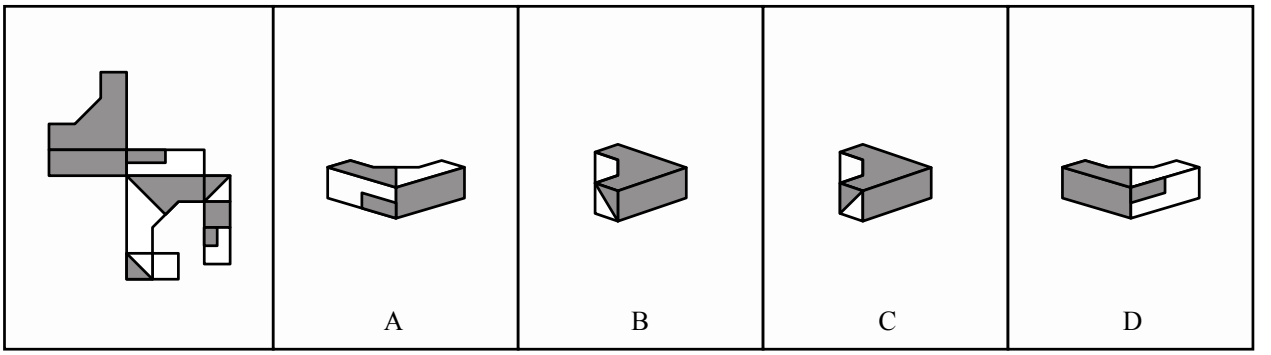

Correct Answer

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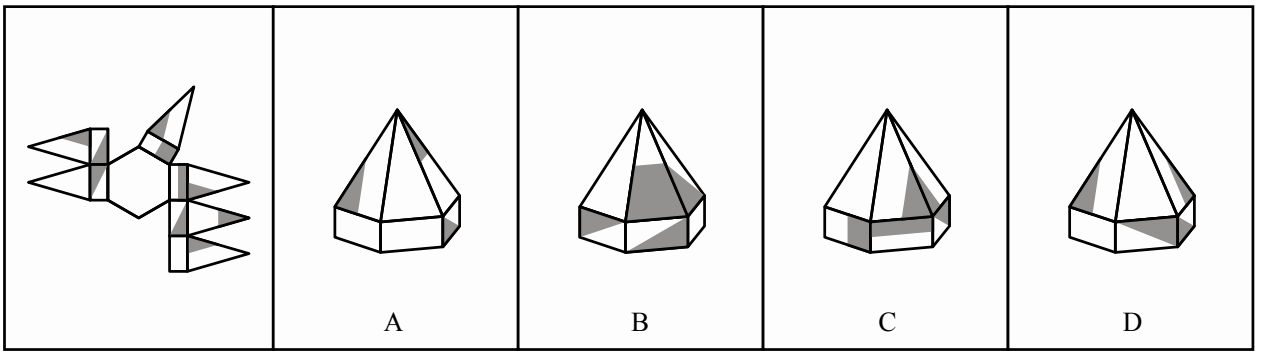

Correct Answer

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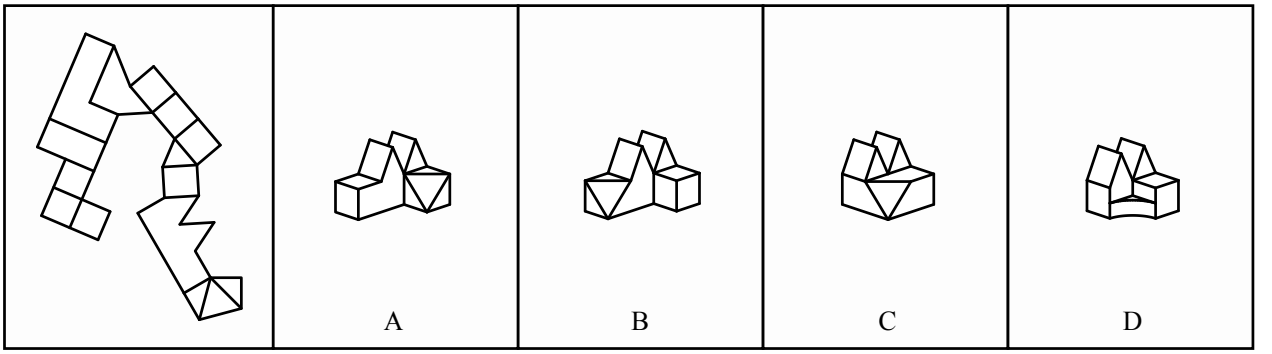

Correct Answer

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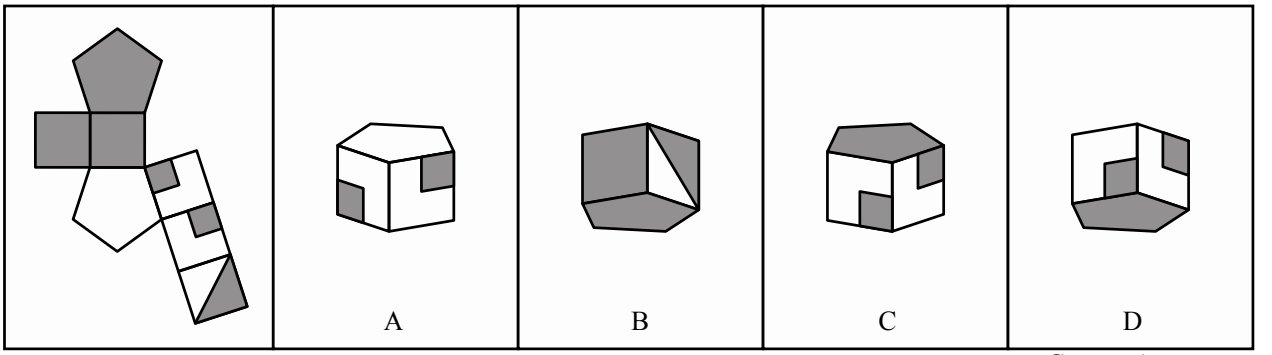

Correct Answer

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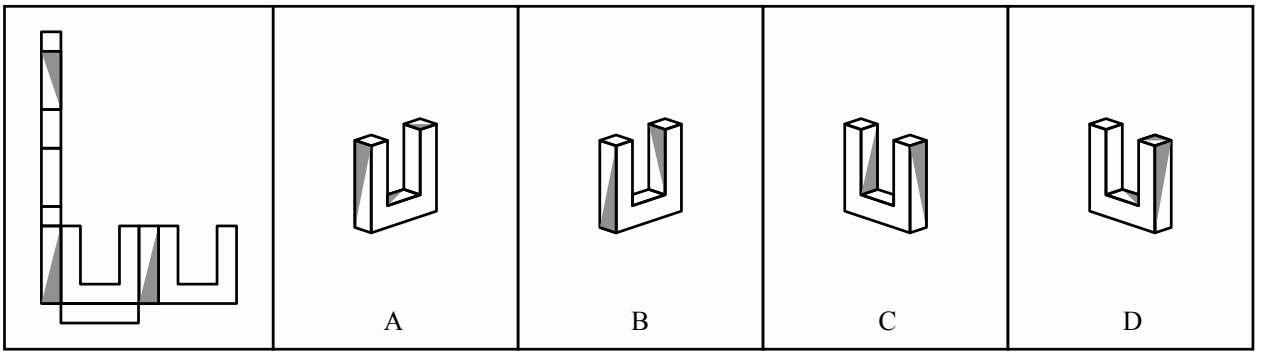

Correct Answer

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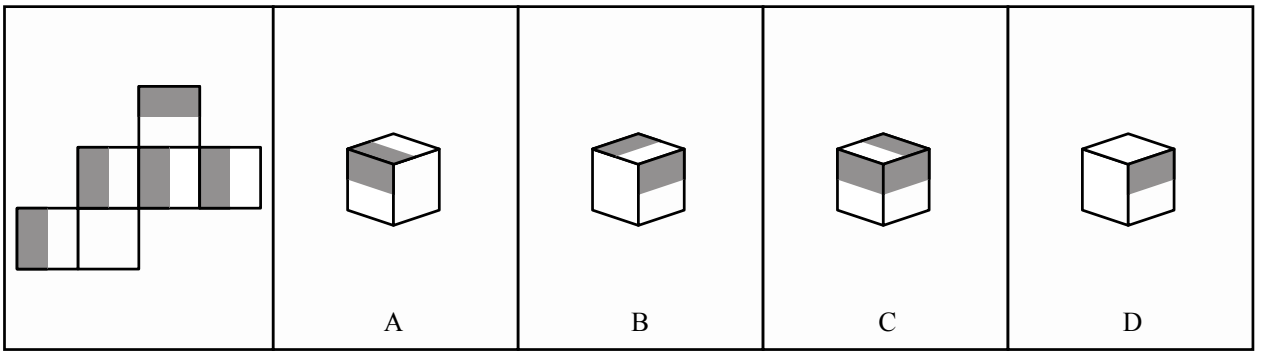

Correct Answer

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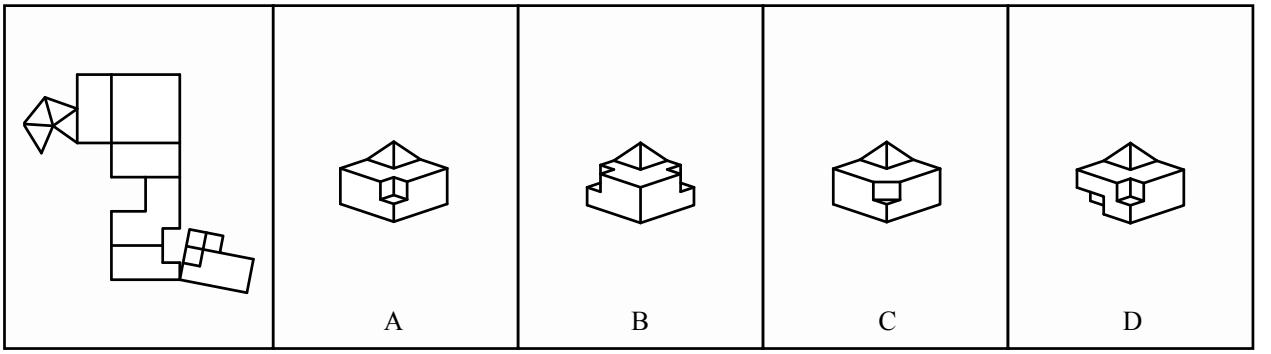

Correct Answer

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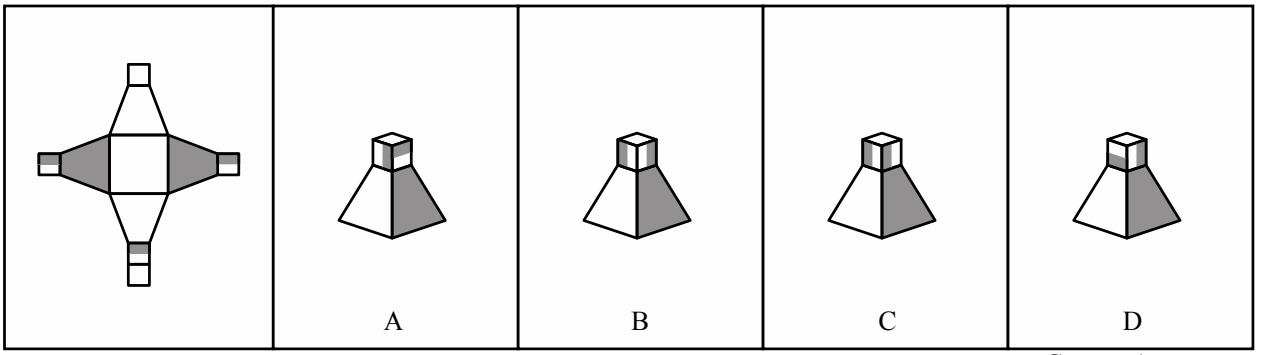

Correct Answer

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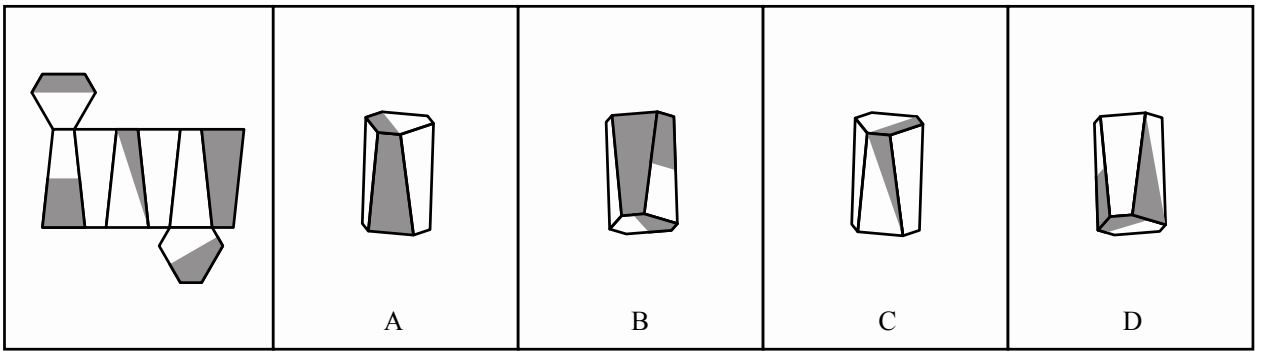

Correct Answer

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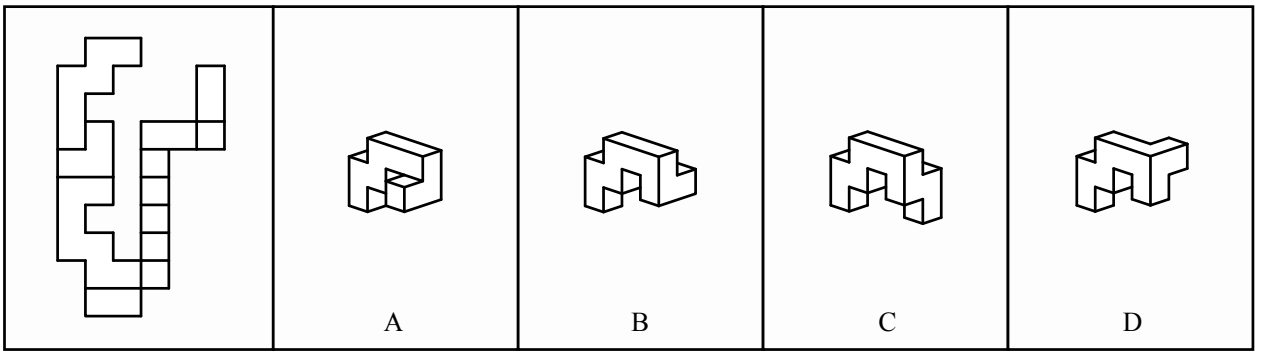

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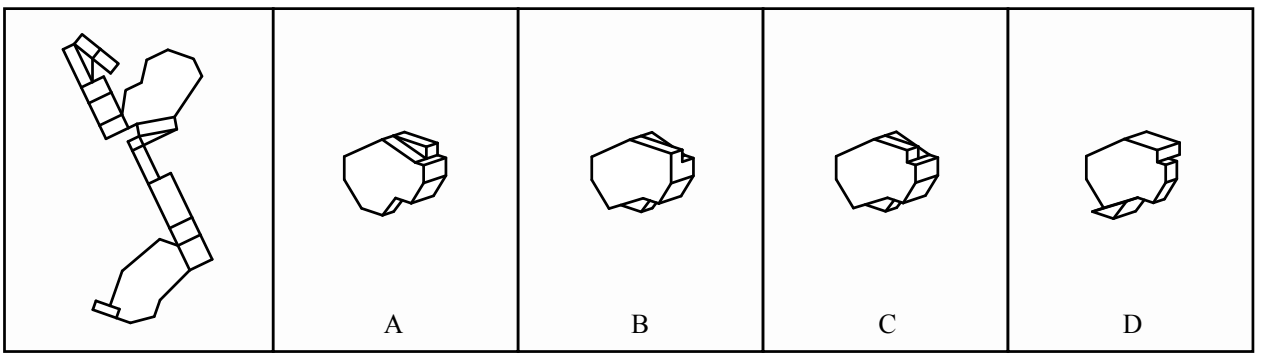

Correct Answer

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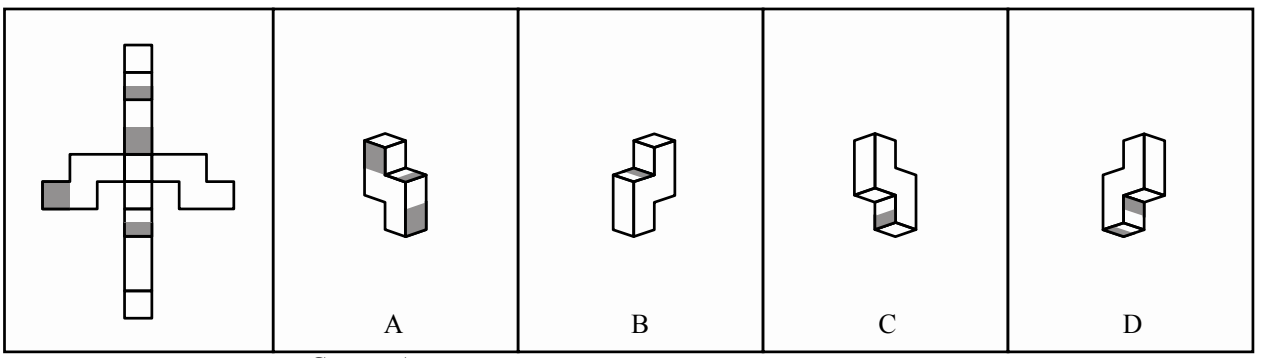

Correct Answer

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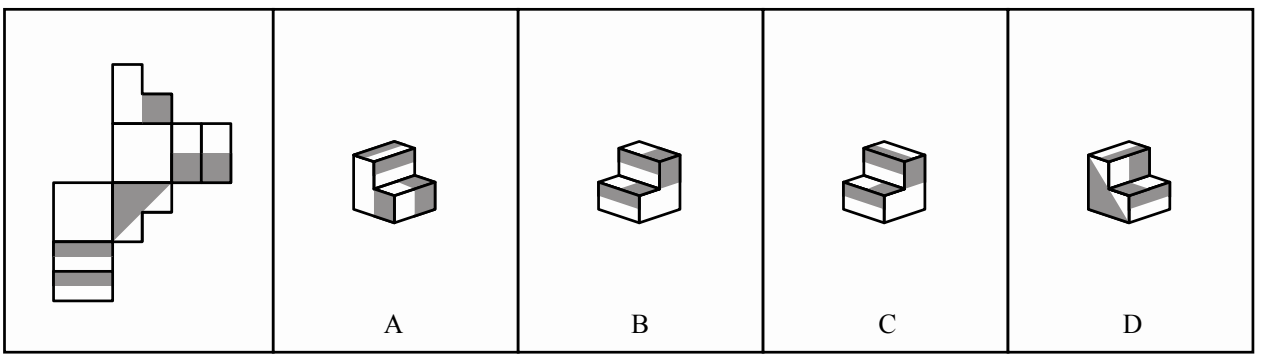


Correct Answer

Solutions – Reading Comprehension Test

1. The first case of DFTD was discovered by which of the following?
   A. A veterinarian
   B. An oncologist
   C. An Australian researcher
   D. A wildlife photographer
   E. A Tasmanian farmer

   According to the second paragraph, "In 1996, wildlife photographer Christo Baars set out to capture images of the iconic Tasmanian devil. Unintentionally, the photographer observed several devils with faces severely disfigured by large neoplasms – these photographs were the first known incidence of DFTD"

2. Which of the following correctly describes the allograft theory of disease transmission?
   A. DFTD is spread via sexual intercourse
   B. Pesticides and organic chemicals cause spontaneous DFTD
   C. DFTD is transmitted via retroviruses
   D. DFTD is transmitted via airborne droplets
   E. DFTD is transmitted via biting

   According to paragraph three, "The allograft theory was first proposed by A.M. Pearse et al. in a 2006 *Nature* paper. Pearse notes that in the late stages of DFTD, the tumours ulcerate, and fragments become easily dislodged during the devil's frequent fighting behaviour … This led scientists to hypothesize that DFTD is transmitted when cancer cells are passed directly between devils via biting behaviour."

3. Which of the following is NOT a potential cause of death in Tasmanian devils with DFTD?
   A. Starvation
   B. Organ failure
   C. Pulmonary embolism
   D. Secondary infection

   According to the first paragraph, "DFTD is highly lethal, with death occurring usually within six months of inoculation due to organ failure, secondary infection, or starvation"

4. How is DFTD different from HPV and CTVT, respectively?
   A. DFTD is bacterial; DFTD is not contagious
   B. DFTD is non-viral; DFTD is not sexually transmitted
   C. DFTD causes latent tumours; DFTD is not spread through allograft theory
   D. DFTD is non-viral; DFTD is far less lethal
   E. DFTD affects animals instead of humans; DFTD is not sexually transmitted

   According to paragraph four, "Unlike other transmissible tumours such as human papillomavirus (HPV), DFTD is non-viral. The only other non-viral transmissible cancer is canine transmissible venereal tumour (CTVT), which effects the genitalia of dogs and is sexually transmitted"

5. What scientific journal was the allograft theory of disease transmission first published in?
   A. Science
   B. The Lancet
   C. Nature
   D. The Journal of Infectious Diseases
   E. PLOS Pathogens

   According to paragraph three, "The allograft theory was first proposed by A.M. Pearse et al. in a 2006 Nature paper"

6. Tasmanian devils can reduce the transmission of disease by removing reservoirs for zoonotic pathogens such as canine transmissible venereal tumour (CTVT)
   A. Both the statement and reason are correct and related
   B. Both the statement and reason are correct but NOT related
   C. The statement is correct but the reason is NOT
   D. The statement is NOT correct, but the reason is correct
   E. NEITHER the statement NOR the reason is correct

   According to paragraph five, "By removing reservoirs for zoonotic pathogens such as lymphocytic choriomeningitis virus and *Toxoplasma gondii*, devils reduce the transmission of both animal and human disease". CTVT is not explicitly described in the passage as a zoonotic disease. Therefore, the statement is true, but the reason is false.

7. What does the author describe as three key aspects of DFTD?
   A. Pathophysiology, transmission, social impact
   B. Transmission, pathophysiology, preservation
   C. Global impact, preservation, transmission
   D. Transmission, prevention, education
   E. Economy, ecology, public health

   According to the first paragraph, "Three key aspects of this disease are transmission, global impact, and preservation"

8. Which of the following chromosomal arrangements was NOT found in the 11 facial tumours from wild and euthanized devils?
   A. Chr1q duplication
   B. ChrX deletion
   C. Haploid Chr6
   D. ChrY deletion
   E. Chr1 deletion

   According to paragraph three, "The authors found that all of the 11 facial tumours analyzed consistently had the same chromosomal rearrangements (chr1 deletion, chrX deletion, chrY deletion, haploid chr6, chr1q deletion, and four unknown chromosomal fragments)"

9. During what year did Tasmanian devils experience a population bottleneck?
   A. 1996
   B. 2006
   C. 1830
   D. 1900
   E. 2001

   According to paragraph five, "… Tasmanian devils have a very high degree of genetic similarity because of a population bottleneck during the 1900s that resulted in widespread inbreeding"

10. How is DFTD similar to post-transplant metastasis?
    A. Both conditions are contagious
    B. In both situations, the cancer is able to bypass the immune system
    C. Both conditions are more common in immunocompromised patients
    D. In both situations, the cancer does not contain MHC I surface markers
    E. Both diseases have significant economic, cultural, and environmental effects

    A → Incorrect. The author only explicitly states that *DFTD* is contagious: "… DFTD is transmitted when cancer cells are passed directly between devils via biting behaviour"
    B → Correct. The author states in paragraph four: "… DFTD is known for its ability to evade immune detection via the absence of major histocompatibility complex (MHC) class I molecules and the production of immunosuppressive cytokines. This is similar to how many human cancers modulate the anti-tumour response by reducing their immunogenicity"
    C → Incorrect. The author only states that *post-transplant metastasis* occurs when "… latent tumours from a donor are able to re-enter a proliferative state thanks to the recipient's immunocompromised condition". See paragraph four
    D → Incorrect. The author only states that *DFTD* is able to "… evade immune detection via the absence of major histocompatibility complex (MHC) class I molecules …". See paragraph four
    E → Incorrect. The author only reference DFTD as having "… significant economic, cultural, and environmental effects". See paragraph four

11. Which of the following statements would the author most likely agree with?
    A. The Tasmanian devil is an insignificant species for Australia's well-being
    B. Captive breeding is an effective strategy to preserve the devil species
    C. Killing infected devils is morally acceptable
    D. Tasmanian farmers were unknowingly harming themselves by killing the devils
    E. Scientists are unlikely to find a cure for DFTD

    A → Incorrect. According to paragraph six, "Tasmania's national parks and unique geography help make it the destination of choice for a significant portion (16%) of visitors to Australia. Animals such as the devil play a large role in creating this allure for foreign visitors, through both official representation and popular culture". Therefore it is clear that the author believes the devil to be of considerable importance to Australia
    B → Incorrect. In paragraph eight, captive breeding can "… retain up to 95% of the wild population's genetic diversity". However, the author does not argue that greater retention of diversity equates to greater effectiveness of preservation. This answer choice *may* be correct only under certain circumstances. We must examine the other options for statements the author would *more likely* agree with
    C → Incorrect. Although the author states in paragraph eight that "Early efforts at controlling the DFTD epidemic involved field-level work such as the monitoring of disease propagation and the early trapping/culling of infected devils to reduce disease prevalence", the author does not provide his/her opinion on morality of this practice. We can only conclude that the author's stance is neutral on this issue

D → Correct. At the beginning of paragraph five, the author states "As early as 1830, the devil was treated as a pest by the agricultural industry and culled in large numbers". However, the author later claims that Tasmanian farmers actually *benefit* from the speed at which the devil removes carcasses, which prevents the spread of harmful insects to livestock. Therefore we can conclude with near certainty that the author would agree with this answer choice statement
E → Incorrect. In the last paragraph, the author states "Given that we are fortunate to be in this era of incredible medical advancement, this puts us in a unique and very promising position to eventually eradicate the disease and save the endangered devils from extinction". This suggests the author believes in the opposite of what the answer choice states

12. Which of the following lab techniques were NOT used in the study by Kreiss *et al.*?
    A. Western blotting
    B. ELISA
    C. Flow cytometry
    D. Sonication
    E. G-banding

According to the second last paragraph, "… Kreiss et al. inactivated 108 DTFD tumour cells via freeze/thawing or sonication … Jugular blood was drawn 14 days before and after each immunization and analyzed for antibody response via flow cytometry, enzyme-linked immunosorbent assay (ELISA), and western blot"

13. Which of the following is NOT a human cancer vaccine?
    A. STDP-1
    B. BiovaxID
    C. Oncophage
    D. Sipuleucel-T

According to the second last paragraph, "Since the majority of human cancer vaccines (Sipuleucel-T, BiovaxID, Oncophage, etc.) are therapeutic immunostimulants and not preventative agents, fabrication of the DFTD vaccine may serve as point of insight for scientists working on ways to proactively treat human cancers"

14. What is the main idea of the second last paragraph?
    A. Humoral and cell-mediated immune responses can be mediated by vaccines
    B. STDP, captive breeding, blood testing, and oocyte vitrification are some of the efforts made in controlling DFTD
    C. Influenza kills 10 times more animals than DFTD annually
    D. Advances in human and animal medicine can be used to inform each other
    E. Many principle in human and animal medicine are identical and interchangeable

A → Incorrect. Although this was demonstrated in the 2015 study, this is not the focus of the author's discussion
B → Incorrect. This is the main idea of the third last paragraph, not the second last
C → Incorrect. This is not mentioned anywhere in the paragraph, much less the passage
D → Correct. The author spends the majority of the paragraph discussing how advances in the 2015 study may have applications in human cancer vaccines. The author also states at the beginning of the paragraph: "The line between human and animal medicine is becoming increasingly blurred in today's society, a trend exemplified by the 2015 vaccine breakthrough that resulted from the application of immunotherapy to DFTD"
E → Incorrect. Although the author believes that the fields of human and animal medicine are becoming increasingly interconnected, this answer choice takes this opinion to the extremes. We cannot conclude that the author thinks that human and animal medicine are interchangeable

15. Which of the following is NOT a positive outcome of DFTD's existence?
    A. Fabrication of a DFTD vaccine may provide insight for human cancer vaccines
    B. Increased motivation for the research and development of CTVT therapies
    C. Reduction of animal encroachment onto human settlements
    D. The disease revolutionized the way cancer biologists conceptualize oncogenesis
    E. Development of a novel prophylactic cancer vaccine

A → Incorrect. According to the second last paragraph, "… fabrication of the DFTD vaccine may serve as point of insight for scientists working on ways to proactively treat human cancers"

B → Incorrect. According to the last paragraph, "Research into the transmission of the disease has revolutionized the way cancer biologists conceptualize oncogenesis and has increased the motivation for scientists to develop therapies for CTVT and even human cancers"
C → Correct. Paragraph seven states that the removal of the Tasmanian devil may lead to a top-down trophic cascade that results in habitat destruction. Because of this, animals may encroach onto human settlements, thus *negatively* effecting residential areas. Therefore this is not a positive outcome
D → Incorrect. According to the last paragraph, "Research into the transmission of the disease has revolutionized the way cancer biologists conceptualize oncogenesis and has increased the motivation for scientists to develop therapies for CTVT and even human cancers"
E → Incorrect. According to the last paragraph, "Preservation responses for Tasmanian devils has led to the development of a novel prophylactic cancer vaccine, the theory of which may one day be applied to human cancers"

16. The first case of DFTD occurred in sometime during the 20th century.

    Evidence that suggested biting behaviour could transmit DFTD was first discovered in 2006.

    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

According to the last paragraph, "DFTD is a fairly recent disease—the "patient zero" event causing the DFTD epidemic occurred sometime during the 21st century". Therefore the first statement is false.

The second paragraph states that "… in 2006, a devil that had escaped from a park was recaptured with bite marks. She later wounded a male, and both devils developed DFTD six months later". Therefore the second statement is true.

17. What is the author's tone in the last paragraph?

    A. Impartial
    B. Satirical
    C. Sarcastic
    D. Optimistic
    E. Ambivalent

A → Incorrect. Although the author summarizes the passage's points in a fairly neutral way, the last sentence very clearly expresses the author's opinion about DFTD
B → Incorrect. The author does not use irony to ridicule or mock individuals, corporations, governments, or society with the intention of entertaining and prompting improvement
C → Incorrect. The author does not use hyperbole or exaggeration to convey that he/she believe the opposite of what is written to be true
D → Correct. In the last sentence, the author choses to emphasize the positive aspects of the DFTD problem and conveys a sense of hope to the reader
E → Incorrect. The author does not express uncertainty or fluctuation between two ideas

18. In which paragraph does the author discuss the history of the Tasmanian devil species?

    A. Paragraph two
    B. Paragraph three
    C. Paragraph four
    D. Paragraph five
    E. Paragraph six

In paragraph five, the author begins to discuss how the Tasmanian devil was treated historically by farmers and the agricultural industry. Paragraphs two-four discuss DFTD, not the devil species itself. Paragraph six discusses the devil's role in Australian and Tasmanian tourism, not the species' history

19. In paragraph eight, why does the author use quotes around the words "insurance" and "ambassadors"?

    A. To indicate dislike or contempt for the words
    B. To suggest skepticism
    C. To indicate that they are not his/her own words
    D. To highlight the irony of the words
    E. To indicate that the words are too superfluous for the relatively mundane subject they describe

Paragraph eight is written from a very neutral and objective point of view. The author does not attempt to project his/her opinion that the situation is disliked, skepticism-inducing, ironic, or mundane. Therefore the best answer is C)

20. Which of the following describes a similarity between the citizens of Texas and Colorado?
    A. The teeth of people from Texas were stained, while the teeth of people from Colorado showed more decay
    B. The teeth of people from both Texas and Colorado showed no staining but more decay
    C. The teeth of people from Texas showed more decay, while the teeth of people from Colorado were stained
    D. The teeth of people from both Texas and Colorado showed no decay but were stained
    E. The teeth of people from both Texas and Colorado showed both staining and decay

    According to paragraph two, "In the early 1900s, Dr. Frederick S. McKay began an almost 30-year search for the cause of the staining of teeth that was prevalent in Colorado … In his investigation, McKay found the condition common in other states, including Texas … In 1928, he concluded that such teeth, although stained, showed 'a singular absence of decay,' and that both the staining and the decay resistance were caused by something in the water"

21. The author describes Frederick S. McKay as practicing "shoe leather epidemiology".

    Fluoridation has been shown to increase the incidence of cavities from 20 to 40%
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

    According to paragraph three, "Years of 'shoe leather epidemiology' by Dr. H. Trendley Dean traced the dental status of 7,000 children who drank naturally fluoridated water in 21 cities in four states". Therefore the first statement is false.

    According to paragraph five, "Recent data have shown that fluoridation has been reducing the incidence of cavities 20% to 40% in children and 15% to 35% in adults". Therefore the second statement is also false.

22. What is the concentration of fluoridated tap water in parts per million?
    A. 1 ppm
    B. 2 ppm
    C. 3 ppm
    D. 10 ppm
    E. 20 ppm

    According to the first paragraph, "Fluoridation is the adjustment of the natural fluoride concentration to about one part of fluoride to one million parts of water". Therefore, the concentration is one parts per million

23. Which of the following statements is the author LEAST likely to agree with?
    A. The fluoridation of water is an entirely man-made and artificial phenomenon
    B. Individuals who spread misinformation about fluoridation are a risk to public health
    C. There is an ideal concentration of fluorine
    D. Tap water fluoridation will actually save a community money in the long term
    E. The majority of Americans live in communities with fluoridated water

    A → Correct. In the first paragraph, the author states that "Fluoride is a mineral that occurs naturally in most water supplies". Therefore, it is very unlikely that the author would agree that the concept of fluoridation is *entirely* artificial
    B → Incorrect. Throughout the passage, the author argues that fluoridation is effective and essential for public health. In the last paragraph, the author states "In conclusion, fluoridation is supported by libraries of articles that document its safety and effectiveness—more so than any other public health measure". Furthermore, the author states in the first paragraph that "Although fluoridation is safe and effective in preventing tooth decay, the scare tactics of misguided poisonmongers have deprived many communities of its benefits". Therefore the author would agree with the statement in this answer choice
    C → Incorrect. According to paragraph three, "In 1943, [Dean] reported that the ideal amount of fluoride was one part per million parts of water. This concentration was demonstrated to result in healthy, attractive teeth that had one-third as many cavities as might otherwise be expected—and no staining". Therefore the author would agree with the statement in this answer choice
    D → Incorrect. According to paragraph seven, "… the Public Health Service estimates that every dollar spent for community fluoridation saves about fifty dollars in dental bills". Therefore the author would agree with the statement in this answer choice

E → Incorrect. According to paragraph five, "Currently, more than 140 million Americans live in fluoridated communities. But 80 million others receive public water supplies that are not fluoridated—thanks largely to the efforts of poisonmongers". Therefore the author would agree with the statement in this answer choice

24. Which of the following diseases is NOT discussed by antifluoridationists in order to scare people?
    A. Kidney disease
    B. Cancer
    C. Alzheimer's disease
    D. Heart disease

According to paragraph six, "The antifluoridationists' ("antis") basic technique is the big lie. Made infamous by Hitler, it is simple to use, yet surprisingly effective. It consists of claiming that fluoridation causes cancer, heart and kidney disease, and other serious ailments that people fear"

25. What is the author's tone throughout the passage?
    A. Impartial
    B. Analytical
    C. Cynical
    D. Argumentative
    E. Solemn

A → Incorrect. The author does not remain objective and non judgement throughout the entire passage. He/she spends the majority of the passage criticizing the tactics of antifluoridationists, calling them "poisonmongers"
B → Incorrect. This answer choice is wrong for the same reasons as option A)
C → Incorrect. Although the author does blame poisonmongers for endangering public health, he/she does not state or imply that poisonmongers have ulterior, selfish motives for doing so. Therefore, the author is not cynical
D → Correct. The author has a very pro-fluoridation stance and spends the majority of the passage criticizing antifluoridationists, calling them "poisonmongers"
E → Incorrect. The author does not write in a serious, formal, and dignified manner to express sadness about the issue

26. In paragraph four, what is the author describing with the phrase "water engineering"?
    A. The underground infrastructure for water distribution in cities
    B. The filtration of heavy metals and other impurities from tap water
    C. The replacement of natural water with an artificial substitute
    D. The alteration of the chemical composition of tap water
    E. The construction of pumping facilities

The author uses the phrase to suggest that the natural anti-cavity effects of water from Texas and Colorado may be replicated scientifically. Later in the paragraph, he/she discusses altering the chemical composition of tap water by adding fluoride. Therefore the correct answer is D)

27. Newburgh was the first city in New York to have artificially fluoridated tap water.

    Newspaper editors often allow antifluoridationists to publish articles in order to generate controversy
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

Although paragraph three mentions that Dr. Trendley Dean studied children who drank water with fluoride in 21 cities, this was a result of *natural* fluoridation. The first city to have artificially fluoridated tap water is Newburgh, mentioned in paragraph four: "One such test was conducted in the neighbouring cities of Newburgh and Kingston, New York. First, the children in both cities were examined by dentists and physicians; then fluoride was added to Newburgh's water supply". Therefore the first statement is true.

According to paragraph eight, "… antis are very eager to have their views printed. Scientific journals will rarely publish them, but most local newspapers are willing to express minority viewpoints regardless of whether facts support them. A few editors even welcome the controversy the antis generate—expecting that it will increase readership". Therefore the second statement is true.

28. Which of the following best describes the "laundry list" tactic?
    A. Quote statements that are either out of date or out of context
    B. Quote people who claim to be experts
    C. Make a statement that conveys only part of the truth, in order to deliberately deceive
    D. Make a large number of arguments such that opponents are overwhelmed
    E. Make a fear-inducing statement that is blatantly false

    A → Incorrect. This describes the technique used in antifluoridationist documents, discussed in paragraph nine
    B → Incorrect. This describes another tactic discussed in paragraph eleven. It is not the "laundry list" tactic
    C → Incorrect. This describes the "half-truths" tactic discussed in paragraph ten
    D → Correct. According to paragraph seven, "A variation of the big lie is the laundry list. List enough 'evils,' and even if proponents can reply to some of them, they will never be able to cover the entire list"
    E → Incorrect. This describes the "big lie" tactic discussed in paragraph six

29. During what year was fluoride found to be the chemical responsible for the "Texas teeth" phenomenon?
    A. 1900
    B. 1943
    C. 1931
    D. 1928
    E. 1970

    According to paragraph two, the benefits of naturally flouridated water were discovered in 1928, but the actual chemical substance was identified in 1931: "In 1931, the 'something' was identified as fluoride"

30. Which of the following is NOT a reason why the author distrusts any "rewards" offered by antifluoridationists?
    A. It is unknown who would judge the evidence provided by profluoridationists
    B. An upfront payment is requested to cover "any costs associated if the evidence is deemed invalid"
    C. If a lawsuit is filed to collect the award, the courts would likely not enforce the offer
    D. There is no guarantee that any money would be recovered, since all antifluoridationists reside under American jurisdiction
    E. The cost of a potential lawsuit to collect the award would be at least $25,000

    A → Incorrect because it is true. In the second last paragraph, the author mentions: "The offer did not state who would judge the evidence, but it was safe to assume that the antis themselves would have appointed the judges"
    B → Incorrect because it is true. According to the second last paragraph, "… a $100,000 offer required the pros to post a bond 'to cover any costs which the offerers of the reward might incur if the proof is deemed invalid'"
    C → Incorrect because it is true. According to the second last paragraph, "If a suit had been filed to collect the reward, the court might have ruled that the offer was a gambling bet that should not be enforced by a court"
    D → Correct because it is false. Although the author agrees that there is a slim chance of any money being recovered, he/she believes the reason for this is because most of the award sponsors were "… elderly and scattered widely throughout the United States and Canada". Therefore the second part of the answer choice is incorrect
    E → Incorrect because it is true. According to the second last paragraph, "Such a suit would have required at least $25,000 for the bond and legal fees"

31. Which of the following techniques does the author expect antifluoridationists to use for years to come?
    A. Innuendo
    B. The big lie
    C. The laundry list
    D. The waiting game
    E. Half-truths

    According to paragraph twelve, "The waiting game is a related gambit in which antis suggest that waiting a bit longer will help to resolve 'doubt' about fluoridation's safety. No doubt, some antis will continue to use this argument for a few hundred more years"

32. Anti-vaccine parents often argue that since the efficacy of a new vaccine have not yet been fully proven, we should not vaccinate our children. This falls under which of the following tactics?
    A. The big lie
    B. Half-truths
    C. The laundry list
    D. Innuendo
    E. Misquote

    A → Incorrect. The parents are not making a fear-mongering claim that is blatantly false
    B → Incorrect. The parents are not leaving out part of the truth, they are simply stating an argument
    C → Incorrect. The parents are not listing a large number of arguments in order to overwhelm opponents
    D → Correct. The parents claim that the effects of a new intervention have *not yet* been validated. This is a defining feature of the "innuendo" discussed in paragraph twelve
    E → Incorrect. The parents do not quote an out-of-date or out-of-context document or scientist

33. What is the purpose of this paragraph?
    A. To convince the reader that fluoridation is safe and has no side effects
    B. To educate the reader about the importance of fluoridation and how to recognize scare tactics used by antifluoridationists
    C. To inform the reader of the history of tap water fluoridation, as well as future plans
    D. To explain how antifluoridationists prevented widespread tap water fluoridation in America
    E. To illustrate the logistical and mechanical infrastructure behind tap water fluoridation

    A → Incorrect. Although the author mentions in paragraph one that "fluoridation is safe and effective in preventing tooth decay", he/she does not focus on this for the entire passage
    B → Correct. The first five paragraphs are dedicated to explaining the history and importance of fluoridation, while the rest of the passage lists common tactics used by antifluoridationists to scare the public
    C → Incorrect. Although the author discusses the history of fluoridation in the first four paragraphs, this is not the main focus of the passage
    D → Incorrect. The author never mentions that antifluoridationists prevented widespread tap water fluoridation in America. In fact, the author states in paragraph five that more than 140 million Americans live in fluoridated communities, but only 80 million receive non-fluoridated tap water
    E → Incorrect. There is no mention of the logistics or mechanics behind fluoridation anywhere in the passage

34. Which of the following groups is NOT mentioned by the author to be in agreement with profluoridationists?
    A. Scientific groups
    B. Civic groups
    C. Bureaucratic groups
    D. Health groups

    According to the last paragraph, "[fluoridation] is supported by a variety of health, scientific, and civic groups that could hardly be expected to agree on any other single measure"

35. The extinction of *Apis mellifera* would most likely lead to which of the following scenarios?
    A. The collapse of agricultural ecosystems
    B. The elimination of all honey, beeswax, and bee propolis products
    C. A decline in food production, due to a shortage of labour
    D. The extinction of many flowering plants
    E. The extinction of *Crithidia bombi*

    A → According to paragraph one, the European honeybee is important for the fertilization of food crops. However, there is no indication that the honeybee is the only species that supports the entire agricultural ecosystem. Therefore this answer is too extreme
    B → Although paragraph one mentions that the European honeybee produces honey, beeswax, and bee propolis, there is no indication that it is the *only* species that produces these products. Therefore, extinction of *Apis mellifera* would not cause the elimination of all these products. This answer choice is too extreme
    C → Correct. Paragraph one mentions "Without honeybees, food production would be a lot more labour intensive." This would likely decrease production capacity, if there is not enough labour to meet the increased demand
    D → Although paragraph one mentions that the European honeybee pollinates many crops, there is no mention of flowers in the entirety of the passage. This answer choice is out of scope
    E → According to paragraph five, "Hives with the greatest genetic diversity had the greatest resistance to infection by *Crithidia bombi*, a common parasite." However, the experiment was conducted with *Bombus terrestris*, not *Apis mellifera*. Therefore this answer choice is incorrect

36. Which of the following statements about Hamilton's kinship theory is correct?
    A. It explains why altruistic behaviour may be evolutionarily disfavoured
    B. Artificially decreasing genetic diversity has detrimental effects on worker cooperation
    C. It explains why altruistic behaviour may be evolutionarily favoured
    D. It is not just the fitness of an individual organism, but the fitness of its genetic material
    E. Evolution considers only individual fitness

A → Incorrect. According to paragraph. three, "Hamilton's kinship theory is a powerful explanation for why altruistic behaviour may be evolutionarily favoured"
B → Incorrect. According to paragraph three, "… artificially increasing genetic diversity has been shown to have detrimental effects on worker cooperation"
C → Correct. According to paragraph three, "Hamilton's kinship theory is a powerful explanation for why altruistic behaviour may be evolutionarily favoured"
D → Incorrect. This answer choice describes inclusive fitness, not Hamilton's kinship theory. It is a right answer to the wrong question
E → Incorrect. According to paragraph three, "According to Hamilton's kinship theory, evolution not only favours individual fitness, but also the inclusive fitness of an organism"

37. Which of the following can NOT occur?
    A. Diploid queen mates with haploid drone and produces a new diploid worker
    B. Diploid queen produces a haploid drone
    C. Diploid worker produces a haploid drone
    D. Diploid worker mates with haploid drone and produces a diploid worker
    E. Diploid queen mates with haploid drone and produces a new diploid queen

A → Incorrect because it can occur. According to paragraph two, "Honeybee queens lay both fertilized and unfertilized eggs–fertilized eggs become female bees (A.K.A. workers) and unfertilized eggs become male bees (A.K.A. drones)"
B → Incorrect because it can occur. According to paragraph two, "Honeybee queens lay both fertilized and unfertilized eggs–fertilized eggs become female bees (A.K.A. workers) and unfertilized eggs become male bees (A.K.A. drones)"
C → Incorrect because it can occur. According to paragraph two, "… fertilized eggs become female bees (A.K.A. workers) and unfertilized eggs become male bees (A.K.A. drones) … Some workers are capable of laying eggs, but these are always haploid."
D → Correct. According to paragraph two, "… fertilized eggs become female bees (A.K.A. workers) and unfertilized eggs become male bees (A.K.A. drones) … Some workers are capable of laying eggs, but these are always haploid. So, in effect, only queen bees are capable of producing workers and new queen bees."
E → Incorrect because it can occur. According to paragraph two, "Honeybee queens lay both fertilized and unfertilized eggs–fertilized eggs become female bees (A.K.A. workers) and unfertilized eggs become male bees (A.K.A. drones) ... only queen bees are capable of producing workers and new queen bees"

38. Why is *Apis mellifera* polyandrous while *Bombus terrestris* is not?
    A. *Apis mellifera* has minimum genetic diversity
    B. *Apis mellifera* is more prone to infection by *Crithidia bombi*
    C. Apis mellifera has crossed an evolutionary barrier
    D. *Bombus terrestris* is a eusocial species
    E. *Bombus terrestris* does not practice haplodiploidy

A → Incorrect. According to paragraph five, we can infer that *Apis mellifera* is at the end of the U-shaped fitness distribution with the *maximum* genetic diversity
B → Incorrect. According to paragraph five, we would expect *Apis mellifera* to be more *resistant* to infection by *Crithidia bombi*, since it has greater genetic diversity
C → Correct. According to paragraph five, "These two factors resulted in a U-shaped distribution of fitness, with fitness being greatest at minimal genetic diversity, and after the threshold of diversity necessary for improved resistance was passed. The authors hypothesized that this distribution of fitness represented an evolutionary barrier to evolving polyandry—a barrier that *B. terrestris* had not crossed, but that *A. mellifera* had."
D → Incorrect. The author mentioned that *Apis mellifera* is a eusocial species in paragraph two. However, they did not explicitly mention that *Bombus terrestris* was also a eusocial species
E → Incorrect. Although it can be inferred that *Bombus terrestris* practices haplodiploidy (since males are drones), this is not the reason why the species is not polyandrous. Therefore, this answer choice is irrelevant

39. What is a "drone comet"?

A. A congregation of queen bees
B. A swarm of male bees pursuing a queen
C. A swarm of workers pursing a queen
D. A swarm of drones pursuing a worker
E. A congregation of workers

According to paragraph four, "When the queens arrive for their nuptial flights, drones pursue them through the air in dense swarms of more than 100 individuals (called "drone comets"), mating rapidly during flight."

40. Polyandry is a mating system in which one male mates with multiple females.

The genetic scrambling hypothesis states that queens favour maximum genetic diversity.

A. Both statements are TRUE
B. Both statements are FALSE
C. The first statement is TRUE, the second is FALSE
D. The first statement is FALSE, the second is TRUE

According to paragraph four, "Polyandry is a mating system in which one female mates with multiple males."

According to paragraph six, "Research has found that all males that successfully mate have roughly equal representation in the patrilines of the hive. This supports the genetic scrambling hypothesis–that queens favour a strategy of maximum genetic diversity, without favouring any particular male."

41. What tone is the passage written in?

A. Argumentative
B. Agnostic
C. Informative
D. Serious
E. Cynical

A → Incorrect. The author does not attempt to convince the reader that any particular theory or idea is correct
B → Incorrect. The author does not appear to be unwilling to commit to a particular theory. In fact, the author implies in the final paragraph that he or she agrees with the genetic scrambling hypothesis, even if it is against "common sense"
C → Correct. Throughout the passage, the author simply presents evidence without seeking to convince the reader. By allowing the reader to come to their own conclusions, this passage seeks to inform in an objective manner
D → Incorrect. The author does not convey that sexual selection in honeybees has profound implications that remains careful consideration
E → Incorrect. The author does not convey a distrust of human sincerity or integrity

42. The sperm length of *A. mellifera* is correlated to which of the following?

A. Number of females mates
B. Number of spermatheca
C. Genetic Diversity
D. Body weight
E. Body size

According to paragraph six, "A 2003 study by Baer, Schmid-Hempel, Høeg, and Boomsma showed that sperm length correlated to drone body size …"

43. What is the purpose of paragraph four?

A. To explain the importance of honey bees
B. To introduce the topic of polyandry
C. To summarize the previous paragraph
D. To introduce the topic of polygamy
E. To critique evidence for mating behaviour

A → Incorect. This is the purpose of paragraph one, not four
B → Correct. The entire paragraph is dedicated to discussing polyandry, the mating system of *A. mellifera*
C → Incorrect. With the phrase "Apart from haplodiploidy, another unusual reproductive characteristic of *A. mellifera* is …", the author suggests that paragraph four is a continuation (not summary) of the prior paragraph
D → Incorrect. The passage introduces the topic of polyandry, not polygamy. Polygamy is never mentioned in the passage
E → Incorrect. The author simply discusses mating behaviour, and does not present nor criticize any evidence supporting it

44. When was the study by Schmid-Hempel, Høeg, and Boomsma published?

A. 2001
B. 2002
C. 2003
D. 2004
E. 2005

According to paragraph six, "A 2003 study by Baer, Schmid-Hempel, Høeg, and Boomsma showed that sperm length correlated to drone body size …"

45. The degree of relatedness between siblings sired by the same drone is 0.5, because the likelihood of them getting the same allele from their haploid father is 100%, and the likelihood of getting the same allele from the queen is 50%
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

    According to paragraph three, "… between two worker bees sired by the same drone, the degree of relatedness is 0.75, because the likelihood of them getting the same allele from their haploid father is 100%, and the likelihood of getting the same allele from the queen is 50% ($1\times0.5+0.5\times0.5=0.75$)". Therefore the statement is incorrect but the reason is correct.

46. What is the main idea of paragraph six?
    A. The genetic scrambling hypothesis is convincing but not supported by research
    B. Cryptic female choice and sperm competition occurs in the lateral oviducts
    C. Genetic diversity can both increase or decrease evolutionary fitness
    D. Sperm length may be a selected trait, but females do not seem to favour some males over others based on the trait
    E. The variance of sperm lengths produced in drones is greater than the variance of sperm lengths found stored in queens

    A → Incorrect. The end of paragraph six states that research does in fact support the genetic scrambling hypothesis
    B → Incorrect. This is mentioned in the paragraph but is too narrow and specific to be its main idea
    C → Incorrect. This is the main idea of paragraph five, not six
    D → Correct. Throughout the paragraph, the author explicitly presents evidence that supports this idea. For instance: "A 2003 study by Baer, Schmid-Hempel, Høeg, and Boomsma showed that … the variance of sperm lengths produced in drones was greater than the variance of sperm lengths found in the stored in the spermatheca of queens" and "Research has found that all males that successfully mate have roughly equal representation in the patrilines of the hive"
    E → Although this is mentioned in the paragraph, it is too narrow and specific to be its main idea

47. According to the author, what would "common sense" dictate as traits selected for by queens?
    A. Body size and sperm length
    B. Genetic diversity
    C. Health, aggression, and appearance
    D. Pollination and social abilities
    E. Flight patterns, aggression, and appearance

    According to the last paragraph, "… common sense would perhaps dictate that honeybee queens would select the healthiest, most aggressive, or most flashy drones to mate with"

48. Which of the following is NOT true?
    A. Polyandry increases the hive's resistance to parasites and other pathogens
    B. Schmid-Hempel published at least two studies on the honeybee
    C. The degree of relatedness between siblings is 0.5 in diploid-diploid sexual reproduction
    D. Only queens can lay diploid eggs
    E. The nuptial flight of queens involve both drones and workers

    A → Incorrect because it is true. According to paragraph five, "… polyandry increases a hive's resistance to pathogens"
    B → Incorrect because it is true. In paragraph five, the author mentions "This hypothesis was tested by Baer and Schmid-Hempel in 2001 …" and in paragraph six, "A 2003 study by Baer, Schmid-Hempel …" Therefore Schmid-Hempel published at least two studies on the honeybee
    C → Incorrect because it is true. According to paragraph three, "In ordinary diploid sexual reproduction, the degree of relatedness between siblings is 0.5, because there is a 50% chance that they will receive the same allele from the mother, and a 50% chance that they will receive the same allele from the father ($0.5 \times 0.5 + 0.5 \times 0.5 = 0.5$)"
    D → Incorrect because it is true. According to paragraph two, "Only queens can mate with drones, and only queens can lay diploid eggs"
    E → Correct, this is false. According to paragraph four, "When the queens arrive for their nuptial flights, drones pursue them through the air in dense swarms of more than 100 individuals (called "drone comets"), mating rapidly during flight". There is no mention that worker bees are involved

49. What is a spermatheca?

A. The site of sperm production in males
B. The site of sperm storage in males
C. The site of sperm storage in females
D. The site of sperm lengthening in males
E. A male insemination organ

According to paragraph four, "Queens have organs called lateral oviducts in which they store the sperm of many males, using it to fertilize eggs throughout the year"

50. According to paragraph three, what is the degree of relatedness between diploid siblings bred from two haploid parents?

A. 0%
B. 25%
C. 50%
D. 75%
E. 100%

According to the logic presented in paragraph three, the likelihood that the siblings getting the same allele from their haploid father is 100%, and the likelihood of getting the same allele from their haploid mother is also 100%. Therefore, the degree of relatedness is equal to $1 \times 0.5 + 1 \times 0.5 = 1$

FULL-LENGTH 3 MEDIUM DIFFICULTY

SCORE CONVERSION SCALE

Biology		Chemistry		PAT		RCT	
Percent →	DAT Score	Percent →	DAT Score	Percent →	DAT Score	Percent →	DAT Score
1–5%	0	1–5%	0	1–5%	0	1–5%	0
5–10%	1–3	5–10%	1–3	5–10%	1–3	5–10%	1–3
10–15%	3–5	10–15%	3–5	10–15%	3–5	10–15%	3–5
15–20%	5–8	15–20%	5–8	15–20%	5–8	15–20%	5–8
20–25%	8–11	20–25%	8–11	20–25%	8–11	20–25%	8–11
25–30%	12	25–30%	12	25–30%	11–14	25–30%	12
30–35%	13	30–35%	13	30–35%	15	30–35%	13
35–40%	14	35–40%	14	35–40%	16	35–40%	14
40–45%	15	40–45%	15	40–45%	17	40–45%	15
45–50%	16	45–50%	16	45–50%	18	45–50%	16
50–55%	17	50–55%	17	50–55%	19	50–55%	17
55–60%	18	55–60%	18	55–60%	20	55–60%	18
60–65%	20	60–65%	20	60–65%	21	60–65%	19
65–70%	22	65–70%	22	65–70%	23	65–70%	20
70–75%	23	70–75%	23	70–75%	24	70–75%	21
75–80%	24	75–80%	24	75–80%	25	75–80%	22
80–85%	26	80–85%	26	80–85%	27	80–85%	24
85–90%	28	85–90%	28	85–90%	28	85–90%	26
90–95%	29	90–95%	29	90–95%	29	90–95%	28
95–100%	30	95–100%	30	95–100%	30	95–100%	30

FULL-LENGTH 4 HIGHER DIFFICULTY

SURVEY OF THE NATURAL SCIENCES

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Survey of Natural Sciences:

1. Each item is a question and/or incomplete statement followed by possible answers or completions. Read the item, decide which answer choice is the best, and bubble in the corresponding circle on the answer sheet
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 60 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. **DO NOT TURN PAST THE STOP PAGE AND ON TO THE NEXT SECTION UNTIL INSTRUCTED**
6. At the end of this section, the answer sheet is collected. The booklet remains at your table for use during the next section

TIME LIMIT:
60 minutes

TEST NAME:
SNS

TEST NUMBER:
04

This is a DAT simulation.

This section is composed of 70 questions:
Biology (1-40) and General Chemistry (41-70)

1. The cellular respiration of one glucose molecule yields 38 ATP in hepatocytes and 36 ATP in osteocytes. Which of the following is most likely to explain this difference?
   A. Hepatocytes use oxidative phosphorylation, while osteocytes use substrate-level phosphorylation
   B. Hepatocytes use the glycerol-phosphate shuttle, while osteocytes use the malate-aspartate shuttle
   C. Hepatocytes use lactic acid fermentation, while osteocytes use ethanol fermentation
   D. Hepatocytes use the malate-aspartate shuttle, while osteocytes use the glycerol-phosphate shuttle
   E. Hepatocytes contain more mitochondria than osteocytes

2. Cilia and flagella are both composed of:
   A. Microfilaments
   B. Microtubules
   C. Intermediate filaments
   D. Sarcomeres
   E. Myosin

3. In a population of poisonous beetles, some individuals are able to avoid predation thanks to bright pigmentation. Over time, the percentage of brightly-coloured beetles increases and the coloration is recognized by a greater number of predators. Which of the following best describes this phenomenon?
   A. Stabilizing selection
   B. Heterosis
   C. Balanced polymorphism
   D. Negative frequency-dependent selection
   E. Positive frequency-dependent selection

4. An adrenal tumour results in the hypersecretion of hormones from the zona fasciculata. Which of the following complications is most likely?
   A. Grave's disease
   B. Hypernatremia
   C. Cushing's syndrome
   D. Increased growth of body hair
   E. Increased epinephrine levels

5. Which of the following embryonic structures does the vertebral column develop from?
   A. Dorsal hollow nerve chord
   B. Pharyngeal gill slits
   C. Notochord
   D. Spinal column
   E. Somites

6. What is the difference between tracheids and vessel elements?
   A. Tracheids are part of the phloem while vessel elements are part of the xylem
   B. Vessel elements carry glucose while tracheids carry only water and minerals
   C. Tracheids have pits while vessel elements have perforation plates
   D. Tracheids are composed of wider and shorter cells, compared to vessel elements
   E. Tracheids only contain primary cell walls, while vessel elements contain both primary and secondary cell walls

7. How are platelets or thrombocytes created?
   A. Differentiation from a myeloid progenitor during hematopoiesis
   B. Cytoplasmic derivative of megakaryocytes
   C. Differentiation from a lymphoid progenitor during hematopoiesis
   D. Cytoplasmic derivative of macrophages
   E. Secreted by granulocytes

8. Which of the following chemical conversions do nitrifying bacteria catalyze?
   A. Nitrogen gas into ammonia
   B. Nitrate into nitrogen gas
   C. Nitrite into nitrate
   D. Ammonium into nitrite
   E. Ammonium into nitrogen gas

9. A bacterial cell develops a chromosomal mutation in which the *lac* repressor gene *LacI* is deleted. Which of the following will occur?
   A. Failure of the repressor to bind to the promoter
   B. Constitutive transcription of lactose catabolism genes
   C. Increased concentration of the inducer molecule
   D. Failure of RNA polymerase to bind to the promotor
   E. Failure of the corepressor to bind to the repressor

10. Plasma cells, erythrocytes, and granulocytes have which of the following in common?
   A. They are myelocytes
   B. They are anucleate
   C. They are lymphocytes
   D. They contain MHC II
   E. They are mesoderm-derived

11. Which of the following correctly lists the epidermal layers from superficial to deep?
   A. Spinosum, granulosum, lucidum, basale
   B. corneum, lucidum, spinosum, granulosum
   C. Basale, spinosum, granulosum, corneum
   D. Lucidum, granulosum, spinosum, corneum
   E. Corneum, granulosum, spinosum, basale

12. In angiosperm fertilization, which of the following divides by mitosis to produce an embryo sac?
   A. Endosperm
   B. Megasporangium
   C. Polar nuclei
   D. Megaspore
   E. Ovule

13. Which of the following terrestrial biomes is dominated by grass, large herbivorous animals, and nutrient-poor soil?
   A. Taiga
   B. Temperate grassland
   C. Temperate forest
   D. Savanna
   E. Chaparral

14. Which of the following statements regarding ovulation is INCORRECT?
   A. A secondary oocyte is released into the fallopian tubes after a spike in LH levels
   B. The granulosa cells of the corpus luteum secrete estrogen
   C. The zona pellucida develops during the follicular phase
   D. Progesterone and inhibin are leased during the luteal phase
   E. If implantation occurs, human chorionic gonadotropin (hCG) is produced

15. Which of the following proteins are involved in receptor-mediated endocytosis?
   A. Myosin
   B. Dynein
   C. Kinesin
   D. Clathrin
   E. Actin

16. A population of rabbits enters a new Northern environment. The larger rabbits are hunted by native predators, while the smaller rabbits die from hypothermia due to their high surface area to volume ratio. What is this phenomenon an example of?
    A. Sexual selection
    B. Directional selection
    C. Frequency-dependent selection
    D. Stabilizing selection
    E. Disruptive selection

17. A patient presents with a gallstone blocking the passage of bile into the duodenum. Which of the following diets would be recommended?
    A. High protein
    B. Low carbohydrates
    C. Low protein
    D. High fat
    E. Low fat

18. Which of the following structures is NOT derived from the ectoderm?
    A. Limbic system
    B. Oral mucosa
    C. Osteocyte
    D. Tooth enamel
    E. Melanocytes

19. What triggers renin production?
    A. High blood pressure detected by juxtaglomerular cells
    B. Low blood pressure detected by juxtaglomerular cells
    C. High blood pressure detected by macula densa cells
    D. Low blood pressure detected by macula densa cells
    E. Activation of the parasympathetic nervous system

20. Which one of the following differences between monocots and dicots is INCORRECT?
    A. Dicots have flower petals in multiples of three, while monocots have petals in multiples of four
    B. Dicots have branching leaf veins, while monocots have parallel veins
    C. Stem vascular bundles are scattered in dicots, and are arranged in a ring in monocots
    D. Dicots have a taproot system, while monocots have a fibrous root system
    E. Dicots have two cotyledons, while monocots have one cotyledon

21. Which of the following is composed of organelles arranged perpendicularly?
    A. Centromere
    B. Pericentriolar material
    C. Centriole
    D. Centrosome
    E. Spindle fiber

22. Two strains of bacteria are cultured in a sterile growth medium containing nuclease. One strain is ampicillin-resistant while the other is ampicillin-susceptible. After co-culture, both strains are ampicillin-resistant. Which of the following most likely caused this?
    A. Transposable elements
    B. Conjugation
    C. Transformation
    D. Transduction
    E. Mutation

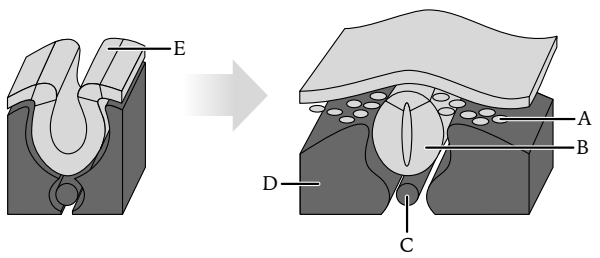
23. A patient arrives to hospital with a chronic neurodegenerative disease acquired after eating raw beef. Which of the following is most likely the cause of his/her condition?
    A. Viruses
    B. Bacteria
    C. Coacervates
    D. Prions
    E. Demyelination

24. If a city has an instantaneous growth rate of 200 people/year, a caring capacity of 900, and a current population of 300, what is the maximum per capita growth rate?
    A. 1 person/year
    B. 1.5 people/year
    C. 2 people/year
    D. 200 people/year
    E. 300 people/year

25. The chromatin remodelling complex is a component of which of the following?
    A. Post-translational regulation
    B. Post-transcriptional regulation
    C. Transcriptional regulation
    D. The Shine-Dalgarno sequence
    E. The spliceosome

26. Which of the following mRNA strands would produce the longest polypeptide?
    A) 5′–CAGAUGAUUGUUGCGUAACAUCAA–3′
    B) 5′–ACCGCUGCCAUGACCAGCUAGGGC–3′
    C) 5′–GGGGAUGCCAAUAUGCCAUAAACG–3′
    D) 5′–AUGGCUAAUAAAAGGUUGUCGUGA–3′
    E) 5′–AUGGUUGUCGCUUAAAAUAAAGGA–3′

27. In the following figure demonstrating neurulation, identify the structure labelled "B"



    A. Neural plate
    B. Somite
    C. Neural crest
    D. Neural tube
    E. Notochord

28. Which of the following is the most common excitatory neurotransmitter in the brain?
    A. Glutamate
    B. Acetylcholine
    C. GABA
    D. Epinephrine
    E. Dopamine

29. Which of the following statements regarding developmental cleavage is true?
    A. Meroblastic cleavage results in complete penetration of the cleavage furrow
    B. In determinate cleavage, blastomeres retain totipotency and remain unspecialized
    C. Spiral cleavage occurs in deuterosomes
    D. The pre-cleavage zygote has the same volume as the sum of all blastomeres
    E. Yolk is concentrated towards the animal pole

30. Which of the following cells matures into a macrophage?
    A. Megakaryocyte
    B. Monocyte
    C. Lymphocyte
    D. Plasma cell
    E. Leukocyte

31. Where does pollen germination occur?
    A. The style
    B. The anther
    C. The filament
    D. The stigma
    E. The ovary

32. Which of the following hormones is the best indicator of pregnancy?
    A. Estrogen
    B. Progesterone
    C. Leutenizing hormone
    D. Gonadotropin releasing hormone
    E. Human chorionic gonadotropin

33. Which of the following statements regarding blood is correct?

    I. It is a connective tissue

    II. It is involved in cellular communication

    III. When centrifuged, leukocytes appear in the hematocrit layer

    A. II
    B. I and II
    C. I and III
    D. II and III
    E. I, II, and III

34. Anterior pituitary neurons release neurohormones directly into the hypothalamic hypophyseal portal system. Which of the following synapses is this an example of?

    A. Axoaxonic
    B. Axosomatic
    C. Axosecretory
    D. Axodendritic
    E. Electrical

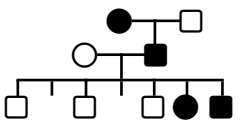
35. Which of the following is the second product of the glycolytic pathway?

    A. Glyceraldehyde 3-phosphate
    B. Fructose 6-phosphate
    C. Fructose 1,6-bisphosphate
    D. Glucose 6-phosphate
    E. Dihydroxyacetone phosphate

36. If a piece of paper is soaked in auxin and embedded into the right side of a plant shoot, which of the following will occur?

    A. Coleoptile bends towards the left
    B. Coleoptile grows faster than normal
    C. Coleoptile bends towards the right
    D. Coleoptile undergoes abscission
    E. Coleoptile grows slower than normal

37. A genetic disease is identified to have the following pedigree. What is the most likely inheritance pattern?



    A. Autosomal recessive
    B. Autosomal dominant
    C. X-linked recessive
    D. X-linked dominant
    E. Y-linked

38. Cardiac output equals which of the following?

    A. Blood Pressure × Heart Rate
    B. Stroke Volume ÷ Heart Rate
    C. Stroke Volume × Blood Pressure
    D. Stroke Volume × Heart Rate
    E. Heart Rate ÷ Stroke Volume

39. Fur colour is an incomplete dominant trait that has a X-linked inheritance pattern. Homozygous dominant individuals are brown, while homozygous recessive individuals are white. Heterozygotes are beige. If a beige female mates with a brown male, what is the probability that their female offspring would be brown?

    A. 0%
    B. 25%
    C. 50%
    D. 75%
    E. 100%

40. Which of the following statements regarding the endocrine system is correct?

    A. ACTH is released by the posterior pituitary
    B. Thyroxine is produced via the coupling of monoiodotyrosine with diiodotyrosine
    C. Insulin is a monoamine derivative
    D. Mineralocorticoids are produced in the adrenal medulla
    E. PTH increases blood calcium levels

41. How many electrons are transferred in the following redox reaction, under acidic conditions?

$$Pb + PbO_2 + SO_4^{2-} \rightarrow PbSO_4$$

A. 1
B. 2
C. 3
D. 4
E. 5

42. Which of the following statements are true for a reaction occurring at $-271°C$ with a positive change in enthalpy?

A. The reaction is spontaneous for any ΔS
B. The reaction is spontaneous if $\Delta H < 2\Delta S$
C. The reaction is spontaneous for any ΔH
D. The reaction is non-spontaneous if $\Delta H < \Delta S$
E. The reaction is non-spontaneous if $\Delta H > \Delta S$

43. If 1 L of 3 M NaOH is added to 2 L of an aqueous solution containing 3 mol of $Cu(OH)_2$, what is the Q_{sp} of $Cu(OH)_2$? Will a precipitate form? The solubility product of $Cu(OH)_2$ in water is 5.

A. 9; precipitate
B. 9; no precipitate
C. 8; precipitate
D. 4; precipitate
E. 4; no precipitate

44. Considering the following reaction, how many litres of ammonia gas are generated from the reaction of 22 L of nitrogen gas and 44 L of hydrogen gas under STP conditions?

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$$

A. 15 L
B. 30 L
C. 33 L
D. 60 L
E. 66 L

45. Which of the following is the correct cell diagram for the redox equation shown below?

$$Zn_{(s)} + CuSO_{4(aq)} \rightarrow ZnSO_{4(aq)} + Cu_{(s)}$$

A. $Cu_{(s)} \mid Cu^{2+}_{(aq)} \parallel Zn^{2+}_{(aq)} \mid Zn_{(s)}$
B. $Cu^{2+}_{(aq)} \mid Cu_{(s)} \parallel Zn_{(s)} \mid Zn^{2+}_{(aq)}$
C. $Zn_{(s)} \mid ZnSO_{4(aq)} \parallel CuSO_{4(aq)} \mid Cu_{(s)}$
D. $Zn^{2+}_{(aq)} \mid Zn_{(s)} \parallel Cu_{(s)} \mid Cu^{2+}_{(aq)}$
E. $Zn_{(s)} \mid Zn^{2+}_{(aq)} \parallel Cu^{2+}_{(aq)} \mid Cu_{(s)}$

46. 58 grams of salt are added to 360 mL of water at 25°C. If the k_f and k_b of pure water is 1.86 and 0.512 $°C \cdot kg \cdot mol^{-1}$ respectively, which of the following is expected to occur?

A. Osmotic pressure increases by $\dfrac{(298)(0.082)(2)}{0.36}$ kPa
B. Vapour pressure decreases by $\dfrac{1}{21}$
C. Freezing point deceases by $\dfrac{1.86}{0.36}$ °C
D. Vapour pressure decreases by $\dfrac{20}{21}$
E. Boiling point increases by $\dfrac{(0.512)(2)}{0.36}$ $°C \cdot kg \cdot L^{-1}$

47. The following list contains the equation and standard enthalpy change of several reactions. Using this information, what is the standard enthalpy change for reaction ④?

① $SrO + CO_2 \rightarrow SrCO_3$ $\Delta H° = -230$ kJ
② $2SrO \rightarrow 2Sr + O_2$ $\Delta H° = 1000$ kJ
③ $2SrCO_3 \rightarrow 2Sr + 2C + 3O_2$ $\Delta H° = 2500$ kJ
④ $C + O_2 \rightarrow CO_2$ $\Delta H° = ?$

A. − 980 kJ
B. + 520 kJ
C. + 980 kJ
D. −520 kJ
E. −1770 kJ

48. How much energy does it take to bring a 5 g sample of water from −5°C to 120°C? The specific heat capacity of water is 4 J/g°C. The latent heat of fusion and vaporization is 0.5 kJ/g and 2 kJ/g, respectively.

A. 2512.5 kJ
B. 15 kJ
C. 2500 kJ
D. 5 kJ
E. 12.5 kJ

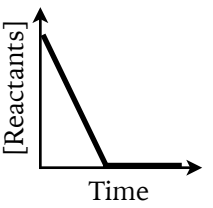
49. Which of the following compounds is INSOLUBLE in water?

A. Potassium acetate ($KC_2H_3O_2$)
B. Sodium nitrate ($NaNO_3$)
C. Magnesium sulfate ($MgSO_4$)
D. Ammonium chloride (NH_4Cl)
E. Calcium sulfate ($CaSO_4$)

50. A 500 mL sample of nitric acid is titrated with 0.1 M calcium hydroxide. If it takes 100 mL of the titrant to reach the equivalence point, what is the initial concentration of the analyte?

A. 0.025 M
B. 0.05 M
C. 0.1 M
D. 0.25 M
E. 0.5 M

51. Which of the following statements is correct regarding the figure shown below?



A. This illustrates a first-order reaction
B. The rate law for this reaction is $r = k[A]^2$
C. The units of the rate constant (k) for this reaction is 1/s
D. The rate vs initial reactant concentration graph would be a horizontal line
E. Rate is proportional to the concentration of the reactant

52. The molecular formula for bromate is BrO_3^-. What is the molar ratio of Br to O in a molecule of hypobromite?

A. 1:1
B. 1:2
C. 1:3
D. 3:1
E. 2:1

53. If an orbital's principle quantum number is 3, then which of the following can NOT be its magnetic quantum number?

A. 1
B. 0
C. −2
D. 3
E. 2

54. 5 grams of $C_6H_{10}O_5$, $C_6H_{12}O_6$, C_6H_6, $C_3H_8O_3$, and H_2O are each dissolved separately in 10 L of C_4H_{10}. Which solute would produce the solution with the lowest vapour pressure?

A. $C_6H_{10}O_5$
B. $C_6H_{12}O_6$
C. C_6H_6
D. $C_3H_8O_3$
E. H_2O

55. Which of the following is a valid measure of rate for the reaction shown below?

$$4FeS + 7O_2 \rightarrow 2Fe_2O_3 + 4SO_2$$

A. $\frac{\Delta[O_2]}{7\Delta t}$
B. $\frac{-\Delta[FeS]}{4\Delta t}$
C. $\frac{-\Delta[Fe_2O_3]}{2\Delta t}$
D. $\frac{-\Delta[FeS]}{\Delta t}$
E. $\frac{\Delta[SO_2]}{\Delta t}$

56. After centrifuging a solution, you notice the formation of a solid pellet at the bottom of the test tube. What is the liquid that rests on top?

A. Titrant
B. Organic phase
C. Supercritical fluid
D. Analyte
E. Supernatant

57. What form of radioactive decay does NOT involve the creation of a new neutron, proton, or photon?

A. Electron capture
B. Beta positive decay
C. Alpha decay
D. Beta negative decay
E. Gamma decay

58. A 1 L tank containing 100 kPa of oxygen is connected via stopcock to a 4L tank containing 50 kPa of nitrogen. If the stopcock is opened while temperature is held constant, what is the final pressure?

A. 10 kPa
B. 20 kPa
C. 40 kPa
D. 60 kPa
E. 90 kPa

59. Which of the following hybridization states describes the bonding orbitals in PF_5?

A. sp
B. sp^2
C. sp^3
D. sp^3d
E. sp^3d^2

60. The reaction shown below is allowed to reach equilibrium in a 2 L container. If the concentration of NO_2 at equilibrium is 4 M, how many grams of are N_2O_4 present?

$$N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)} \quad K = 0.5$$

A. 16 g
B. 32g
C. 64 g
D. 2944 g
E. 5888 g

61. Which of the following is the correct electron configuration for chromium?

A. $1s^2, 2s^1, 2p^6, 3s^2, 3p^5, 4s^2, 3d^4$
B. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^4$
C. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 4d^4$
D. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, 3d^5$
E. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, 4d^5$

62. Given the standard cell potentials of the two half-reactions shown below, what is the change in Gibbs free energy?

$$Cu^{2+} + 2e^- \rightarrow Cu \quad E_r^\circ = 0.34 \text{ V}$$
$$Fe^{2+} + 2e^- \rightarrow Fe \quad E_r^\circ = -0.44 \text{ V}$$

A. $-(2)(9\times10^4)(0.10)$ J
B. $-(2)(9\times10^4)(0.78)$ J
C. $(2)(9\times10^4)(0.10)$ J
D. $(2)(9\times10^4)(0.78)$ J
E. $-(9\times10^4)(0.34)$ J

63. 11.4 moles of $C_6H_{12}O_6$, $CaCl_2$, NaCl, $MgSO_4$, and $FeCl_3$ are each dissolved separately in 6 L of H_2O. Which solute would produce the solution with the lowest freezing point?

A. $C_6H_{12}O_6$
B. $CaCl_2$
C. NaCl
D. $FeCl_3$
E. $MgSO_4$

64. The following reaction is first order with respect to $TiCl_4$ and second order with respect to H_2O:

$$TiCl_4 + 2H_2O \rightarrow TiO_2 + 4HCl$$

If rate is equal to 4 M/s at 25°C and 2 M reactant concentrations, then what is the rate constant?

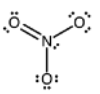
A. 0.5 s^{-1}
B. $0.5 \text{ M}^{-1} \cdot \text{s}^{-1}$
C. $0.5 \text{ M}^{-2} \cdot \text{s}^{-1}$
D. $1 \text{ M} \cdot \text{s}^{-1}$
E. $1 \text{ M}^{-2} \cdot \text{s}^{-1}$

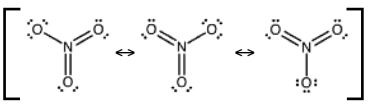
65. Which set of coefficients would balance the following reaction?

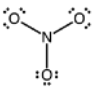
$$HCl + K_2Cr_2O_7 \rightarrow KCl + CrCl_3 + H_2O + Cl_2$$

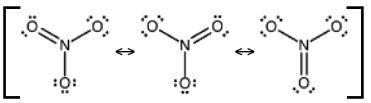
A. 14, 1, 2, 2, 7, 3
B. 10, 1, 2, 2, 7, 1
C. 26, 3, 6, 6, 21, 1
D. 8, 1, 2, 2, 7, 3
E. 2, 1, 2, 2, 7, 3

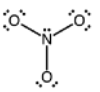
66. What is the correct lewis structure for NO_3^-?

A. 

B. 

C. 

D. 

E. 

67. Which of the following statements regarding reaction coordinate diagrams is correct?
    A. The activation energy of forward and reverse reactions are equal
    B. Catalysts decrease the ΔH of a reaction
    C. Spontaneous reactions have a small E_a
    D. Potential energy peaks at the transition state
    E. In a spontaneous reaction, the lowest potential energy occurs at the intermediates

68. What is the standard enthalpy of formation of N_2O, given the following reaction?

$$2N_2O_{(g)} \rightarrow 2N_{2(g)} + O_{2(g)} \quad \Delta H^\circ = -164\ \text{kJ}$$

    A. 164 kJ/mol
    B. 82 kJ/mol
    C. 55 kJ/mol
    D. −82 kJ/mol
    E. Cannot be determined

69. In which of the following reactions is $\Delta S < 0$?
    A. $CH_{4(g)} + 2H_2S_{(g)} \rightarrow CS_{2(g)} + 4H_{2(g)}$
    B. $K_2Cr_2O_{7(s)} \rightarrow 2K^+_{(aq)} + Cr_2O^{2-}_{7(aq)}$
    C. $CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(l)}$
    D. $C_3H_8O_{(l)} \rightarrow C_3H_8O_{(g)}$
    E. $N_2H_4O_{3(s)} + \text{heat} \rightarrow N_2H_4O_{3(aq)}$

70. Decompression sickness is caused by dissolved gasses (primarily N_2) coming out of the blood upon rapid depressurization of the body. This phenomenon can be explained with:
    A. Boyle's law
    B. Charle's law
    C. Gay-Lussac's law
    D. Henry's law
    E. Avogadro's law

STOP

You have completed the SNS section of the DAT.
You will receive a 10 min break before the next section.

FULL-LENGTH 4 HIGHER DIFFICULTY

PERCEPTUAL ABILITY TEST

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Perceptual Ability Test:

1. Each item is a question requiring perceptual skills. This section contains six sub-sections. Read the specific instructions before starting each sub-section. Decide which answer choice is correct and bubble in the corresponding circle on the answer sheet. **Do not stop after each subsection; continue to answer all 90 questions**
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 60 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. **DO NOT TURN PAST THE STOP PAGE AND ON TO THE NEXT SECTION UNTIL INSTRUCTED**
6. At the end of this section, the answer sheet is collected. The booklet remains at your table for use during the next section

TIME LIMIT:
60 minutes

TEST NAME:
PAT

TEST NUMBER:
04

This is a DAT simulation.

PART 1

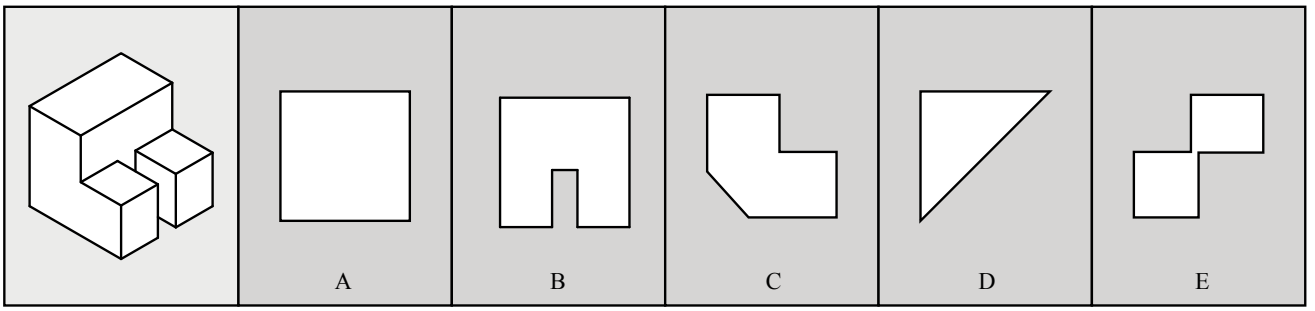
For questions 1 to 15, the test contains questions similar to the example shown below. A three-dimensional object is shown in the light-coloured box on the left. Various two-dimensional answer choices are shown on the right, in dark-coloured boxes.

In each question, your task is to visualize how the three-dimensional object would look from all sides. Then from the answer choices, you must choose a two-dimensional keyhole which would allow the three-dimensional object to pass through. Finally, bubble in the corresponding circle on your answer sheet.

The rules are as follows:

1. Before passing through the keyhole, the object may be rotated in any direction
2. Once the object starts passing through the keyhole, it cannot be rotated
3. Both the object and the keyhole are drawn to scale. They should have the same dimensions
4. There are no irregularities in the hidden parts of the objects

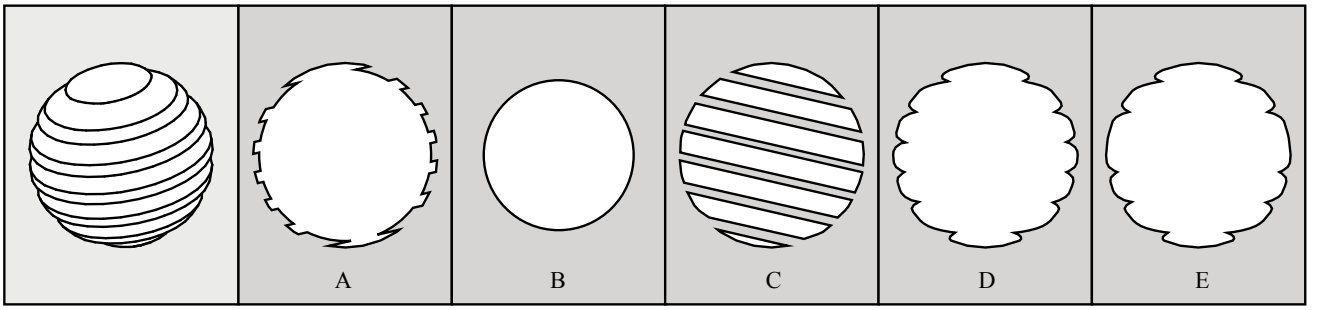
Example Question (Do NOT mark the answer to this example on your answer sheet)



The correct answer is B because the object would pass through this keyhole if the bottom or top side was rotated and inserted first

Please proceed to the questions

1.



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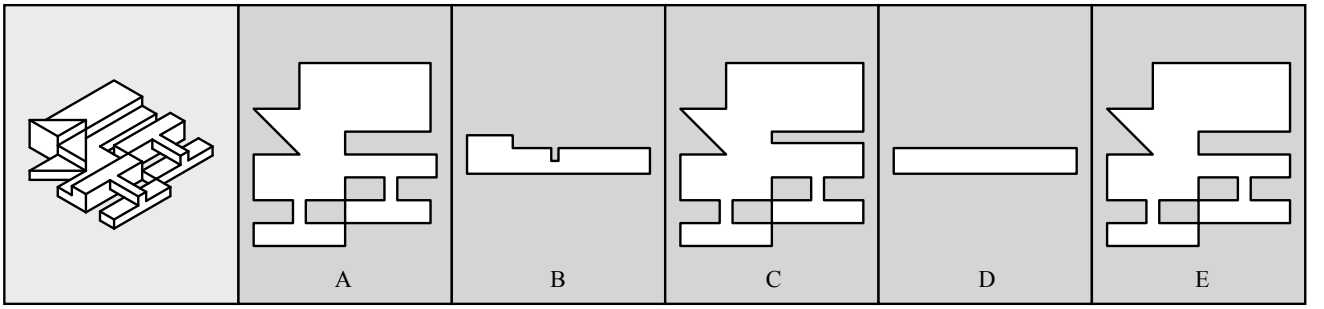

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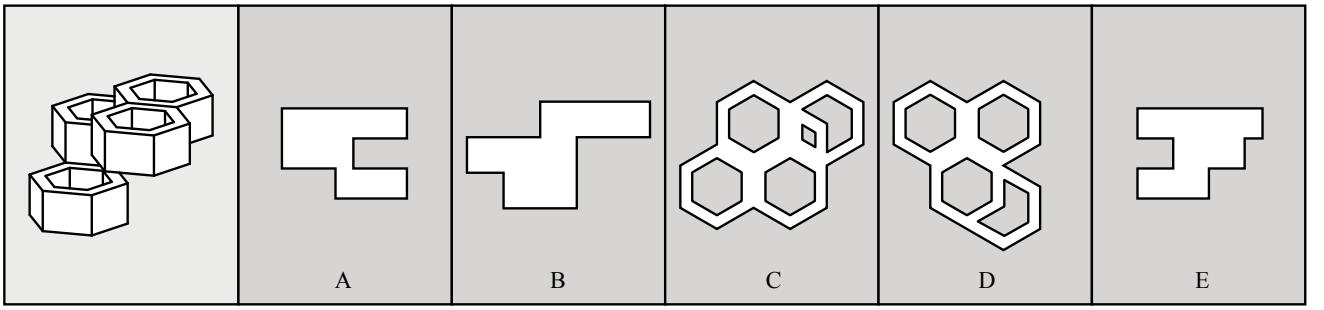

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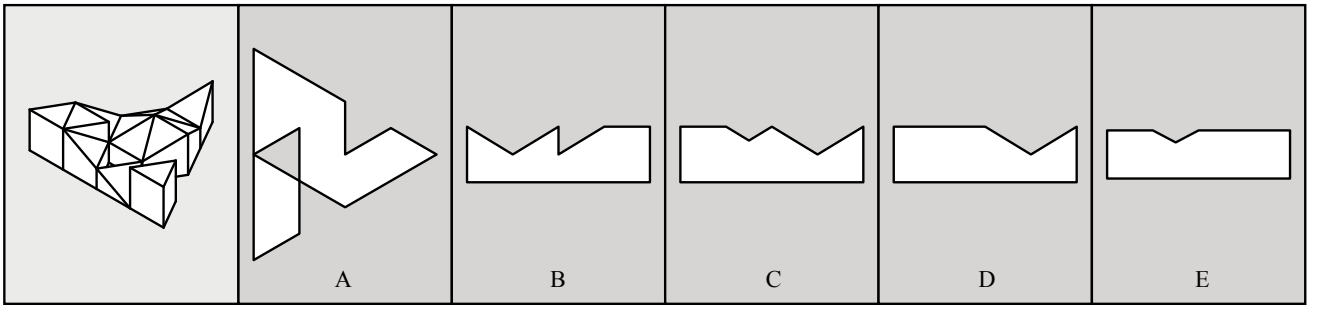

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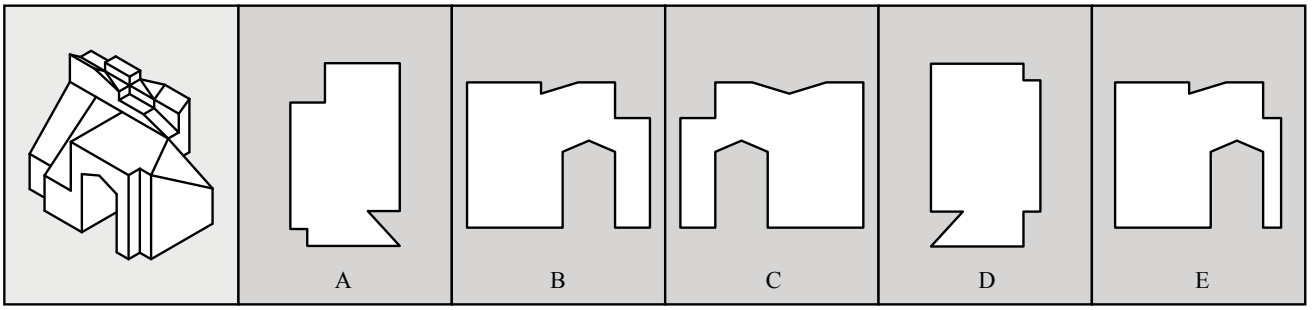

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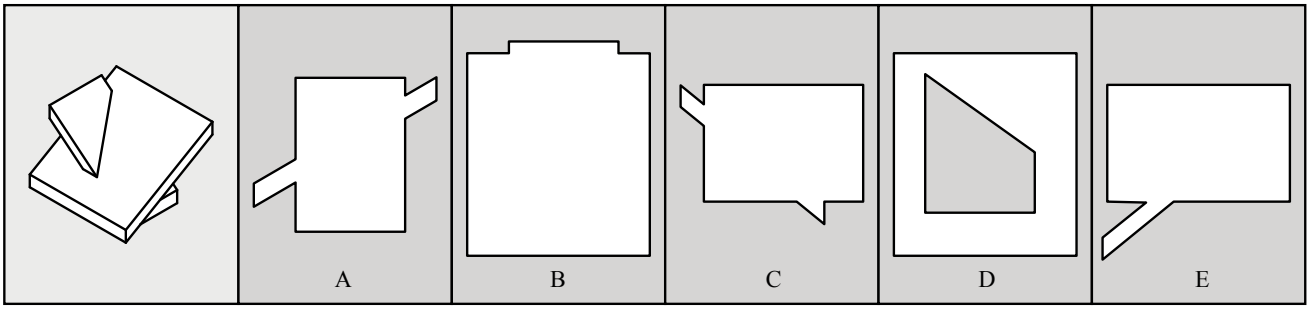

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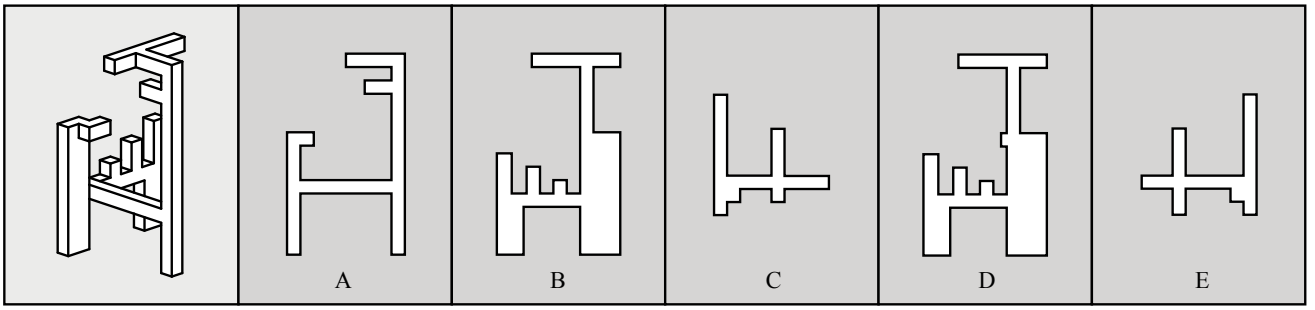

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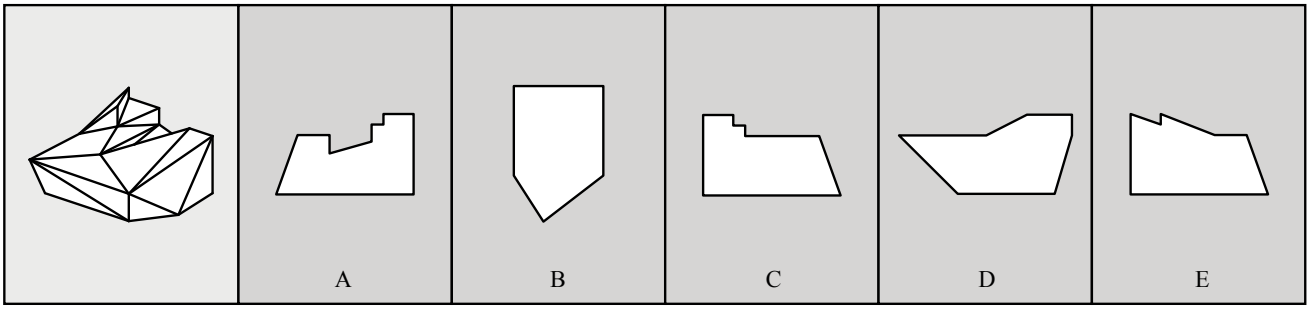

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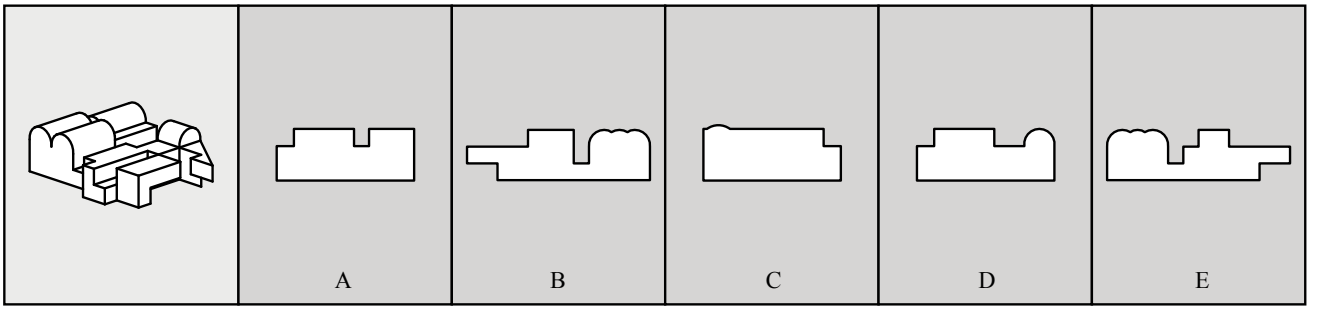

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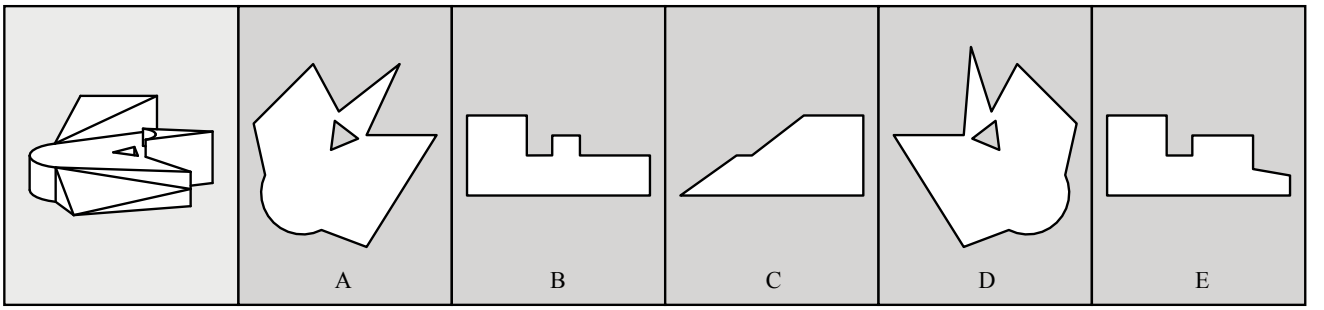

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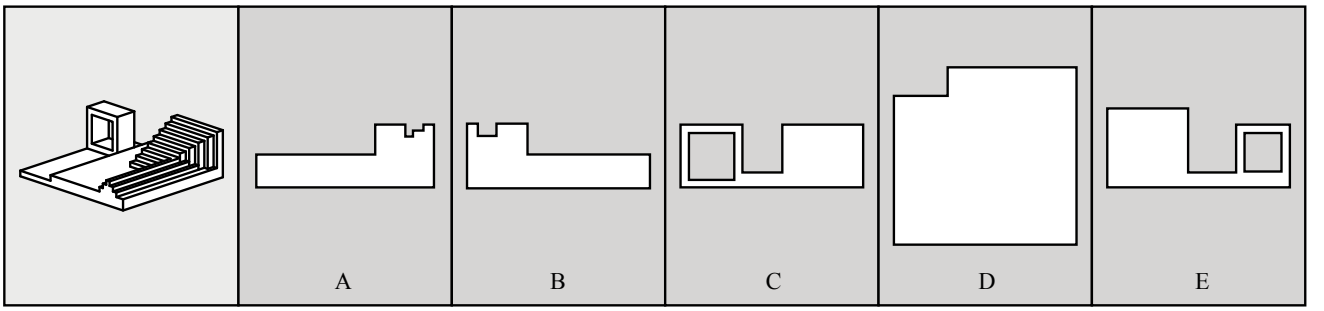

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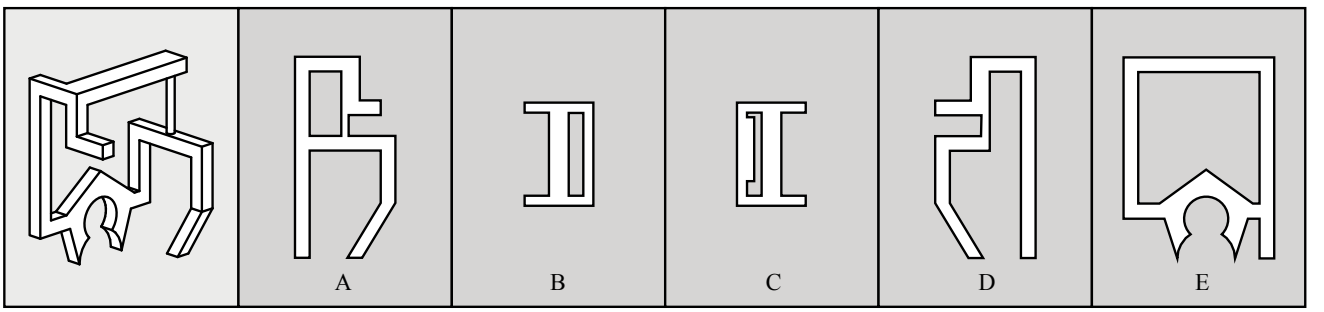

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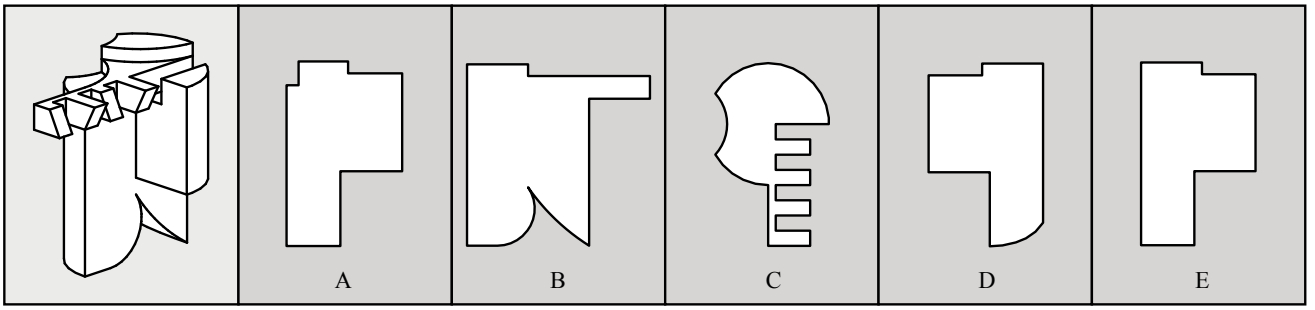

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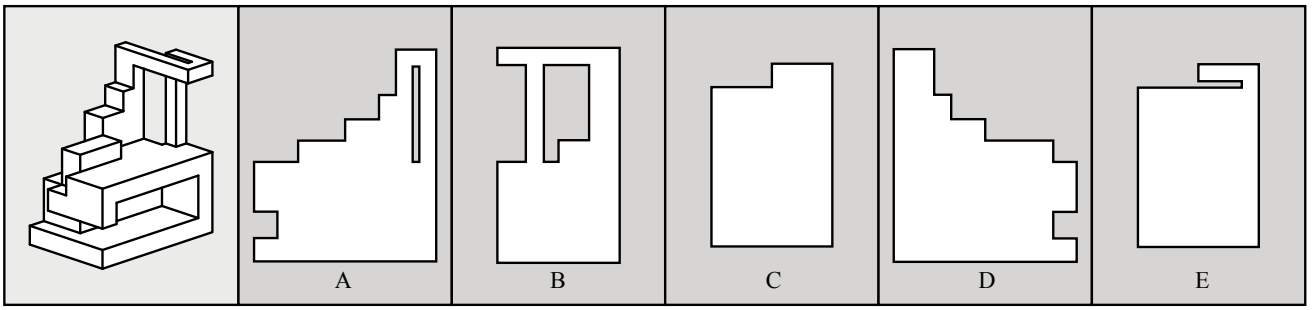

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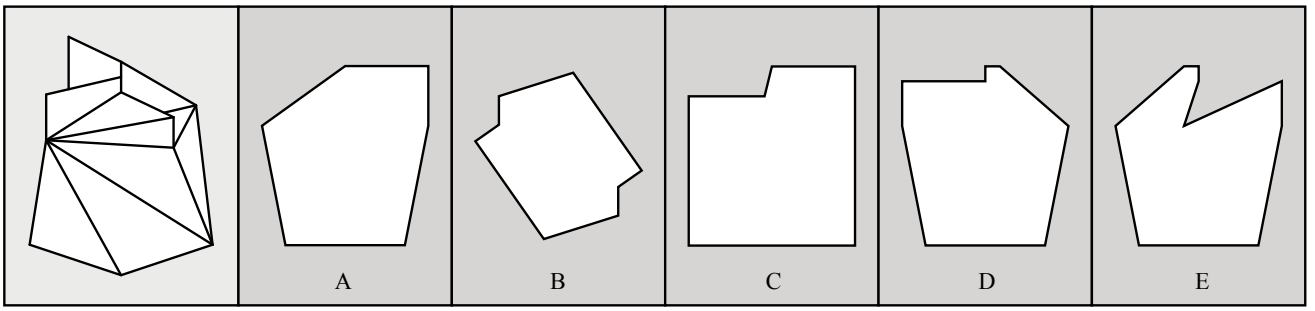
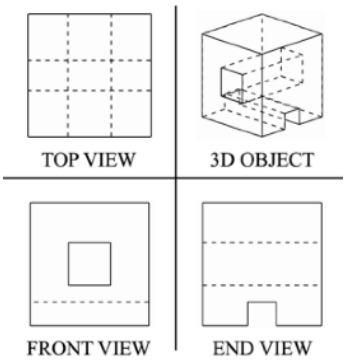


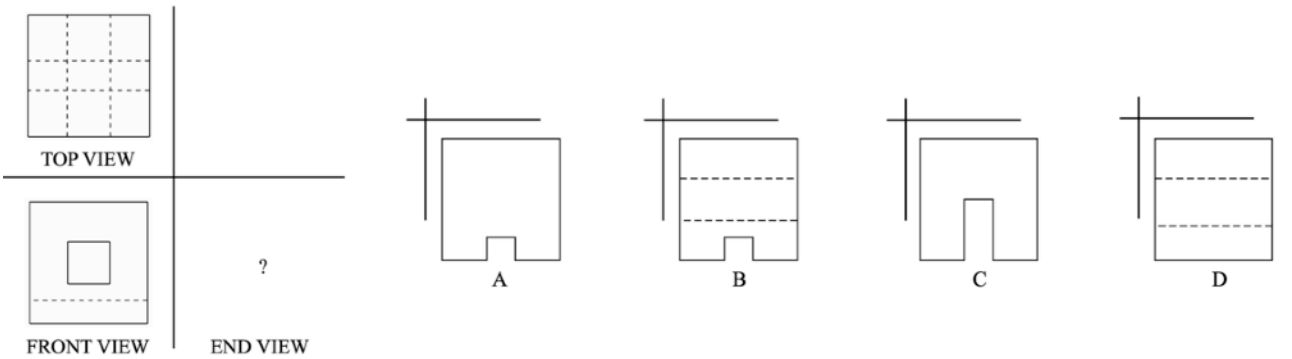
PART 2

For questions 16 to 30, the test contains questions similar to the example shown below. The top, front, and end projections of a three-dimensional object are shown. Edges that are obscured by parts of the object are shown as dotted lines, while edges that can be directly seen are shown as solid lines.



In each question, one of the three projections will be missing. Your task is to choose the projection that would complete the set of three projections in a manner consistent with the three-dimensional object (not shown).

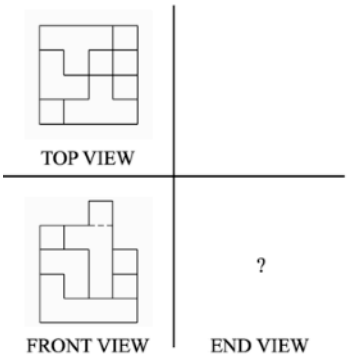
Example Question (Do NOT mark the answer to this example on your answer sheet)

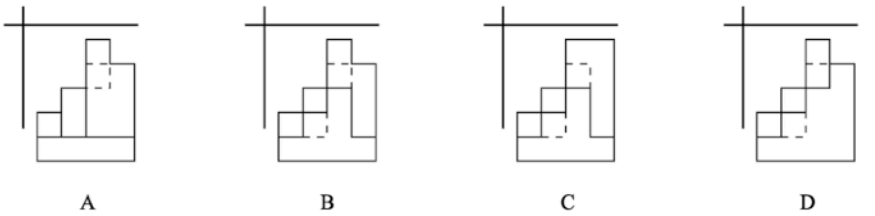


The correct answer is B because the object should have a rectangular tunnel at the bottom running left-to-right, and another square tunnel running front-to-back.

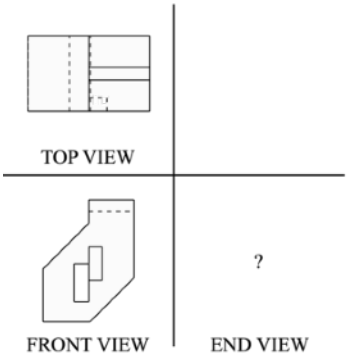
Please proceed to the questions

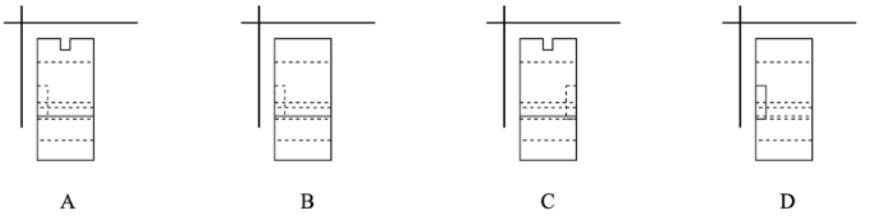
16. Choose the correct END VIEW



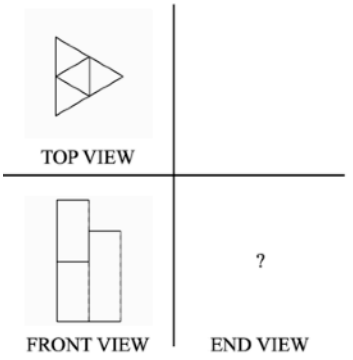


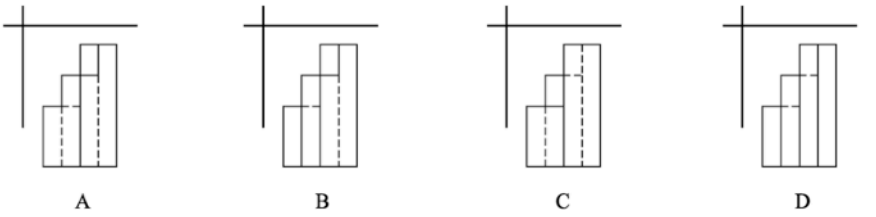
17. Choose the correct END VIEW



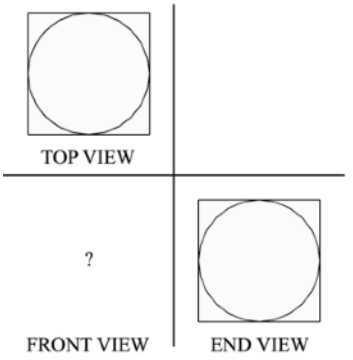


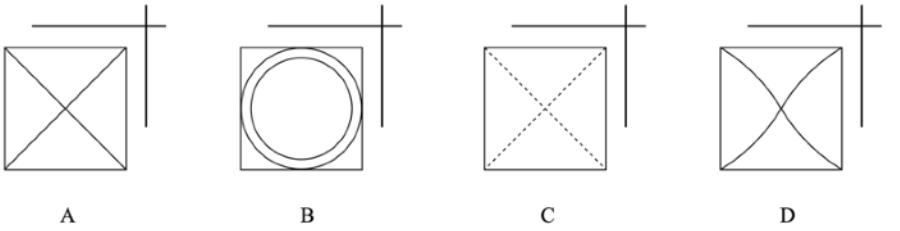
18. Choose the correct END VIEW



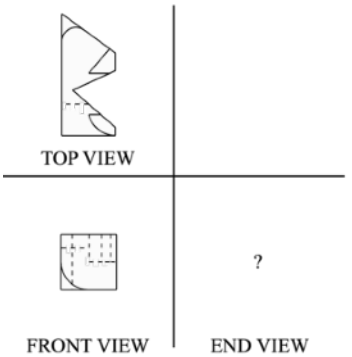


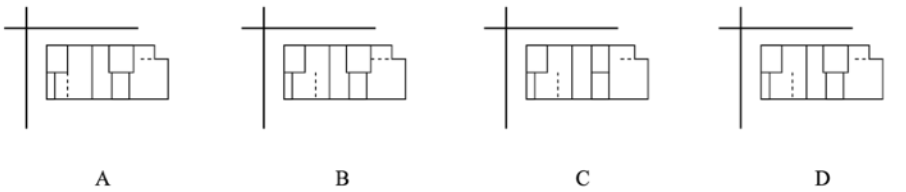
19. Choose the correct FRONT VIEW



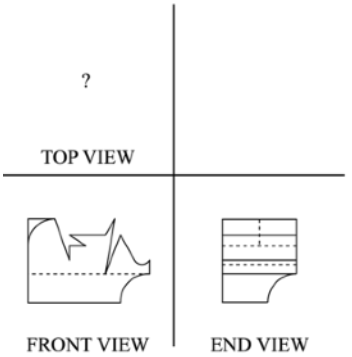


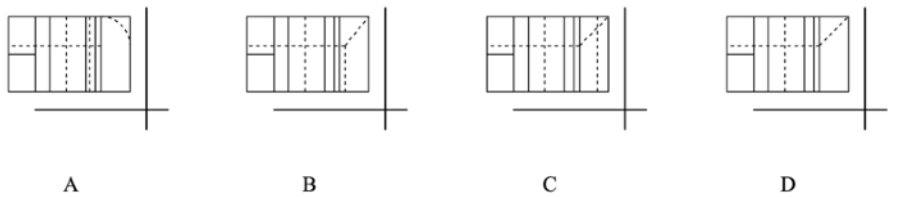
20. Choose the correct END VIEW



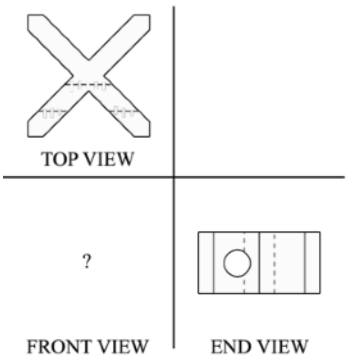


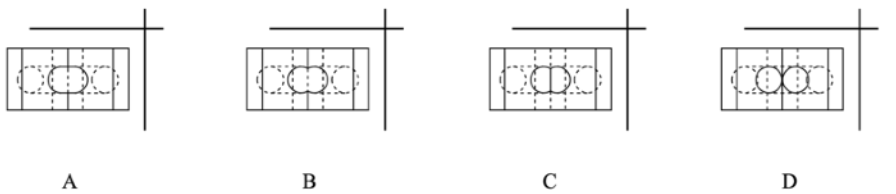
21. Choose the correct TOP VIEW



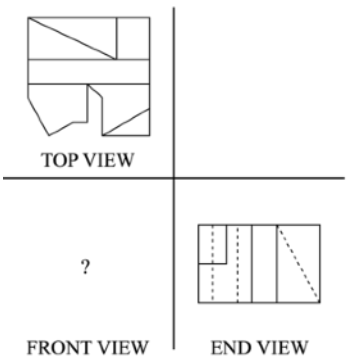


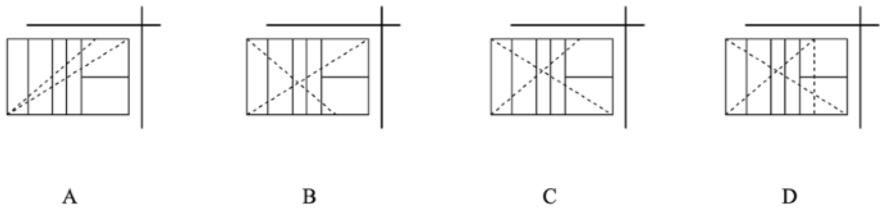
22. Choose the correct FRONT VIEW



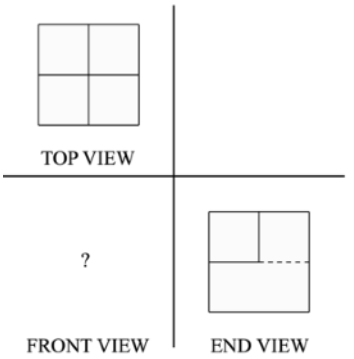


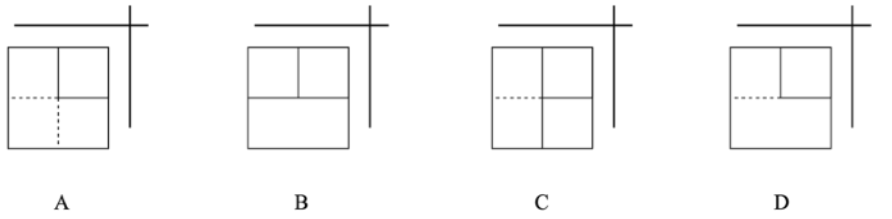
23. Choose the correct FRONT VIEW



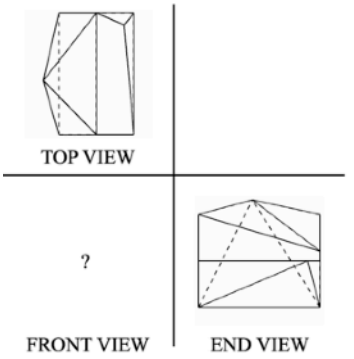


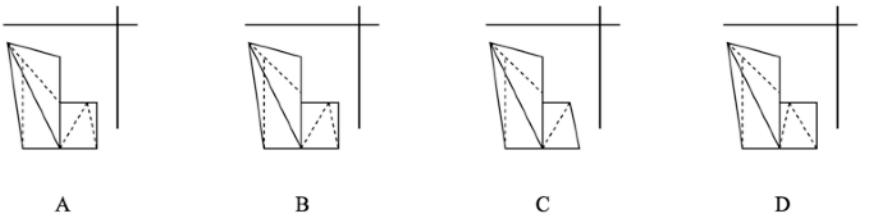
24. Choose the correct FRONT VIEW



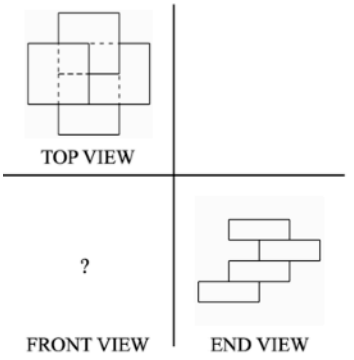


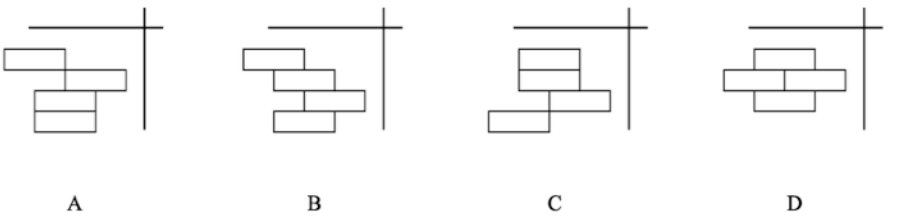
25. Choose the correct FRONT VIEW



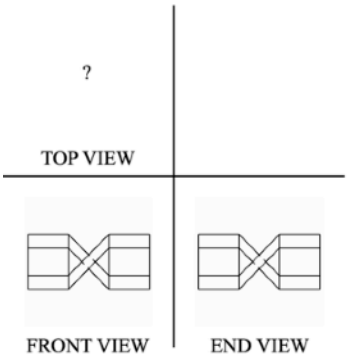


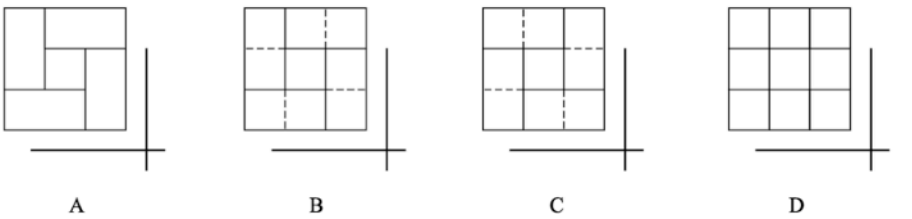
26. Choose the correct FRONT VIEW



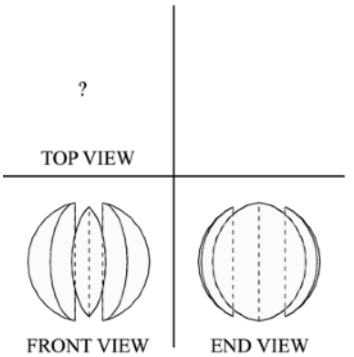


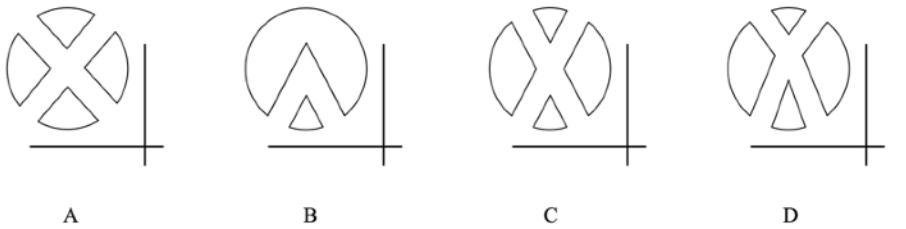
27. Choose the correct TOP VIEW



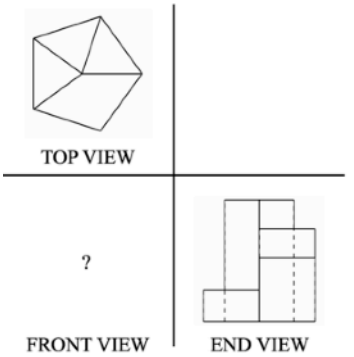


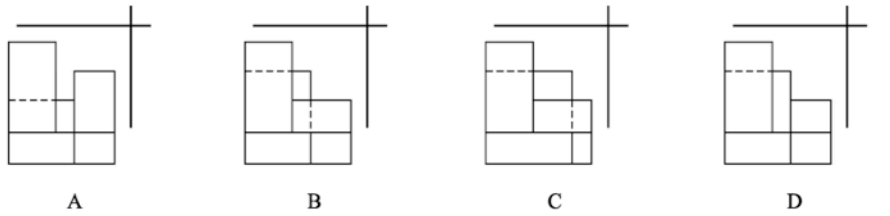
28. Choose the correct FRONT VIEW



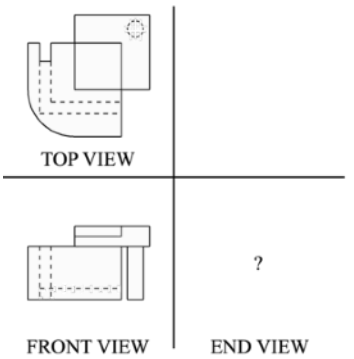


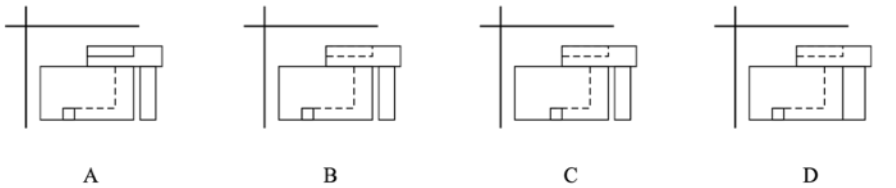
29. Choose the correct FRONT VIEW





30. Choose the correct END VIEW

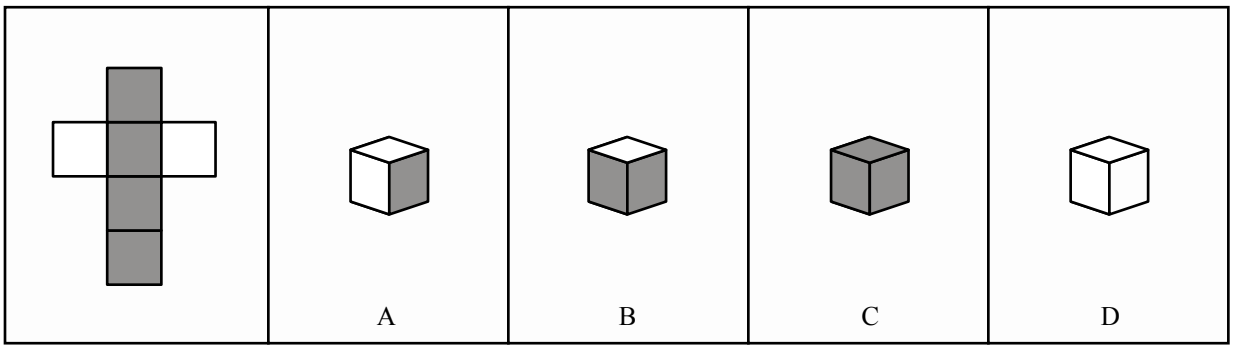




PART 6

For questions 76 to 90, the test contains two-dimensional patterns similar to the example shown below. This pattern is folded into the page, forming a three-dimensional figure. Your task is to mentally fold the two-dimensional patterns and select the correct three-dimensional figure out of the four presented.

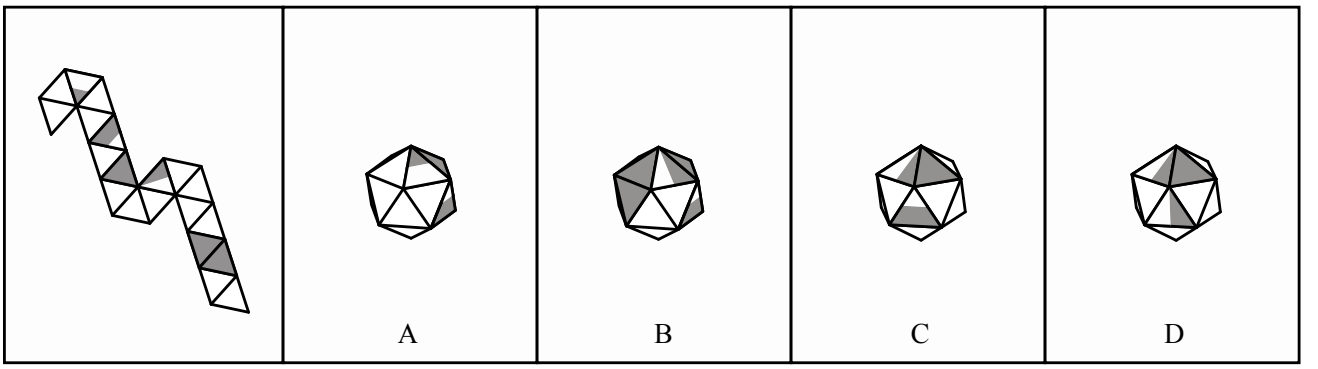
Example Question (Do NOT mark the answer to this example on your answer sheet)



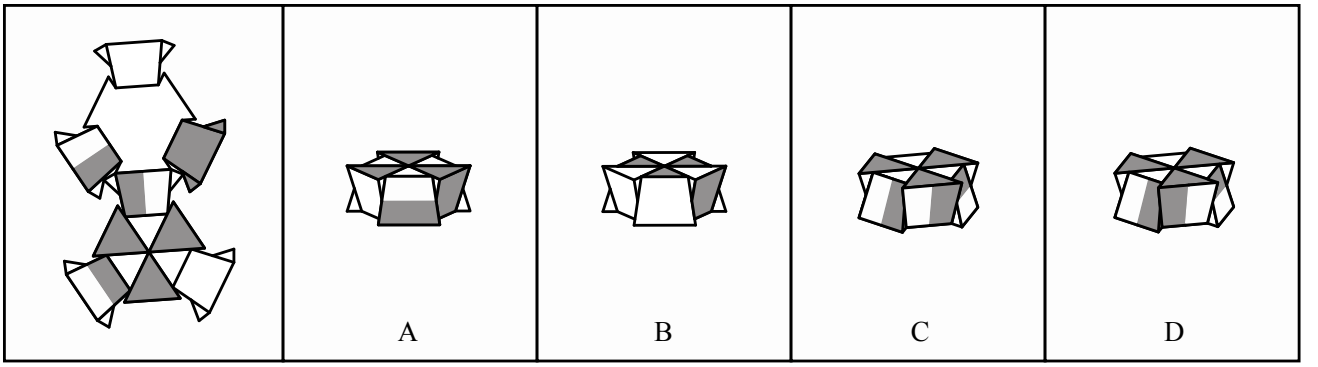
The correct answer is B, since it represents both the correct shape and pattern of shaded faces in the folded three-dimensional figure. There should be four shaded sides that exist side-by-side, and two unshaded sides on opposite ends of the cube.

Please proceed to the questions

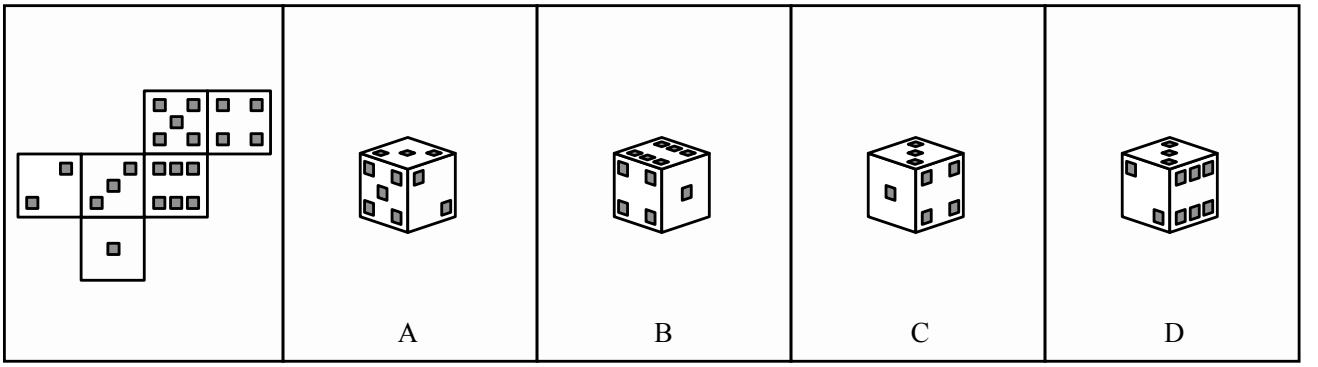
76.



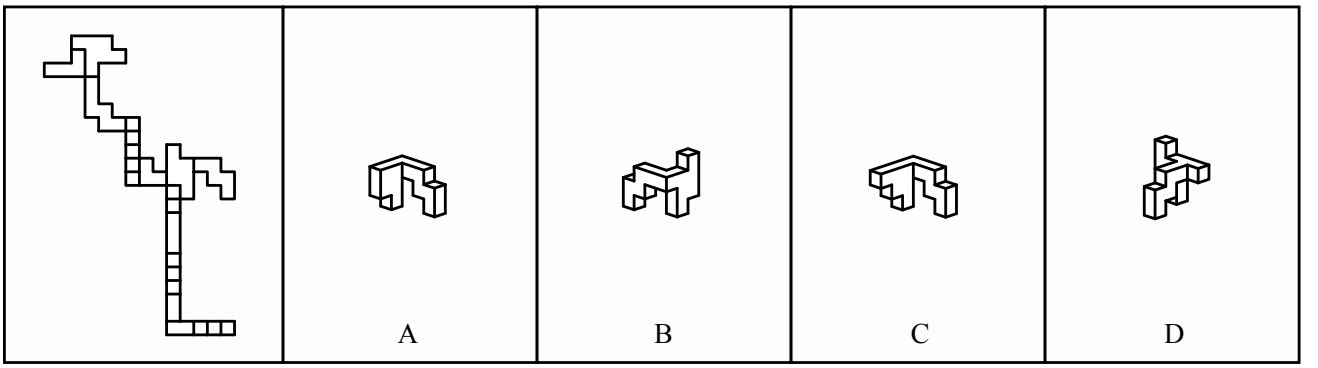
77.



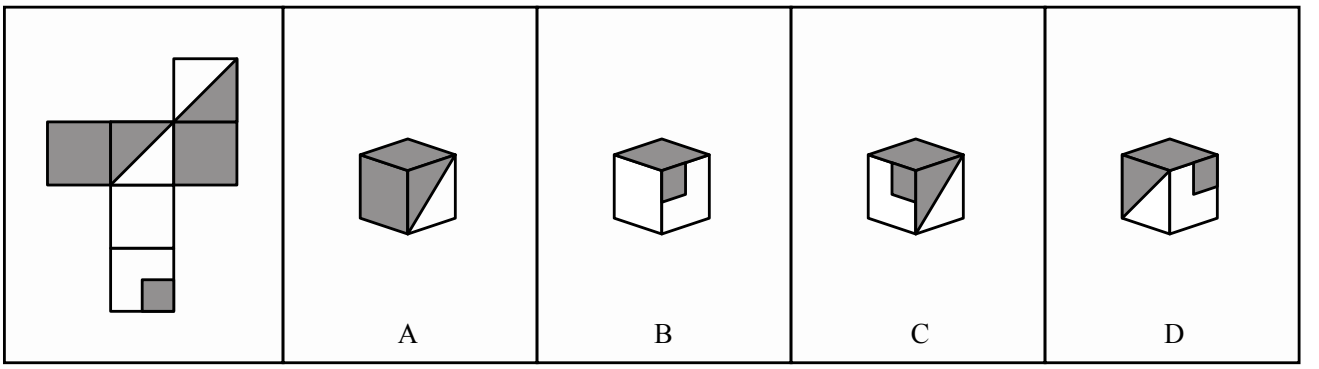
78.



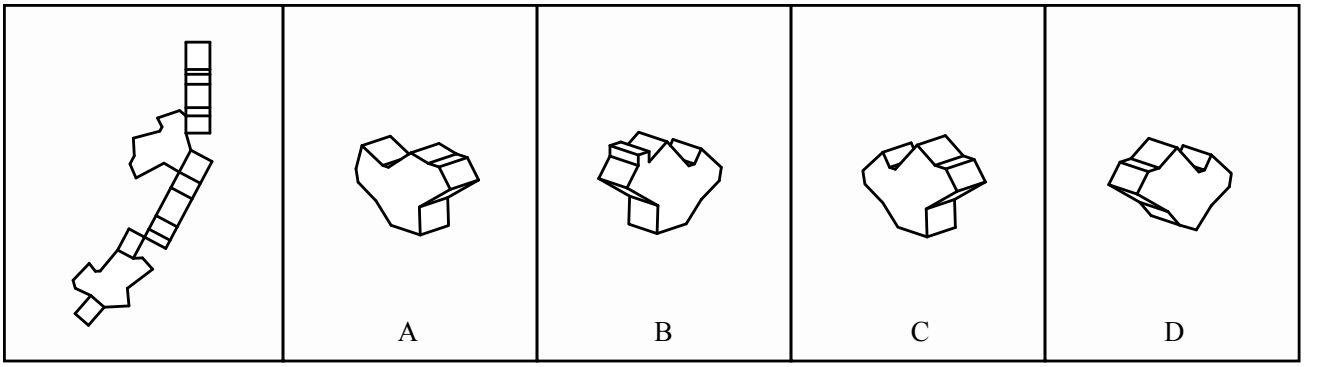
79.



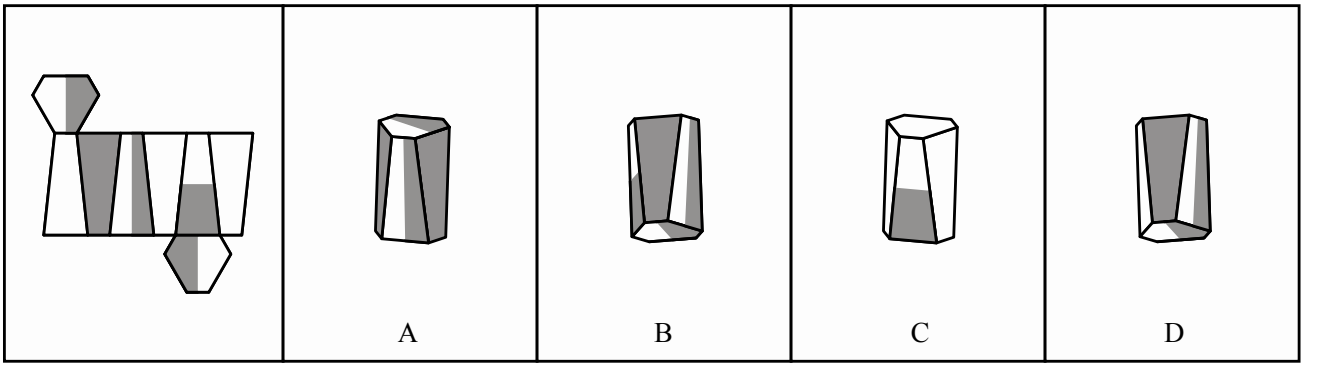
80.



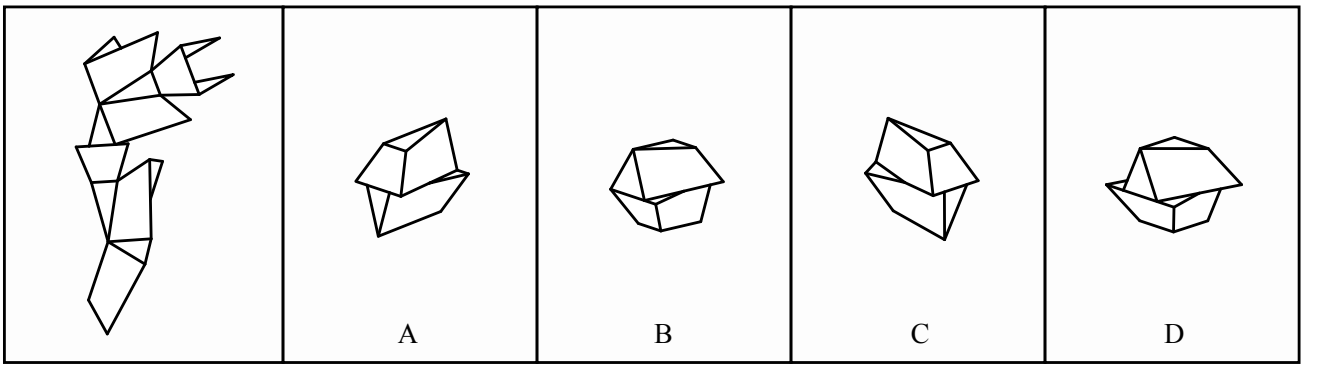
81.



82.



83.



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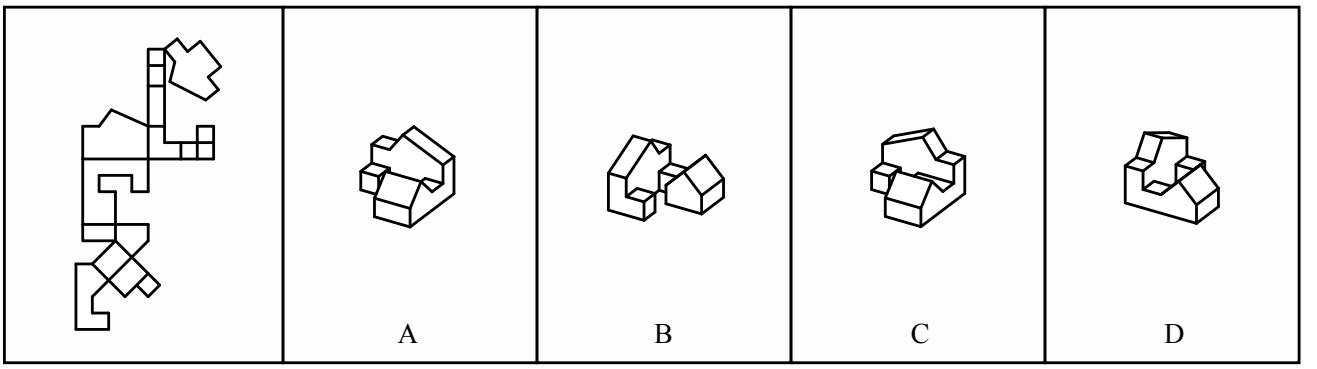

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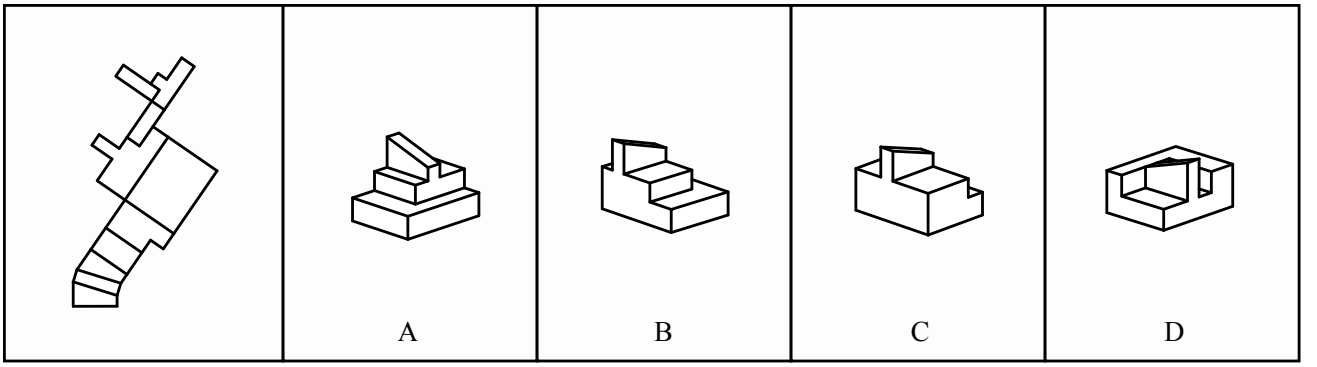
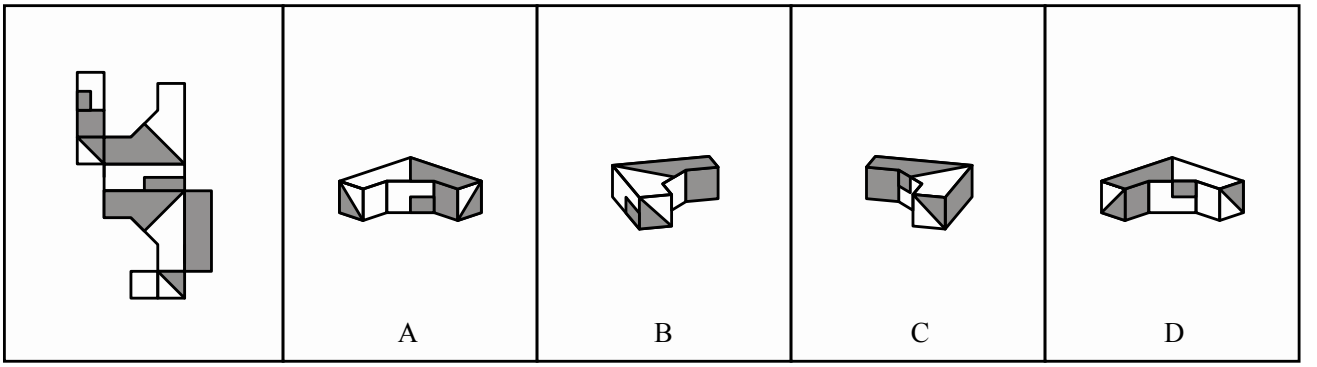
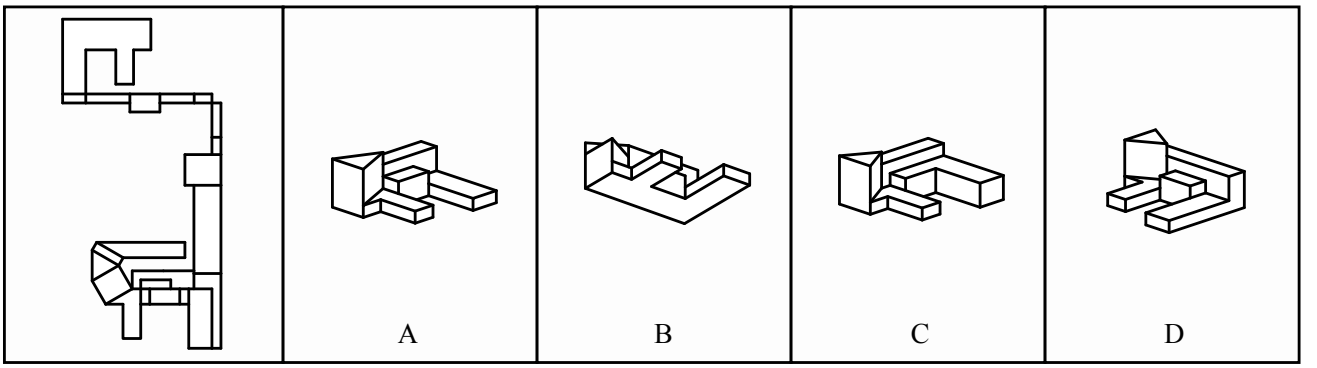


86.



87.



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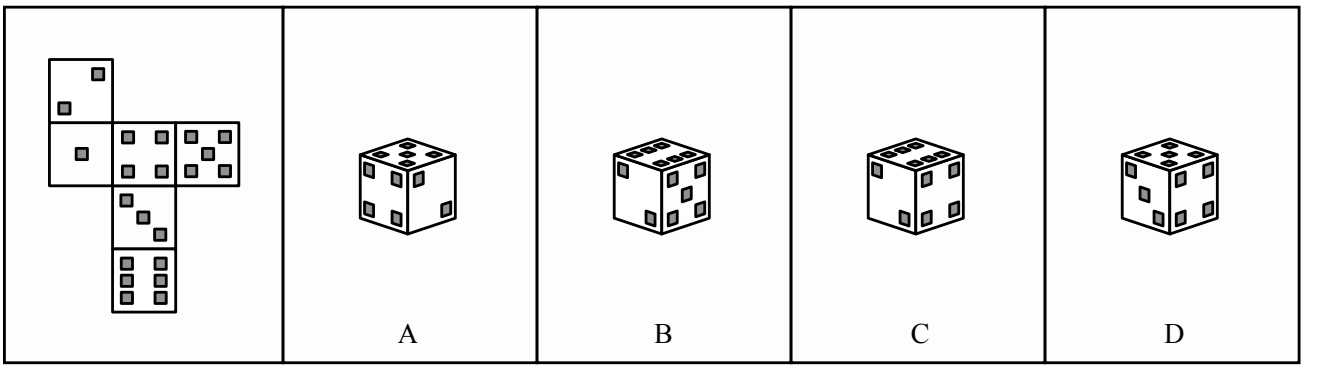
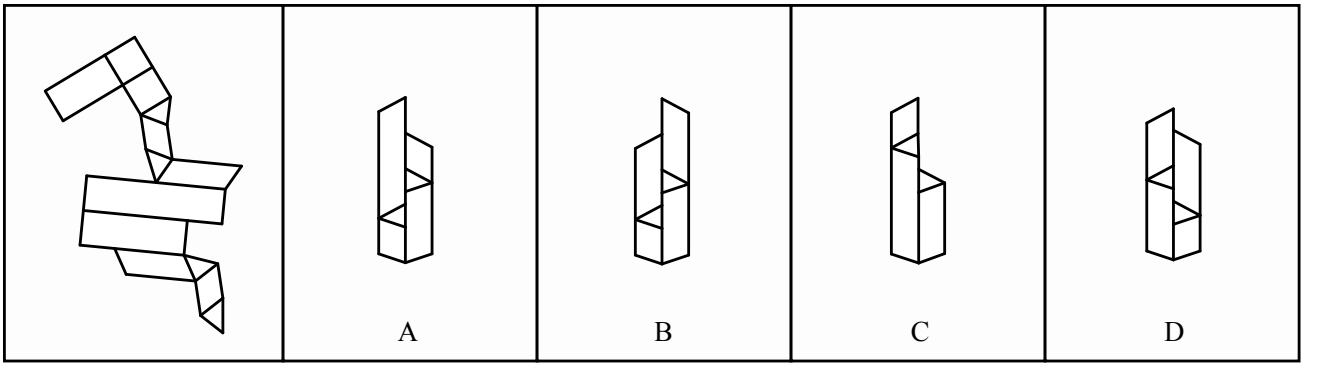
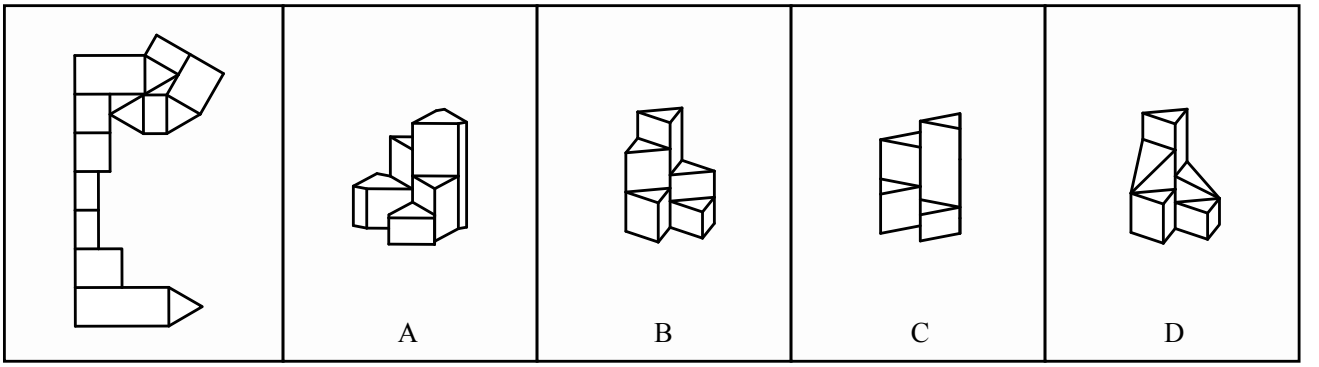


89.



90.



STOP

You have completed the PAT section of the DAT.
You will receive a 10 min break before the next section.

FULL-LENGTH 4 HIGHER DIFFICULTY

READING COMPREHENSION TEST

DO NOT TURN THIS PAGE UNTIL THE TIMER IS STARTED

At this time, ensure that you have prepared your DAT answer sheet such that:

- Your pre-printed identification sticker is placed in the dotted section and the attestation statement is read and signed
- With the supplied HB pencil, you have:
  - Written and bubbled in your DAT identification number
  - Written the test centre code
  - Written the test name and number

Instructions for the Reading Comprehension Test:

1. This test will evaluate your reading comprehension skills. It is composed of three passages. Reach each passage carefully, then proceed to the corresponding questions. Decide which of the presented choices best answers/completes the question/statement. Bubble in the appropriate answer choice on the answer sheet
2. When bubbling in your DAT answer sheet, remember the following:
   a. Use the provided HB pencil
   b. Darken the circle completely
   c. Use the test booklet for notes and rough work, but remember to transfer your answers to the answer sheet
   d. There is no penalty for guessing. Answer all questions
3. You have 50 minutes to complete this section of the DAT. You will be notified when time is up. You cannot continue writing once the time is up, or your exam will be voided
4. **WHEN THIS SECTION IS COMPLETE, PUT DOWN YOUR PENCIL AND TURN TO THE STOP PAGE**
5. At the end of this section, the answer sheet is collected and the Dental Aptitude Test simulation is now complete

TIME LIMIT:
50 minutes

TEST NAME:
RCT

TEST NUMBER:
04

This is a DAT simulation.

Passage 1

Occupational Risks of Coal Mining

Coal mining is an occupation that has existed since the 1880s but has remained relatively unchanged for many years. The extraction of coal can take on a variety of methods: surface, strip, contour, and underground mining are all approaches that are most appropriately used in specific geological conditions. The coal industry is a key economic driver for many countries. However, the occupational hazards associated with extraction and transportation are complex and varied, due to the plethora of different chemical, physical, and biological exposures generated from coal dust and mining paraphernalia. This essay will focus on three of these general exposures – gaseous environmental contaminants, airborne particulates, and microbial bioaerosols.

Let us begin our discussion with a case report. 67 years ago, a middle-aged miner in excellent health collapsed suddenly and was brought to the surface unconscious. In hospital, he showed signs of acute respiratory distress and died two hours later. Autopsy demonstrated a pO_2 level below reference range (75-100 mmHg) and pulmonary edema, indicating asphyxiation as the cause of death. Subsequent investigation revealed that the man may have been overwhelmed by inhaled methane gas that escaped from a fire-damp (pockets of underground flammable gas). In another case report occurring 66 years later, another miner faces a very different health problem. This individual has been working in the mining industry for 20 years and suffers from dyspnea, chronic coughing, tachypnea, and cyanosis. After transplantation of the left lung, histology is performed. Progressive massive fibrosis (PMF) is present throughout the upper lobe, indicating silicosis, a restrictive lung disease caused by inhalation of dust. Comparing this second case study to the first one illustrates how the most common occupational pathologies found in today's miners differ from those 67 years ago. Although improved technology (i.e. handheld gas detectors) and government regulation has led to the reduction of many causes of acute injury to workers, modern miners are still burdened with chronic health issues. Careful analysis of the environmental risk factors for developing chronic lung disease is critical for the understanding and management of the potential health hazards of coal mining.

Although the hazards of mining are obvious even to the untrained eye, one of the most serious dangers is invisible – the insidious effects of toxic gases. In a 2009 paper investigating German coalminers, the main sources of exposure to carbon monoxide and nitrogen oxides were from diesel engines used in continuous mining machines and rail transportation. From a retrospective cohort study of 1,369 coalminers, the mean NO and NO_2 exposure over 24 years were calculated to be 1,748 ppm and 19.6 ppm respectively. The NO and NO_2 exposure for an 8-hour workday was reported to be 1.35 ppm and 0.21 ppm respectively. While these values were found to be in compliance with German law, a 2018 review article by Zhang *et al*. demonstrates a 2.0% increase in relative risk for chronic obstructive pulmonary disease (COPD) when exposed long-term to NO_2 concentrations as low as 0.01 ppm. Aside from this, many other studies demonstrate the damaging effects of chronic NO_2 exposure that may be faced by coalminers.

Another major environmental hazard to coalminers is the generation of airborne particulates (coal dust, silica powder, etc.) during coal extraction. This results in a number of respiratory diseases, the most common being coal worker's pneumoconiosis (CWP), which demonstrated a standardized mortality ratio (SMR) of 79.70 (95% CI 72.1 to 87.67) in a 2014 prospective cohort study of 8,829 America coalminers with a follow-up of 37 years. CWP is often diagnosed in individuals with a history of coal mine dust exposure and is more common in workers at the coal face, which has the highest concentrations of dust. Silica is another airborne particulate associated with development of silicosis, a form of pneumoconiosis. Both silicosis and CWP may progress to progressive massive fibrosis (PMF), characterized by the presence of fibrotic lesions in the upper lung. PMF has a poor prognosis, with a median survival of only 2.5 years. Other pulmonary diseases in which coal dust exposure has been shown to increase risk include: COPD, emphysema, lung cancer, hypersensitivity pneumonitis, and occupational asthma.

The final environmental hazard we will discuss is microbial bioaerosols produced from

disrupted soil and untreated water. The role that microorganisms play in occupational health is a relatively novel field of research; one that has not yet been applied to the coal-mining industry until recently. In a landmark paper by Wei *et al*., pyrosequencing and real-time polymerase chain reaction (RT-PCR) was used to identify and classify 37,191 genomic DNA reads obtained from bioaerosol samplers fitted with 0.22 μm pore filters. The total concentrations of bacteria, archaea and fungi were $1.02x10^8$, $1.44x10^8$, and $9.60x10^4$ cells/m^3 respectively. The experimenters observed a very high level of microbe diversity and identified 336 (1.87%) potentially pathogenic bacterial sequences. The most common pathogens were in the phyla γ-Proteobacteria (1.12%), Firmicutes (0.73%), and Actinobacteria (0.02%). *Mycobacterium* is an example of an Actinobacteria that is known to cause tuberculosis (TB). This is incredibly relevant to occupational health given that in a 2018 study, 66.4% of miners with CWP were found to be comorbid with a latent TB infection. Studies have also confirmed that inhalable hypha and spores from fungi are associated with skin allergies and asthma.

The pathogenesis of COPD in individuals chronically exposed to NO_2 remains unknown. However, acute NO_2 poisoning is known to cause pulmonary edema, bronchitis, and pneumonitis when NO_2 is spontaneously hydrolyzed to nitrous and nitric acid upon contact with moisture in the lung. Nitrous acid is a powerful oxidizing agent that can cause chemical burns, oxidative stress, and lipid peroxidation. The respiratory epithelium becomes damaged due to destruction of type I pneumocytes, releasing fluid that results in edema.

Alveolar macrophages (AM) cells play a major role in the pathophysiology of CWP. Under physiological conditions, AM cells remove foreign particles from the alveolar surfaces and kill microbes via phagocytosis followed by oxidative burst. In CWP, excessive exposure to a complex mixture of exogenous substances in coal dust triggers production of oxygen radicals, arachidonic acid metabolites, cytokines, and other pro-inflammatory mediators. Additionally, platelet-derived growth factor (PDGF) and insulin-like growth factor-1 (IGF-1) are highly secreted by AM cells in patients with PMF. Fibroblasts possess the receptor tyrosine kinase (RTK) cell surface receptor targeted by PDGF, thus inducing overproduction of connective tissue leading to fibrosis. IGF-1 is also found to be upregulated in pulmonary fibrosis. Hung *et al*. found that in bleomycin-induced murine lung injury, IGF-1 stimulates differentiation of fibroblasts into a myofibroblast phenotype.

Finally, the mechanism of microbial bioaerosol-induced TB is described by the *Mycobacterium tuberculosis* complex (MTC). MTC is a phylogenetically related group of *Mycobacteria* that cause TB in humans and animals. Like coal dust, *M. tuberculosis* is phagocytosed by alveolar macrophages (AM) cells. However, fusion of the mature phagosome to lysosomes containing hydrolytic enzymes is prevented by *M. tuberculosis* inhibiting sphingosine kinase and Ca^{2+} signalling through an unknown pathway. The bacteria then multiply in AM cells, which produce cytokines attracting an ineffective counterattack of inactivated monocytes, lymphocytes, and neutrophils. Macrophages fuse to form multi-nucleated giant cells, forming a protective granuloma. Tissue inside the granuloma undergoes caseous necrosis, followed by fibrosis and calcification. These calcifications are visible on x-rays and may indicate a former TB infection or an ongoing latent infection.

Reduction in occupational exposure to explosive gases such as methane have been greatly reduced through the introduction of safety lamps. However, toxic levels of insidious gases like CO and NO_2 are much harder to detect in an economical manner. Gas detectors serve as modern "canaries in the coal mine" but are expensive to acquire and maintain. Personal protective equipment such as gas masks are effective but should only be used as last-resort measure, given that the majority of CO and NO_2 emissions can be addressed directly by eliminating diesel-burning equipment from poorly ventilated areas and using electrical equipment instead.

Airborne particulates such as coal dust can be managed by spraying water over machinery, as done historically. Modern approaches include installing plastic ventilation curtains (used to direct airflow) and installing canopy air curtain (CAC) technology on shuttle cars, which forms a shield of

clean air over drivers. Employee monitoring with spirometry testing and frequent physical examinations can be made mandatory on a policy-level to improve early diagnosis of pulmonary disease.

Finally, microbial bioaerosol hazards can be managed by requiring workers to wear N95 respirators, used by nurses, biologists, forensic pathologists, and other individuals with similar biological occupational hazards. Additionally, prophylactic vaccinations against *M. tuberculosis*, *Staphylococcus*, and *Clostridium* should be mandatory.

Most governments have implemented legislation that controls the level of occupational hazards coalminers are exposed to. For instance, the Mine Safety and Health Administration (MSHA) of the United States enacted the 2014 "Dust Rule," which set maximum allowable levels of dust in coal mines, required operators to conduct air quality tests quarterly during shifts, and improved the availability of approved respiratory equipment. However, very little government oversight currently exists regarding biological hazards in the workplace. As demonstrated by Wei *et al*., chronic exposure to exotoxins or endotoxins from bioaerosols are correlated with eye and skin irritation, as well as respiratory disorders such as allergic lung inflammation, chronic airway obstruction, byssinosis, bronchitis, tuberculosis, and asthma. As more research is conducted in this field, it becomes clear that abiotic dangers are not the only issues that warrant our attention. We must take a holistic approach if we wish to maximize the positive clinical outcomes of hazard management. Only by better understanding the interplay of biological, environmental, and individual determinants of health will we be able to enact comprehensive laws that serve to protect our workers.

1. Which of the following conditions does NOT result from the spontaneous hydrolysis of NO_2?
   A. Bronchitis
   B. Asthma
   C. Pneumonitis
   D. Pulmonary edema

2. Which of the following statements would the author most likely DISAGREE with?
   A. Improvements in safety technology has simply shifted the most common forms of occupational injury from acute to chronic
   B. It is difficult to fully protect coal miners from all hazards due to the diversity of exposures
   C. German regulations for maximum NO_2 exposure should be tightened
   D. Legislation is the most important factor in protecting workers from occupational hazards
   E. The significance of bioaerosols as an occupational hazard of coal mining has been historically under-appreciated

3. Mycobacterium is a Proteobacteria that is known to cause tuberculosis.

   Macrophages and airborne particulates both play an important role in CWP.
   A. Both statements are TRUE
   B. Both statements are FALSE
   C. The first statement is TRUE, the second is FALSE
   D. The first statement is FALSE, the second is TRUE

4. What was the concentration of archea found in the Wei *et al.* study?
   A. 9.60×10^4
   B. 1.44×10^8
   C. 1.44×10^4
   D. 1.02×10^4
   E. 1.02×10^8

5. Which of the following pulmonary diseases is not augmented with exposure to coal dust?
   A. Hypersensitivity pneumonitis
   B. Emphysema
   C. Asthma
   D. Bronchitis
   E. lung cancer

6. Which of the following statements is most likely to be true?
   A. Oxidative stress and lipid peroxidation result from chronic NO_2 exposure
   B. Edema results from the destruction of type II pneumocytes
   C. Pulmonary edema, bronchitis, and pneumonitis, are risk factors for COPD
   D. Adding PDGF to a cell culture of fibroblasts will result in fibrosis
   E. IGF-1 converts fibroblasts into myofibroblasts in many human lung diseases

7. What is the standardized mortality ratio of coal worker's pneumoconiosis?
   A. 10×4
   B. 5×40
   C. 20×4
   D. 5×20
   E. 20×3

8. What is the author's tone in paragraph two?
   A. Agnostic
   B. Analytical
   C. Informative
   D. Melancholy
   E. Casual

9. Which of the following techniques is NOT used to protect workers from airborne particulates or bioaerosols?
   A. Installing ventilation curtains
   B. Wearing N95 respirators
   C. Installing CAC technology
   D. Prophylactic vaccinations
   E. Spraying water over machinery

10. Exposure to endotoxins are correlated with skin irritation.

    Exposure to exotoxins are are correlated with chronic airway obstruction and byssinosis.
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

11. How did Wei et al. collect microorganism samples for pyrosequencing?
    A. N95 filters
    B. Nanopores
    C. Bioaerosol samplers
    D. Wired mesh
    E. Alveolar macrophages

12. Which of the following safety policies is the author most likely to implement in the USA?
    A. Mandatory gas masks for all coalminers
    B. Limit daily NO_2 exposure to 0.21 ppm
    C. Install gas detectors in every mineshaft
    D. Replacing diesel engines with electric motors
    E. Limit the allowable level of dust in coal mines

13. How many coalminers were involved in the 2014 study?
    A. 37,191
    B. 8,829
    C. 1,748
    D. 1,369
    E. 8,892

14. What message is the author trying to convey in paragraph three?
    A. There is no "safe" level of NO_2 exposure
    B. The use of diesel machinery should be limited in underground mines
    C. There should be a limit for the number of hours coalminers are allowed to work per day
    D. The long-term dangers of exposure to toxic gasses such as NO and NO_2 often first manifest through warning signs
    E. The long-term consequences of toxic gasses such as NO and NO_2 are under-appreciated and under-regulated

15. Which of the following techniques was used to analyze DNA from bioaerosol samplers?
    A. Next-generation sequencing
    B. Gel electrophoresis
    C. Restriction digest
    D. Polymerase chain reaction
    E. Molecular cloning

16. Which of the following describes the Mycobacterium tuberculosis complex?
    A. A collection of clinical signs and symptoms
    B. A protein-substrate complex
    C. A group of evolutionarily related bacteria
    D. A lesion formed by calcified granulomas
    E. An assembly of a mature phagosome, lysosome, and hydrolytic enzymes

17. In the study by *Wei et al.*, what percentage of potentially pathogenic bacterial sequences were related to Actinobacteria?
    A. $\frac{0.02}{1.87}\%$
    B. $\frac{1.12}{1.87}\%$
    C. $\frac{0.73}{1.87}\%$
    D. $\frac{0.02}{1.12}\%$
    E. $\frac{0.73}{1.12}\%$

18. How is methane different from carbon monoxide?
    A. Methane is more dangerous to coalminers
    B. Methane can be more easily detected
    C. Carbon monoxide is explosive
    D. Carbon monoxide is produced via electrical equipment
    E. Methane can cause asphyxiation

19. What does MSHA stand for?
    A. Mine Security and Health Alliance
    B. Municipal Social Housing Association
    C. Mineable Sulphur, Hassium, and Antimony
    D. Mine Safety and Health Administration
    E. Municipal Safety and Health Association

20. Which of the following factors does the author NOT mention as important for occupational health in coalminers?
    A. Socioeconomic factors
    B. Environmental hazards
    C. Biological hazards
    D. Abiotic dangers
    E. Genetic factors

Passage 2

HIV Prevention and Treatment

Although global commitment to control the HIV/AIDS pandemic has increased significantly in recent years, the virus continues to spread with alarming and increasing speed. By the end of 2005, an estimated 40 million people worldwide were living with HIV infection or disease, a notable rise from the 35 million infected with HIV in 2001. In 2005, close to 5 million new HIV infections and 3 million AIDS deaths occurred, more of both than in any previous year. Sub-Saharan Africa remains the region most affected by HIV/AIDS; however, the virus is now spreading rapidly in Asia and parts of Eastern Europe.

Although no single country has been spared the virus, the epidemic has affected certain regions of the world disproportionately, and Sub-Saharan Africa remains by far the hardest hit region. With only 10 percent of the world's population, it accounts for more than 75 percent of all HIV infections worldwide and more than 75 percent of AIDS-related deaths estimated for 2003. Asia and the Pacific, with several large and populous countries, account for 7.4 million infections, or 19.5 percent of the current burden of disease. Prevention and treatment efforts in Sub-Saharan Africa and Asia—regions that together represent 85 percent of all current infections—have dictated, and will continue to dictate, global trends in the burden of HIV- and AIDS-related mortality.

Despite the rapid spread of HIV, several countries have achieved important success in curbing its transmission. The extraordinary potential of HIV prevention is exemplified by such diverse efforts as Thailand's 100 percent condom program, Uganda's remarkable decrease in HIV prevalence, and the community-based syndromic management of sexually transmitted infections (STIs) in Mwanza, Tanzania.

Successes also include the development and effective use of highly sensitive and specific HIV screening tests, which have virtually eliminated infection from the blood supply in the developed world and in most parts of the developing world. In addition, the administration of a short course of nevirapine to mothers during labor and to newborns postpartum reduces the risk of mother-to-child transmission (MTCT) by as much as 47 percent. However, recent data suggest that such short-term successes may be at the expense of resistance and viral failure once treatment is introduced after delivery.

Enormous advances in HIV/AIDS treatment regimens have fundamentally altered the natural history of the disease and sharply reduced HIV-related morbidity and mortality in countries where such treatments are accessible. The advent of antiretroviral drugs in the late 1980s began a revolution in the management of HIV, which can be seen as analogous to the use of penicillin for treating bacterial infections in the 1940s. The most notable advance on the treatment front is the use of combination antiretroviral therapy, which is far more effective than monotherapy (zidovudine or AZT), the previous "gold standard". Recent declines in the price of combination antiretroviral therapy in developing countries from US$15,000 per year to less than US$150 in some countries have prompted numerous developing countries to introduce antiretroviral therapy through the public sector. These declines also pose difficult questions regarding the optimal allocation of limited resources for HIV/AIDS, as well as the potential impact on already strained health care infrastructures.

Obstacles to effective HIV control include lack of prevention/care coverage and lack of rigorous evaluations. Notwithstanding these treatment strides, global efforts have not proved sufficient to control the spread of the pandemic or to extend the lives of the majority of those infected. The desired level of success has not yet been achieved for several reasons. Most people who could benefit from available control strategies, including treatment, do not have access to them. Modellers commissioned by the World Health Organization (WHO) and the Joint United Nations Programme on HIV/AIDS (UNAIDS) determined that existing interventions could prevent 63 percent of all infections projected to occur between 2002 and 2010. Nonetheless, a 2003 survey of coverage revealed that fewer than one in five people at high risk of infection had access to the most basic prevention services, including condoms, AIDS education, MTCT prevention, voluntary counselling and testing (VCT), and harm reduction programs. WHO and UNAIDS estimate that only

about 7 percent of the nearly 6 million people in need of treatment receive it and that the number of people who require antiretroviral therapy increases by 8,000 each day.

Current coverage shortfalls, combined with the relentless expansion of the epidemic, underscore the acute need for rapid scale-up of prevention and treatment interventions—an imperative that the international community has acknowledged but that remains to be realized after more than 15 years. However, the activities of the Global Fund to Fight AIDS, Tuberculosis, and Malaria and the U.S. President's Emergency Plan for AIDS Relief (a five-year, 15 billion-dollar initiative) suggest a growing commitment to tackle these issues. The latter aims to provide antiretroviral drugs for 2 million HIV-infected people, to prevent 7 million new infections, to provide care for 10 million individuals, and to develop health system capacity in Vietnam and in Africa and the Caribbean. Even though 15 countries are currently slated to receive support from the President's Emergency Plan, many of the countries most affected by HIV/AIDS—including Lesotho, Malawi, Swaziland, and Zimbabwe—are not included in the list of beneficiary countries.

Because antiretroviral therapy has historically been unavailable in most developing countries, national programs have lacked the means to undertake a comprehensive approach to HIV/AIDS (notable exceptions are Argentina, Brazil, and Mexico, which provide universal coverage for antiretroviral therapy). Control of the pandemic demands a two-front battle that emphasizes both prevention and care. Even though the prospect of greater access to treatment increases the feasibility of integrating prevention and care in resource-limited settings, it also raises new questions regarding the selection of optimal prevention programs to pair with treatment programs.

In addition to poor coverage of key interventions, perhaps the greatest challenge to effective global control is the lack of reliable evidence to guide the selection of interventions for specific areas or populations. In the same way that global policy makers are increasingly recognizing the need for rigorous evaluation of development programs to ensure their success and eliminate waste, the need for reliable scientific evaluations of AIDS control programs is equally paramount for the same reasons. There are simply not enough resources to do everything everywhere; choices must be made and priorities set. In the HIV/AIDS field, this information deficit is especially pronounced with respect to HIV prevention in general and prevention implemented on a population level in particular. Currently, the allocation of resources for HIV/AIDS prevention is seldom evidence based, primarily because of a lack of data on both the effectiveness and the cost of interventions.

Few evaluations have collected data specifically on HIV infection as an outcome. In the case of care and treatment, success and failure are more readily and rapidly apparent, leading to a substantial degree of auto-correction of ineffective policies. In contrast, with respect to HIV prevention, it is unlikely that those infections that might have occurred in the absence of a prevention program would be monitored, thus reducing the meaningfulness of the auto-feedback cycle for prevention. This underscores the importance of proactive, rigorous evaluation to differentiate success from failure in a timely manner. Sound evidence on the effectiveness of HIV prevention measures is especially important in light of the tendency of many governments and international aid agencies to avoid programs that address sexual behaviours, drug use, and highly stigmatized and vulnerable populations.

Despite the glaring deficits in AIDS research, the magnitude and seriousness of the global pandemic calls for action in the absence of definitive data. In the absence of firm data to guide program objectives, national strategies may not accurately reflect the priorities dictated by the particular epidemic profile, resulting in highly inefficient investments in HIV/AIDS prevention and care. This waste undoubtedly exacerbates funding shortfalls and results in unnecessary HIV infections and premature deaths.

Adapted from Bertozzi S, Padian NS, Wegbreit J, et al. 2006. *HIV/AIDS Prevention and Treatment*. In: Jamison DT, Breman JG, Measham AR, et al., editors. *Disease Control Priorities in Developing Countries. 2nd edition*.
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21. Which of the following statements would the author most likely agree with?
    A. Controlling the HIV/AIDS pandemic largely depends on limiting the spread of the disease in regions such as Europe and America
    B. Vertical transmission of HIV from mother to newborn has been virtually eliminated thanks to highly sensitive and specific screening tests
    C. Nevirapine treatment may be harmful to the mother and newborn
    D. The global response to the lack of adequate prevention and treatment interventions has been rapid and effective
    E. Zidovudine is often more effective when used independently, rather than in combination with other antiretroviral drugs

22. Which of the following countries does NOT provide universal coverage for antiretroviral therapy?
    A. Brazil
    B. Argentina
    C. India
    D. Mexico

23. Which of the following regions has the highest burden of HIV/AIDS?
    A. Asia
    B. South Africa
    C. Eastern Europe
    D. Sub-Saharan Africa
    E. Western Europe

24. The impact of antiretroviral drugs on HIV treatment is similar in magnitude to the impact of penicillin on the treatment of bacterial infections.

    The current allocation of resources for HIV/AIDs prevention is based on the results of many studies and expert recommendations.
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

25. How many HIV infections does the Emergency Plan for AIDS Relief program estimate itself to be able to prevent?
    A. 2 million
    B. 4 million
    C. 7 million
    D. 10 million
    E. 15 million

26. What is the purpose of the passage?
    A. To advocate for increased research in the public health responses for HIV and AIDS
    B. To advocate for the de-stigmatization of sexually transmitted diseases
    C. To inform the reader of current public health measures to combat HIV/AIDS
    D. To describe how HIV/AIDS grew to a pandemic of massive proportions
    E. To advocate for the withdrawal of government funding until all HIV prevention decisions are evidence-based

27. Why is it difficult for HIV prevention programs to identify and self-correct ineffective policies?
    A. Because prevention programs are relatively underfunded, compared to HIV treatment
    B. Because there is social stigma surrounding HIV prevention
    C. Because there is a research deficit
    D. Because it is difficult to distinguish success from failure
    E. Because such policies are dictated by governments and international agencies

28. Mother-to-child transmission of HIV/AIDS has declined by as much as 47 percent because HIV screening tests have successfully been developed.
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

29. Which of the following is NOT considered a basic prevention service for HIV?
    A. Education
    B. Counselling and testing
    C. Safe injection sites
    D. Harm reduction
    E. Condoms

30. According to the author, which of the following is a valid criticism of the US President's Emergency Plan for AIDS Relief ?
    A. It ignores the needs of countries with a high HIV/AIDS burden, such as Malawi
    B. It does not address the current research deficit and lack of public health data
    C. It is a short-term solution focused on diplomatic vanity rather than improving the health system of countries
    D. It is funded by federal lobbyists who have electoral conflicts of interest
    E. It undermines efforts made by local charities and agencies

31. What is the purpose of the last paragraph?
    A. To make an appeal for scientists to prioritize HIV/AIDS research
    B. To give the reader a sense of hope despite the many problems in the field of HIV prevention and treatment
    C. To explain why auto-correction of ineffective policies is more difficult in HIV prevention
    D. To discuss the efforts and challenges of HIV prevention and treatment in various countries
    E. To warn the reader of the consequences for public health in the absence of research data

32. Which of the following countries is mismatched with its corresponding program/initiative?
    A. Uganda – Decreasing HIV prevalence
    B. USA – Emergency Plan for AIDS Relief
    C. Thailand – 100 Percent Condom Program
    D. Swaziland – Community-Based Syndromic Management of STIs

33. Prevention and treatment efforts in Sub-Saharan Africa dictate global trends in HIV/AIDS-related mortality because it accounts for more than 75 percent of all HIV infections worldwide.
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

34. Which of the following recommendations would the author make to improve HIV control?
    A. Conduct research to develop new control technologies and strategies
    B. Lobby governments to start providing free condoms, testing, and counselling
    C. Privatize the production of antiretroviral drugs to lower prices
    D. Randomize the distribution of basic prevention services

Passage 3

Spontaneous Remission in the Prognosis of Depression

Depression is a disorder many people are familiar with, either from personal experience or from knowing friends or family who have suffered from it. In North America, an estimated 18.9 million people experience at least one major depressive episode per year, making depression the second most common mental health disorder after anxiety disorders. The World Health Organization names depression as the single leading cause of disability worldwide and identifies it as a significant contributor to the global burden of disease.

The Diagnostic and Statistical Manual of Mental Disorders defines a major depressive episode as a period longer than two weeks during which a person experiences the symptoms of major depressive disorder. To be diagnosed with major depressive disorder, a person must meet at least five of nine diagnostic criteria. Examples include "depressed mood most of the day, nearly every day," and "markedly diminished interest or pleasure in all, or almost all, activities". Depression can range in severity from mild to complete incapacitation (e.g. catatonia) and often entails an increased suicide risk.

In the United States, young adults aged 18 to 29 years old have a threefold higher prevalence of major depressive disorder than adults 60 years and above. Additionally, prevalence in women is roughly 1.5 to 3 times greater than prevalence in men (depending on the time period and methodology of the study). Ethnic studies have also found a higher prevalence of major depressive disorder in biracial, First Nations, and white Americans. Lastly, of all American adults with depression, 63.8% experience severe disability due to their disorder. Globally, it's estimated that 300 million people are afflicted with depressive disorders. Surveys conducted by the World Health Organization indicate that prevalence in women around the world is also approximately 1.5 times greater than in men.

The DSM-5 notes that the prognosis of major depressive disorder is fairly variable and susceptible to influence from a number of personal factors. For instance, in some patients a major depressive episode develops from a previously healthy state, whereas in other patients a major depressive episode represents an exacerbation of previous, sub-clinical depressive symptoms. Those in the latter category are much more likely to have the dispositional, lifestyle, and environmental factors that make full symptom remission unlikely. Regardless of the final outcome of treatment, recovery from a depressive episode typically begins after 3 months for 40% of patients and after 1 year for 80% of patients. Generally, the immediate likelihood of remission decreases the longer a patient remains depressed, hence why a significant portion of patients recover during the disproportionately short period of 3 months. In a similar trend, the risk of relapse decreases the longer the period a person remains remitted, although there are several factors that can disrupt this pattern. Among these factors are the aforementioned dispositional, lifestyle, and environmental conditions

that contribute to chronicity. An example of a dispositional factor is low mastery—believing that the circumstances of one's life are determined by external factors. Lifestyle factors which increase the likelihood of relapse include smoking, lack of exercise, and inconsistent sleep. An example of an environmental condition which correlates with likelihood of relapse is work stress. Along with these factors, any comorbid mental health disorders (e.g. schizophrenia, bipolar disorder) are strongly correlated with increased likelihood of relapse.

Spontaneous remission occurs when a patient recovers from an illness without receiving formal treatment. Since the 1950's, it has been a contentious but well-documented phenomenon in psychology. The first major examination of spontaneous remission was in 1952, with the publication of Hans Eysenck's provocative paper *The Effects of Psychotherapy: An Evaluation*. In this paper, Eysenck cites two studies performed by C. Landis and P.G. Denker which compared patients who did and did not receive psychiatric treatment at New York state hospitals. Remarkably, he found that patients who received psychiatric treatment—specifically, psychoanalysis—had a lower rate of remission than patients who received minimal, non-psychological treatment from general practitioners—44% compared to 72%, respectively. In publishing his paper, not only did Eysenck bring spontaneous remission into the academic limelight, he also immediately established the partisan paradigm of the topic due to his attack—intended or otherwise—on the psychoanalytical method (Eysenck was a proponent of behaviour therapy). What followed was a flurry of publications from other prominent psychologists, refuting Eysenck's claims and studying spontaneous remission to back up their own approaches to psychotherapy.

While these initial forays into the topic of spontaneous remission were mostly self-interested, they did demonstrate that a significant portion of untreated patients do experience some degree of spontaneous remission, for almost all neurotic disorders. For instance, Wallace and Whyte found that 65.3% of neurotic patients who had been on waitlists for 3-7 years had improved without treatment (as judged in interviews with psychiatrists). Meanwhile, Saslow and Peters found that only 37% of neurotic patients were judged to have improve over periods of 1-7 years, and only 47% of these patients self-reported improvement. Due to differences in methodology and operationalization, early researchers were unable to determine a base rate for spontaneous remission. However, they were able consistently demonstrate the existence of the phenomenon.

More recent studies on spontaneous remission have been more successful at converging on a base rate. A number of studies from 1970 to 2000 have reported rates of spontaneous remission ranging from 30% to 50% in time periods of 5 weeks to several year. Similar to depression treated with psychotherapy, the rate of spontaneous remission rapidly drops off the longer the depressive episode continues.

The literature on the prognosis of treated and untreated depression is complex and extensive. The factors associated with the onset, recovery, and relapse of treated depression are well understood, and the frequency of spontaneous remission in untreated patients has been thoroughly scrutinized. However, one aspect lacking attention is the rate of relapse for untreated depression. The factors associated with relapse of treated depression are well understood, but it is unclear if these same factors apply to untreated populations. Does the manner in which remission is achieved affect the long-term prognosis of depression and the risk for relapse? If spontaneous remission was found to be associated with a positive prognosis, further studies could be conducted on the differences between spontaneous and therapeutic remission. Any differences discovered could then be applied to psychotherapy to improve long-term effectiveness. Meanwhile, if spontaneous remission was found to be associated with a negative prognosis, this outcome would further emphasize the importance of delivering accessible therapy to people who need it.

In closing, a better understanding of spontaneous remission could lead to improved long-term care for patients suffering from chronic depression, or at the very least bolster the empirical legitimacy of psychotherapy.

35. The prevalence of major depressive disorder in women has been consistently measured to be 1.5 times greater than the prevalence in men.

    Worldwide, around 18.9 million people have some form of depressive disorder.

    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

36. A patient with a history of chronic depression, smoking, insomnia, and bipolar disorder is on "day one" after recovering from a major depressive episode. Which of the following is most likely to happen within the next week?

    A. Spontaneous remission
    B. Suicide
    C. Catatonia
    D. Relapse
    E. Psychosis

37. Which of the following statements is TRUE?

    A. The prognosis of major depressive disorder is relatively consistent from patient to patient
    B. Older patients have a greater risk of developing a major depressive disorder
    C. Recent studies on spontaneous remission are more consistent than early studies
    D. Spontaneous remission was first demonstrated in 1997
    E. The prevalence of major depressive disorder is higher in African Americans

38. Which of the following is the most common mental health disorder?

    A. Bipolar disorder
    B. Depression
    C. Schizophrenia
    D. Obsessive-compulsive disorder
    E. Anxiety disorders

39. A significant portion of depression patients recover during the disproportionately short period of 3 months because their condition developed from a previously healthy state

    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

40. Why was Eysenck's 1952 paper on spontaneous remission provocative?

    A. It provided support for behaviour therapy
    B. It undermined the legitimacy of psychoanalysis
    C. It attacked the beliefs of the majority
    D. The results were not reproducible
    E. It demonstrated extremely high remission rates in patients who underwent psychiatric treatment

41. Which of the following statements best describes the concept of "low mastery"?
    A. The belief that one's depression is a helpless situation that cannot be resolved
    B. The lack of self-confidence in accomplishing a task or goal
    C. The diminished interest or pleasure in all or almost all activities
    D. The belief that the circumstances of one's life are out of his/her control
    E. Complete incapacitation or catatonia

42. Which of the following words can be used to replace "remission" throughout the passage?
    A. Resistance
    B. Progression
    C. Recovery
    D. Exacerbation
    E. Relapse

43. What was the title of Eysenck's paper?
    A. Spontaneous Remission: An Evaluation
    B. Major Depressive Disorder and Spontaneous Remission
    C. Psychoanalysis and Spontaneous Remission
    D. The Effects of Psychotherapy: An Evaluation
    E. The Effects of Psychoanalysis

44. How did Wallace and Whyte measure the rate of spontaneous remission in neurotic patients?
    A. Self-reporting
    B. Interviews
    C. Medical examination
    D. Retrospective survey
    E. Psychoanalysis

45. Which of the following best describes why full remission is difficult for patients with a form of depression that arises from an exacerbation of previous, sub-clinical depressive state?
    A. These patients are more likely to have lifestyle, environmental, and dispositional risk factors
    B. These patients are more likely to have a genetic basis behind the disorder
    C. The immediate likelihood of remission decreases the longer a patient remains depressed
    D. These patients often present with comorbid mental health disorders

46. What does the author describe with the phrase "partisan paradigm" in paragraph five?
    A. The strong support of many scientists for psychoanalysis
    B. The catalyst for disagreement between many prominent psychologists
    C. Eysenck's prejudice in favour of behaviour therapy
    D. The rising popularity of spontaneous remission within academic circles
    E. The contentious but well-documented nature of spontaneous remission

47. Which of the following statements would the author most likely agree with?
    A. The definition for a major depressive episode is broad and subjective
    B. Factors associated with the rate of relapse for untreated depression are well understood
    C. Work stress is a lifestyle factor that is strongly correlated with relapse
    D. Research into the potential effect of spontaneous remission on the prognosis of depression will be beneficial regardless of the actual outcome
    E. Heart disease is the leading cause of disability worldwide

48. What is the tone of the passage?
    A. Critical
    B. Serious
    C. Sympathetic
    D. Informative
    E. Casual

49. In which of the following contexts would you most expect to find this passage?
    A. An informational pamphlet for patients
    B. An academic thesis
    C. A magazine in popular science
    D. A book about the social determinants of depressive disorders
    E. A news release from the World Health Organization

50. Which of the following best describes a "dispositional factor"?
    A. The outward appearance of an individual
    B. A quality or characteristic that is associated with an individual's surroundings
    C. The mood or attitude of an individual
    D. A quality or characteristic that is associated with a particular individual
    E. The diet and exercise of an individual

STOP

You have completed the RCT section of the DAT.
The exam is now over.

FULL-LENGTH 4 HIGHER DIFFICULTY

SOLUTIONS

Survey of Natural Sciences

1. The cellular respiration of one glucose molecule yields 38 ATP in hepatocytes and 36 ATP in osteocytes. Which of the following is most likely to explain this difference?
   A. Hepatocytes use oxidative phosphorylation, while osteocytes use substrate-level phosphorylation
   B. Hepatocytes use the glycerol-phosphate shuttle, while osteocytes use the malate-aspartate shuttle
   C. Hepatocytes use lactic acid fermentation, while osteocytes use ethanol fermentation
   D. Hepatocytes use the malate-aspartate shuttle, while osteocytes use the glycerol-phosphate shuttle
   E. Hepatocytes contain more mitochondria than osteocytes

   A → Incorrect. All aerobic mammalian cells use both substrate level (ex: glycolysis) and oxidative (ex: electron transport chain) phosphorylation
   B → Incorrect. See the explanation for answer choice D)
   C → Incorrect. Ethanol fermentation is not used in mammalian cells
   D → Correct. NADH produced by glycolysis cannot cross the inner mitochondrial membrane and must be indirectly transported from the cytosol to the mitochondrial matrix by one of two shuttle systems. The glycerol-phosphate shuttle converts a cytosolic NADH into a matrix $FADH_2$, while the malate-aspartate shuttle converts a cytosolic NADH into a matrix NADH. During the electron transport chain, NADH produces 3 ATP while $FADH_2$ produces 2. Therefore, the malate-aspartate shuttle is more efficient. This system is found in mammalian kidney, liver, and heart cells
   E → Incorrect. While it is true that hepatocytes have more mitochondria than the average cell, this does not affect the ATP yield per glucose molecule

2. Cilia and flagella are both composed of:
   A. Microfilaments
   B. Microtubules
   C. Intermediate filaments
   D. Sarcomeres
   E. Myosin

   A → Incorrect. Microfilaments function in cytoplasm motility, not cellular motility
   B → Correct. Cilia and flagella are composed of microtubules arranged in a characteristic "9+2" structure
   C → Incorrect. Intermediate filaments provide structural support. Examples include keratin and nuclear lamins
   D → Incorrect. Sarcomeres function in muscle contraction
   E → Incorrect. Myosin functions in sarcomere contraction

3. In a population of poisonous beetles, some individuals are able to avoid predation thanks to bright pigmentation. Over time, the percentage of brightly-coloured beetles increases and the coloration is recognized by a greater number of predators. Which of the following best describes this phenomenon?
   A. Stabilizing selection
   B. Heterosis
   C. Balanced polymorphism
   D. Negative frequency-dependent selection
   E. Positive frequency-dependent selection

   A → Incorrect. Stabilizing selection occurs when individuals with the average phenotype are favoured and extreme phenotypes are reduced. The question stem does not mention that bright coloration is the "average" phenotype.
   B → Incorrect. Heterosis is another term for hybrid vigour, which describes the increased fitness of hybrid offspring compared to non-hybrid offspring

C → Incorrect. Balanced polymorphism occurs when two alleles are maintained in a population because individuals with both are better able to survive than those with only one. Examples include heterosis and heterozygote advantage
D → Incorrect. In negative frequency-dependent selection, the fitness of a particular phenotype *decreases* as the phenotype becomes more common
E → Correct. In positive frequency-dependent selection, the fitness of a particular phenotype *increases* as the phenotype becomes more common

4. An adrenal tumour results in the hypersecretion of hormones from the zona fasciculata. Which of the following complications is most likely?
   A. Grave's disease
   B. Hypernatremia
   C. Cushing's syndrome
   D. Increased growth of body hair
   E. Increased epinephrine levels

A → Incorrect. Grave's disease results from an autoimmune-mediated overproduction of thyroid hormones
B → Incorrect. Hypernatremia (high blood sodium) would result from the hypersecretion of mineralocorticoids (from the zona glomerulosa), not glucocorticoids
C → Correct. The zona fasciculata produces glucocorticoids such as cortisol. Chronic exposure to excess cortisol leads to high blood pressure, abdominal obesity, and anxiety, all of which are signs of Cushing's syndrome
D → Incorrect. This would result from the hypersecretion of androgens (from the zona reticularis), not glucocorticoids
E → Incorrect. Catecholamines like epinephrine and norepinephrine are produced in the medulla of the adrenal gland, not the cortex

5. Which of the following embryonic structures does the vertebral column develop from?
   A. Dorsal hollow nerve chord
   B. Pharyngeal gill slits
   C. Notochord
   D. Spinal column
   E. Somites

A → Incorrect. The dorsal hollow nerve chord develops into the spinal chord, not the bony vertebrae
B → Incorrect. Pharyngeal gills slits develop into the Eustachian tubes of the middle ear
C → Incorrect. The notochord develops into the intervertebral disks, not the bony vertebrae themselves
D → Incorrect. Spinal column is just another word for vertebral column or backbone
E → Correct. Somites are repeating blocks that organize the segmented structure of vertebrates. They develop into the bony vertebrae of the vertebral column

6. What is the difference between tracheids and vessel elements?
   A. Tracheids are part of the phloem while vessel elements are part of the xylem
   B. Vessel elements carry glucose while tracheids carry only water and minerals
   C. Tracheids have pits while vessel elements have perforation plates
   D. Tracheids are composed of wider and shorter cells, compared to vessel elements
   E. Tracheids only contain primary cell walls, while vessel elements contain both primary and secondary cell walls

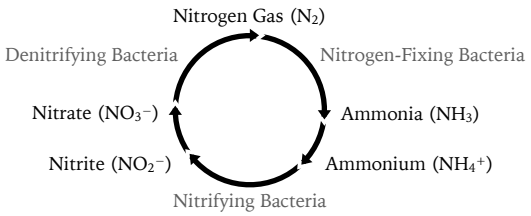
A → Incorrect. Tracheids and vessel elements are both structures of the xylem
B → Incorrect. The phloem carries glucose while the xylem carries only water and minerals
C → Correct. Tracheids are long, thin cells with tapered ends. Water flows through holes in the secondary cell wall called pits. Vessel elements are wider and shorter cells with flat ends. Water flows through holes in both the primary and secondary cell wall called perforation plates
D → Incorrect. See explanation for answer choice C)
E → Incorrect. Tracheids and vessel elements both contain primary and secondary cell walls

7. How are platelets or thrombocytes created?
   A. Differentiation from a myeloid progenitor during hematopoiesis
   B. Cytoplasmic derivative of megakaryocytes
   C. Differentiation from a lymphoid progenitor during hematopoiesis
   D. Cytoplasmic derivative of macrophages
   E. Secreted by granulocytes

A → Incorrect. Although thrombocytes are myelocytes, this answer choice is not specific enough
B → Correct. Thrombocytes are formed from the fragmentation of the cytoplasm of megakaryocytes
C → Incorrect. Thrombocytes are *myelocytes*, not lymphocytes
D → Incorrect. Thrombocytes are derived from megakaryocytes, not macrophages
E → Incorrect. Thrombocytes are not secreted

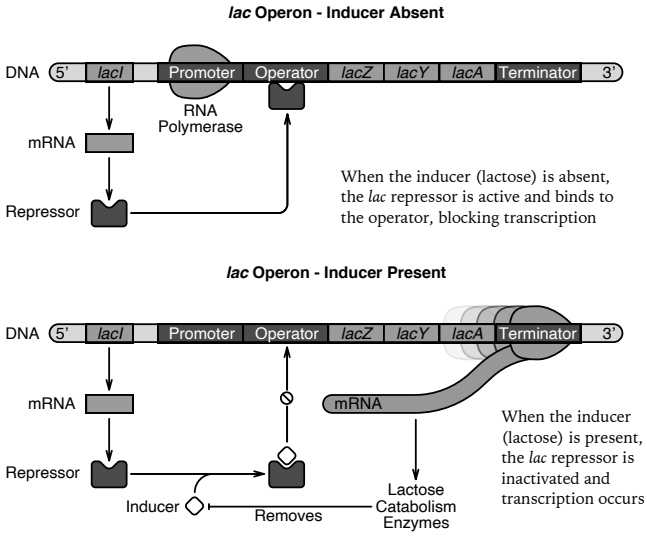
8. Which of the following chemical conversions do nitrifying bacteria catalyze?
   A. Nitrogen gas into ammonia
   B. Nitrate into nitrogen gas
   C. Nitrite into nitrate
   D. Ammonium into nitrite
   E. Ammonium into nitrogen gas

A → Incorrect. This is the function of nitrogen-fixing bacteria
B → Incorrect. This is the function of denitrifying bacteria
C → Incorrect. This process is not mediated by bacteria
D → Correct answer
E → Incorrect. This process does not occur



9. A bacterial cell develops a chromosomal mutation in which the *lac* repressor gene *LacI* is deleted. Which of the following will occur?
   A. Failure of the repressor to bind to the promoter
   B. Constitutive transcription of lactose catabolism genes
   C. Increased concentration of the inducer molecule
   D. Failure of RNA polymerase to bind to the promotor
   E. Failure of the corepressor to bind to the repressor

A → Incorrect. In an operon system, the repressor protein binds to the *operator*, not the promotor
B → Correct. *LacI* codes for the lac repressor protein. If the gene is deleted, there will be no repressor bound to the operator. This allows RNA polymerase to freely transcribe the genes for lactose catabolism
C → Incorrect. We would expect the concentration of the inducer (lactose) to *decrease*, due to constitutive transcription of lactose catabolism genes
D → Incorrect. In an operon system, RNA polymerase is always able to bind to the promotor. It is only blocked from moving to the 3' end of DNA by a repressor protein, which is bound to the operator
E → Incorrect. The *lac* operon is an inducible operon, so it does not involve a corepressor



10. Plasma cells, erythrocytes, and granulocytes have which of the following in common?
    A. They are myelocytes
    B. They are anucleate
    C. They are lymphocytes
    D. They contain MHC II
    E. They are mesoderm-derived

A → Incorrect. Erythrocytes and granulocytes are myelocytes, but plasma cells are lymphocytes
B → Incorrect. Out of the three cell types, only erythrocytes are anucleate
C → Incorrect. Plasma cells are lymphocytes, but erythrocytes and granulocytes are myelocytes
D → Incorrect. Only professional antigen presenting cells (APCs) contain MHC II. B cells are APCs, but erythrocytes and granulocytes are not
E → Correct. All three cells arise from hematopoiesis, which occurs in the bone marrow. The musculoskeletal system is composed of mesoderm-derived tissues

11. Which of the following correctly lists the epidermal layers from superficial to deep?
    A. Spinosum, granulosum, lucidum, basale
    B. corneum, lucidum, spinosum, granulosum
    C. Basale, spinosum, granulosum, corneum
    D. Lucidum, granulosum, spinosum, corneum
    E. Corneum, granulosum, spinosum, basale

The order of all skin layers from superficial to deep is: "Come Let's Get Sun Burnt" → Corneum Lucidum Granulosum Spinosum Basale

12. In angiosperm fertilization, which of the following divides by mitosis to produce an embryo sac?
    A. Endosperm
    B. Megasporangium
    C. Polar nuclei
    D. Megaspore
    E. Ovule

    A → Incorrect. The endosperm is a triploid developmental tissue found inside seeds. It stores carbohydrates, lipids, and proteins to feed the developing embryo
    B → Incorrect. In the ovary, a diploid megasporangium cell divides by meiosis and produces four haploid cells. Only one survives to become a megaspore
    C → Incorrect. The polar nuclei are two haploid cells involved in double fertilization, forming the triploid endosperm
    D → Correct. A megaspore divides by mitosis three times to produce an embryo sac, the multicellular female gametophyte
    E → Incorrect. The ovule is the structure in which the megasporangium, megaspore, and embryo sac are located

13. Which of the following terrestrial biomes is dominated by grass, large herbivorous animals, and nutrient-poor soil?
    A. Taiga
    B. Temperate grassland
    C. Temperate forest
    D. Savanna
    E. Chaparral

    A → Incorrect. A taiga biome is dominated by coniferous trees. Inhabitants may be carnivorous, omnivorous or herbivorous, (ex: wolves, brown bears, caribou). Examples include North America and Russia
    B → Incorrect. Although dominated by grass and grazing animals, temperate grasslands are relatively nutrient-rich. Examples include the prairies of central America
    C → Incorrect. A temperate forest biome is dominated by deciduous trees. Examples include Ontario and Shanghai
    D → Correct. A savanna biome is characterized by plentiful grass, scattered shrubs, warm year-round temperatures, frequent forest fires, and nutrient-poor soil. Examples include Kenya and North Australia
    E → Incorrect. A chaparral is dominated by shrubs and small trees. Examples include the Mediterranean and California

14. Which of the following statements regarding ovulation is INCORRECT?
    A. A secondary oocyte is released into the fallopian tubes after a spike in LH levels
    B. The granulosa cells of the corpus luteum secrete estrogen
    C. The zona pellucida develops during the follicular phase
    D. Progesterone and inhibin are leased during the luteal phase
    E. If implantation occurs, human chorionic gonadotropin (hCG) is produced

    Answer choice B) is correct because it is FALSE. Granulosa cells convert androgens into estrogens. They do not directly produce and secrete estrogen

15. Which of the following proteins are involved in receptor-mediated endocytosis?
    A. Myosin
    B. Dynein
    C. Kinesin
    D. Clathrin
    E. Actin

    A → Incorrect. Myosin is not involved in endocytosis, but rather the contraction of sarcomeres in myocytes
    B → Incorrect. Dynein is a motor protein that transports vesicles and organelles to the minus end of a microtubule
    C → Incorrect. Kinesin is a motor protein that transports vesicles and organelles to the plus end of a microtubule
    D → Correct. Clathrin is required to induce budding of the plasma membrane, forming clathrin-coated vesicles
    E → Incorrect. Actin is not involved in endocytosis, but rather the contraction of sarcomeres in myocytes

16. A population of rabbits enters a new Northern environment. The larger rabbits are hunted by native predators, while the smaller rabbits die from hypothermia due to their high surface area to volume ratio. What is this phenomenon an example of?
    A. Sexual selection
    B. Directional selection
    C. Frequency-dependent selection
    D. Stabilizing selection
    E. Disruptive selection

    A → Incorrect. Sexual selection is the preference of one sex for certain traits in the other sex, resulting in sexual dimorphism

B → Incorrect. Directional selection favours individuals with an extreme phenotype and reduces the frequency of other variations
C → Incorrect. Frequency-dependent selection is when the fitness of a particular phenotype is dependent on the frequency of the phenotype within the population
D → Correct. Stabilizing selection favours the average phenotype and reduces extremes. This reduces genetic diversity
E → Incorrect. Disruptive selection favours extreme phenotypes and reduces the average. This increase genetic diversity

17. A patient presents with a gallstone blocking the passage of bile into the duodenum. Which of the following diets would be recommended?
    A. High protein
    B. Low carbohydrates
    C. Low protein
    D. High fat
    E. Low fat

Bile is produced by the liver, stored in the gallbladder, and released into the duodenum via the common bile duct. Bile emulsifies dietary fat into micelles such that pancreatic lipase can work more efficiently. Without bile secretion, the digestion of fatty foods would be greatly reduced. Therefore, a low-fat diet should be recommended to the patient

18. Which of the following structures is NOT derived from the ectoderm?
    A. Limbic system
    B. Oral mucosa
    C. Osteocyte
    D. Tooth enamel
    E. Melanocytes

A → Incorrect. The limbic system is part of the central nervous system, which is ectoderm-derived
B → Incorrect. The mucosal linings of the mouth, nostrils, and anus are ectoderm-derived
C → Correct. Osteocytes are osteoblasts that have been trapped in bone matrix. They are part of the skeletal system and therefore mesoderm-derived
D → Incorrect. Tooth enamel is ectoderm-derived
E → Incorrect. Melanocytes are located in the deepest layer of the epidermis (stratum basale), which is ectoderm-derived

19. What triggers renin production?
    A. High blood pressure detected by juxtaglomerular cells
    B. Low blood pressure detected by juxtaglomerular cells
    C. High blood pressure detected by macula densa cells
    D. Low blood pressure detected by macula densa cells
    E. Activation of the parasympathetic nervous system

A → Incorrect. Juxtaglomerular cells release renin upon detecting *low* blood pressure
B → Correct answer
C → Incorrect. Macula densa cells detect sodium concentration, not blood pressure. They also release prostaglandin, not renin
D → Incorrect. See explanation for answer C)
E → Incorrect. The renin-angiotensin-aldosterone system (RAAS) is activated by the *sympathetic* nervous system

20. Which one of the following differences between monocots and dicots is INCORRECT?
    A. Dicots have flower petals in multiples of three, while monocots have petals in multiples of four
    B. Dicots have branching leaf veins, while monocots have parallel veins
    C. Stem vascular bundles are scattered in dicots, and are arranged in a ring in monocots
    D. Dicots have a taproot system, while monocots have a fibrous root system
    E. Dicots have two cotyledons, while monocots have one cotyledon

Answer choice A) is correct because the statement is FALSE. Dicots have flower petals that are in multiples of four or five, while monocots have petals in multiples of three

21. Which of the following is composed of organelles arranged perpendicularly?
    A. Centromere
    B. Pericentriolar material
    C. Centriole
    D. Centrosome
    E. Spindle fiber

A → Incorrect. A centromere is a specialized DNA sequence that links a pair of sister chromatids during cell division
B → Incorrect. Pericentriolar material refers to the dense mass of protein that surrounds the centrioles

C → Incorrect. A centriole is a cylinder-shaped organelle composed of microtubules. When paired at 90 degrees with another centriole, it forms a centrosome
D → Correct. A centrosome consists of two centriole organelles orientated perpendicularly from each other
E → Incorrect. A spindle fibre is not an organelle, but rather a microtubule structure that attaches to the centromere perpendicularly during cell division

22. Two strains of bacteria are cultured in a sterile growth medium containing nuclease. One strain is ampicillin-resistant while the other is ampicillin-susceptible. After co-culture, both strains are ampicillin-resistant. Which of the following most likely caused this?

A. Transposable elements
B. Conjugation
C. Transformation
D. Transduction
E. Mutation

A → Incorrect. Transposable elements are sequences of DNA that "jump" from one location to another within a *genome*. Transfer of ampicillin resistance genes from one bacteria to another is not possible through this mechanism
B → Correct. Antibiotic resistance genes are commonly transferred between two bacteria through a sex pilus. The plasmid containing these genes is called the R factor
C → Incorrect. Transformation is when a bacteria picks up DNA (usually a plasmid) from its environment. Since the two strains of bacteria are cultured in a medium containing nucleotide-degrading enzymes, transformation is unlikely
D → Incorrect. Transduction is when a bacteriophage virus moves segments of chromosomal DNA from one bacteria to another. Since the two strains of bacteria are cultured in a sterile medium, transduction is unlikely
E → Incorrect. Mutations are errors in the DNA sequence that result from DNA replication, environmental mutagens, or spontaneous damage. Most mutations are either silent or lethal, and very few actually cause a gain of function

23. A patient arrives to hospital with a chronic neurodegenerative disease acquired after eating raw beef. Which of the following is most likely the cause of his/her condition?

A. Viruses
B. Bacteria
C. Coacervates
D. Prions
E. Demyelination

A → Incorrect. Although some viruses can cause neurological issues, this is often limited to more acute conditions such as encephalitis and meningitis
B → Incorrect. Bacterial infections of the brain are often more acute, similar to viral encephalitis and meningitis
C → Incorrect. Coacervates are protocells that are composed of lipids. Protocells or protobionts were the first compartmentalized living units, precursors to the cell
D → Correct. Prions are infectious, misfolded proteins that are able to cause normal proteins to also fold abnormally. This results in a buildup of amyloid plaques, which causes chronic neurodegenerative pathologies such as Creutzfeldt–Jakob disease and other spongiform encephalopathies
E → Although demyelination of axons is correlated to neurodegenerative diseases such as multiple sclerosis, it is less likely than answer choice D) in the given situation

24. If a city has an instantaneous growth rate of 200 people/year, a caring capacity of 900, and a current population of 300, what is the maximum per capita growth rate?

A. 1 person/year
B. 1.5 people/year
C. 2 people/year
D. 200 people/year
E. 300 people/year

Begin by writing the formula for logistic growth:

$$\frac{dN}{dt} = (r_{max})\left(\frac{K-N}{K}\right)(N)$$

Next, rearrange for the maximum per capita growth rate:

$$r_{max} = \frac{dN}{dt}\left(\frac{1}{N}\right)\left(\frac{K}{K-N}\right)$$

Finally, substitute known values and solve:

$$r_{max} = (200)\left(\frac{1}{300}\right)\left(\frac{900}{900-300}\right)$$

$$r_{max} = (200)\left(\frac{1}{300}\right)\left(\frac{3}{2}\right)$$

$$r_{max} = 1 \text{ person/year}$$

25. The chromatin remodelling complex is a component of which of the following?

A. Post-translational regulation
B. Post-transcriptional regulation
C. Transcriptional regulation
D. The Shine-Dalgarno sequence
E. The spliceosome

A → Incorrect. Post-translational regulation includes protein folding, protein processing, and ubiquitin tagging
B → Incorrect. Post-transcriptional regulation includes alternative splicing, 5' cap addition, poly-A tail addition, and microRNA interference
C → Correct. The chromatin remodelling complex displaces histones to increase the transcription of certain genes
D → Incorrect. The Shine-Dalgarno sequence is a stretch of mRNA in prokaryotes that allows the attachment of the small ribosomal subunit
E → Incorrect. Alternative splicing is a post-transcriptional form of regulation and does not involve the chromatin remodelling complex

26. Which of the following mRNA strands would produce the longest polypeptide?

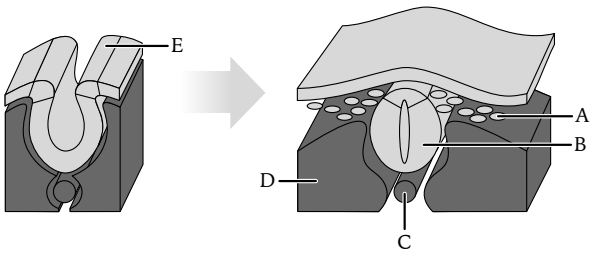
A) 5′–CAGAUGAUUGUUGCGUAACAUCAA–3′
B) 5′–ACCGCUGCCAUGACCAGCUAGGGC–3′
C) 5′–GGGGAUGCCAAUAUGCCAUAAACG–3′
D) 5′–AUGGCUAAUAAAAGGUUGUCGUGA–3′
E) 5′–AUGGUUGUCGCUUAAAAUAAAGGA–3′

The beginning of RNA translation is denoted by the start codon AUG. The end of translation is denoted by the stop codons UAA, UAG, and UGA. Keeping this in mind, we can scan each mRNA sequence and underline the portion that is translated into protein:

A) 5′–CAG**AUG**AUUGUUGCG**UAA**CAUCAA–3′
B) 5′–ACCGCUGCC**AUG**ACCAGC**UAG**GGC–3′
C) 5′–GGGGAUGCCAAU**AUG**CCA**UAA**ACG–3′
D) 5′–**AUG**GCUAAUAAAAGGUUGUCG**UGA**–3′
E) 5′–**AUG**GUUGUCGCU**UAA**AAUAAAGGA–3′

Answer choice D) produces the longest polypeptide (six amino acids long) and is therefore the correct answer

27. In the following figure demonstrating neurulation, identify the structure labelled "B"



A. Neural plate
B. Somite
C. Neural crest
D. Neural tube
E. Notochord

A → Incorrect. The neural plate is a layer of differentiated ectoderm cells that invaginates towards the notochord, forming the neural tube. The neural plate is labeled "E"
B → Incorrect. Somites are repeating blocks that organize the segmented structure of vertebrates. They are labeled "D"
C → Incorrect. The neural crest is composed of cells above and around the neural tube. The neural crest cells are labeled "A" in this figure
D → Correct answer
E → Incorrect. The notochord sits below the neural tube. It is labeled "C" in this figure

28. Which of the following is the most common excitatory neurotransmitter in the brain?

A. Glutamate
B. Acetylcholine
C. GABA
D. Epinephrine
E. Dopamine

A → Correct. Glutamate is the most common excitatory neurotransmitter in the central nervous system
B → Incorrect. Acetylcholine is the most common excitatory neurotransmitter in the *muscles*
C → Incorrect. GABA is the most common *inhibitory* neurotransmitter in the brain
D → Incorrect. Epinephrine is involved in the sympathetic response and is not the most common neurotransmitter
E → Incorrect. Dopamine is involved in pleasure, addiction, and motivation. It not the most common neurotransmitter

29. Which of the following statements regarding developmental cleavage is true?
    A. Meroblastic cleavage results in complete penetration of the cleavage furrow
    B. In determinate cleavage, blastomeres retain totipotency and remain unspecialized
    C. Spiral cleavage occurs in deuterosomes
    D. The pre-cleavage zygote has the same volume as the sum of all blastomeres
    E. Yolk is concentrated towards the animal pole

    A → Incorrect. *Holoblastic* cleavage results in complete penetration, due to the relative absence of yolk in the zygote
    B → Incorrect. Blastomeres retain totipotency in *indeterminate* or *regulative* cleavage
    C → Incorrect. Spiral cleavage occurs in *protostomes*
    D → Correct. The total volume of cytoplasm remains the same throughout cleavage. Only the number of cells increases
    E → Incorrect. Yolk is concentrated towards the *vegetal* pole

30. Which of the following cells matures into a macrophage?
    A. Megakaryocyte
    B. Monocyte
    C. Lymphocyte
    D. Plasma cell
    E. Leukocyte

    A → Incorrect. Megakaryocytes produce fragments of cytoplasm which become thrombocytes or platelets
    B → Correct. Monocytes are the precursors to macrophages. Like neutrophils, monocytes kill bacteria via oxidative and respiratory burst
    C → Incorrect. Lymphocytes are a general category of cells that all originated from a common lymphoid progenitor during hematopoiesis. Macrophages originate from a common *myeloid* progenitor
    D → Incorrect. Plasma cells are specialized B cells that produce high volumes of antibodies
    E → Incorrect. Leukocytes are a general category of cells, known collectively as "white blood cells". This includes all lymphoid cells, along with a few myeloid cells (such as macrophages and granulocytes)

31. Where does pollen germination occur?
    A. The style
    B. The anther
    C. The filament
    D. The stigma
    E. The ovary

    A → Incorrect. The style is a vertical shaft that connects the stigma to the ovary
    B → Incorrect. The anther is where pollen is *produced* by microsporangia. It is not where pollen germinates
    C → Incorrect. The filament is a vertical shaft that supports the anther
    D → Correct. During fertilization, a pollen grain lands on the stigma and a pollen tube grows down into the style. This process is called pollen germination
    E → Incorrect. The ovary is the site of double fertilization, not pollen germination

32. Which of the following hormones is the best indicator of pregnancy?
    A. Estrogen
    B. Progesterone
    C. Leutenizing hormone
    D. Gonadotropin releasing hormone
    E. Human chorionic gonadotropin

    A → Incorrect. Estrogen shows strong correlation to the phases of the menstrual cycle, but is not a reliable indicator for pregnancy
    B → Incorrect. Although progesterone is secreted after implantation to thicken the endometrium and prepare the uterus for gestation of the embryo, it is not the *best* indicator for pregnancy. See answer choice E)
    C → Incorrect. A spike in leutenizing hormone is a great indicator for ovulation, but not for pregnancy
    D → Incorrect. GnRH levels are increased during menstruation, after an absence of implantation
    E → Correct. hCG is produced by the developing blastocyst after successful implantation. hCG prevents atrophy of the corpus luteum and is used in commercial pregnancy tests

33. Which of the following statements regarding blood is correct?

I. It is a connective tissue

II. It is involved in cellular communication

III. When centrifuged, leukocytes appear in the hematocrit layer

A. II
B. I and II
C. I and III
D. II and III
E. I, II, and III

Statement I is correct. Blood is classified as a connective tissue because it is mesoderm-derived, along with other connective tissue types. It also physically and chemically connects different systems within the body.

Statement II is correct. Blood is involved in transporting hormones and signalling molecules.

Statement III is incorrect. When centrifuged, *erythrocytes* (red blood cells) appear clumped together near the bottom of the tube as hematocrit. Lymphocytes (white blood cells) appear in the buffy coat layer, which sits on top of the hematocrit.

34. Anterior pituitary neurons release neurohormones directly into the hypothalamic hypophyseal portal system. Which of the following synapses is this an example of?

A. Axoaxonic
B. Axosomatic
C. Axosecretory
D. Axodendritic
E. Electrical

A → Incorrect. Axoaxonic synapses occur between a presynaptic axon and postsynaptic axon
B → Incorrect. Axosomatic synapses occur between a presynaptic axon and a postsynaptic soma
C → Correct. Axosecretory synapses occur between a presynaptic axon and a blood vessel. In this case, the anterior pituitary cells secrete neurohormones directly into the capillaries of the hypothalamic hypophyseal portal system
D → Incorrect. Axodendritic synapses occur between a presynaptic axon and a postsynaptic dendrite
E → Incorrect. Electrical synapses transmit an action potential between two neurons via gap junctions

35. Which of the following is the second product of the glycolytic pathway?

A. Glyceraldehyde 3-phosphate
B. Fructose 6-phosphate
C. Fructose 1,6-bisphosphate
D. Glucose 6-phosphate
E. Dihydroxyacetone phosphate

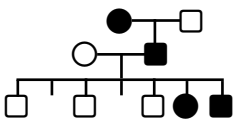
In glycolysis, glucose is first phosphorylated into glucose 6-phosphate (G6P) by the hexokinase enzyme. Then, G6P is restructured into an isomer, fructose 6-phosphate

36. If a piece of paper is soaked in auxin and embedded into the right side of a plant shoot, which of the following will occur?

A. Coleoptile bends towards the left
B. Coleoptile grows faster than normal
C. Coleoptile bends towards the right
D. Coleoptile undergoes abscission
E. Coleoptile grows slower than normal

A → Correct. Auxin promotes cell elongation and is responsible for phototropism. Normally, auxin is produced by the coleoptile (shoot tip) and transported to only regions of the shoot exposed to darkness. This causes the shoot to bend towards the light source and away from the side with auxin
B → Incorrect. Since the auxin is only applied to the right side of the shoot, cells on the right would elongate faster than those on the left, resulting in bending
C → Incorrect. See the explanation for answer choice B)
D → Incorrect. Abscission is the shedding of leaves, stimulated by abscisic acid
E → Incorrect. See the explanation for answer choice B)

37. A genetic disease is identified to have the following pedigree. What is the most likely inheritance pattern?



A. Autosomal recessive
B. Autosomal dominant
C. X-linked recessive
D. X-linked dominant
E. Y-linked

A → Incorrect. For an autosomal recessive inheritance pattern, all offspring must be unaffected if only one parent is affected. This rule is violated by both matings
B → Incorrect. Although this inheritance pattern is possible, it is not the *most* likely. See answer choice D)

C → Incorrect. For an X-linked recessive inheritance pattern, males should be disproportionately affected
D → Correct. For an X-linked dominant inheritance pattern, the mother and all daughters of an affected male must also be affected. Since all three daughters of the second mating are affected, we reasonably conclude that this is the most likely inheritance pattern
E → Incorrect. For a Y-linked inheritance pattern, females cannot be affected. This rule is violated throughout

38. Cardiac output equals which of the following?
    A. Blood Pressure × Heart Rate
    B. Stroke Volume ÷ Heart Rate
    C. Stroke Volume × Blood Pressure
    D. Stroke Volume × Heart Rate
    E. Heart Rate ÷ Stroke Volume

Cardiac output is the total volume of blood pumped by the left ventricle per minute. It is dependent on heart rate (beats per minute) and stroke volume (amount of blood pumped per contraction): Cardiac Output = Stroke Volume × Heart Rate

39. Fur colour is an incomplete dominant trait that has a X-linked inheritance pattern. Homozygous dominant individuals are brown, while homozygous recessive individuals are white. Heterozygotes are beige. If a beige female mates with a brown male, what is the probability that their female offspring would be brown?
    A. 0%
    B. 25%
    C. 50%
    D. 75%
    E. 100%

Let X^B represent the dominant allele and X^b represent the recessive allele.

Since the beige female is a heterozygote, her genotype is X^BX^b. Since the brown male only has one X chromosome, his genotype must be X^BY.

Next, draw a Punnet square:

	X^B	Y
X^B	X^BX^B	X^BY
X^b	X^BX^b	X^bY

Out of the two possible female progeny genotypes, only one will result in brown fur (X^BX^B). Therefore the probability that the couple's female offspring will be brown is ½ or 50%.

40. Which of the following statements regarding the endocrine system is correct?
    A. ACTH is released by the posterior pituitary
    B. Thyroxine is produced via the coupling of monoiodotyrosine with diiodotyrosine
    C. Insulin is a monoamine derivative
    D. Mineralocorticoids are produced in the adrenal medulla
    E. PTH increases blood calcium levels

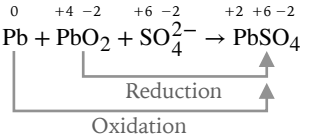
A → Incorrect. Adrenocorticotropic hormone (ACTH) is released by the *anterior* pituitary. The only two major hormones released by the posterior pituitary are antidiuretic hormone (ADH) and oxytocin
B → Incorrect. Thyroxine (T4) is composed of two diiodotyrosine (DIT) components
C → Incorrect. Insulin is a peptide hormone. There are only four monoamine/tyrosine derivative hormones: the thyroid hormones (T3, T4), and the catecholamines (epinephrine, norepinephrine)
D → Incorrect. Mineralocorticoids are produced in the zona glomerulosa of the adrenal cortex
E → Correct. Parathyroid hormone (PTH) increases blood calcium levels by stimulating osteoclast activity and increasing calcium reabsorption in the kidney and intestines. Calcitonin has the opposite effect

41. How many electrons are transferred in the following redox reaction, under acidic conditions?

$$Pb + PbO_2 + SO_4^{2-} \rightarrow PbSO_4$$

    A. 1
    B. 2
    C. 3
    D. 4
    E. 5

First write out the oxidation states and identify each half-reaction:



Write out the half-reactions:

$Pb + SO_4^{2-} \rightarrow PbSO_4$

$PbO_2 + SO_4^{2-} \rightarrow PbSO_4$

Next we balance all non-oxygen and non-hydrogen elements. In this case, Pb and S are already balanced, so we move on to the next step—balance oxygens by adding water:

$Pb + SO_4^{2-} \rightarrow PbSO_4$

$PbO_2 + SO_4^{2-} \rightarrow PbSO_4 + \mathbf{2H_2O}$

Since we are dealing with acidic conditions, balance hydrogens by adding protons:

$Pb + SO_4^{2-} \rightarrow PbSO_4$

$PbO_2 + SO_4^{2-} + \mathbf{4H^+} \rightarrow PbSO_4 + 2H_2O$

Balance charges by adding electrons:

$Pb + SO_4^{2-} \rightarrow PbSO_4 + \mathbf{2e^-}$

$PbO_2 + SO_4^{2-} + 4H^+ + \mathbf{2e^-} \rightarrow PbSO_4 + 2H_2O$

At this point, we can conclude that two electrons are transferred in this redox reaction. If we added up the half-reactions, the fully-balanced equation would be:

$Pb + PbO_2 + 2SO_4^{2-} + 4H^+ \rightarrow 2PbSO_4 + 2H_2O$

42. Which of the following statements are true for a reaction occurring at $-271°C$ with a positive change in enthalpy?

A. The reaction is spontaneous for any ΔS
B. The reaction is spontaneous if $\Delta H < 2\Delta S$
C. The reaction is spontaneous for any ΔH
D. The reaction is non-spontaneous if $\Delta H < \Delta S$
E. The reaction is non-spontaneous if $\Delta H > \Delta S$

Write the equation for change in Gibbs free energy:

$\Delta G = \Delta H - T\Delta S$

After converting degrees Celsius to Kelvin (K = °C − 273), we can substitute temperature into the equation:

$\Delta G = \Delta H - 2\Delta S$

A reaction is spontaneous only when ΔG is negative. When $\Delta H = 2\Delta S$, ΔG is zero. When $\Delta H < 2\Delta S$, ΔG is negative. When $\Delta H > 2\Delta S$, ΔG is positive. Therefore, ΔH must be less than $2\Delta S$ for the reaction to be spontaneous

43. If 1 L of 3 M NaOH is added to 2 L of an aqueous solution containing 3 mol of $Cu(OH)_2$, what is the Q_{sp} of $Cu(OH)_2$? Will a precipitate form? The solubility product of $Cu(OH)_2$ in water is 5.

A. 9; precipitate
B. 9; no precipitate
C. 8; precipitate
D. 4; precipitate
E. 4; no precipitate

First, find the molar concentrations of all ions in the final solution. A dilution calculation is needed because the solution's total volume is increased after NaOH is added:

$$[Na^+] = \frac{(C_1)(V_1)}{V_2} = \frac{(3\text{ M})(1\text{ L})}{3\text{ L}} = 1\text{ M}$$

$$[Cu^+] = \frac{(C_1)(V_1)}{V_2} = \frac{\left(\frac{3}{2}\text{ M}\right)(2\text{ L})}{3\text{ L}} = 1\text{ M}$$

$$[OH^-] = \frac{(C_1)(V_1)}{V_2} = \frac{(3\text{ M})(1\text{ L}) + \left(\frac{3}{2}\text{ M}\right)(2\text{ L})}{3\text{ L}} = 2\text{ M}$$

Since OH^- is a common ion, its final concentration must be obtained by adding up the number of moles and dividing by the solution's final volume.

Next, write out the solubility product quotient (Q_{sp}) equation for the dissolution of $Cu(OH)_2$:

$Cu(OH)_2 \rightleftharpoons Cu^+ + 2OH^-$

$Q_{sp} = [Cu^+][OH^-]^2$

$Q_{sp} = (1\text{ M})(2\text{ M})^2$

$Q_{sp} = 4$

Since $Q_{sp} < K_{sp}$, a precipitate will NOT form.

44. Considering the following reaction, how many litres of ammonia gas are generated from the reaction of 22 L of nitrogen gas and 44 L of hydrogen gas under STP conditions?

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$$

A. 15 L
B. 30 L
C. 33 L
D. 60 L
E. 66 L

Since 1 mol of any gas occupies 22.4 L under STP conditions, we can determine the number of moles of each reactant:

$$n(N_2) = 22\text{ L} \times \frac{1\text{ mol}}{22\text{ L}} = 1\text{ mol}$$

$$n(H_2) = 44\text{ L} \times \frac{1\text{ mol}}{22\text{ L}} = 2\text{ mol}$$

To find the limiting reagent, we divide each reactant's molar value by its corresponding stoichiometric coefficient:

$$\text{quotient}_{N_2} = \frac{1\text{ mol}}{1} = 1$$

$$\text{quotient}_{H_2} = \frac{2\text{ mol}}{3} = 0.66$$

H_2 has the lowest resulting quotient, so it is the limiting reagent. N_2 is the excess reagent.

Next, use molar ratios to determine the amount of NH_3 produced when the 2 moles of limiting reagent is consumed:

$$n_{NH_2} = n_{H_2} \times \frac{2}{3} = 2\text{ mol} \times \frac{2}{3} = \frac{4}{3}\text{ mol}$$

Since 1 mol of any gas occupies 22.4 L under STP conditions, therefore we can calculate the volume of NH_3 produced:

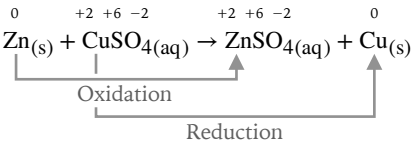
$$V_{NH_3} = \frac{4}{3}\text{ mol} \times 22\text{ L/mol} \approx 30\text{ L}$$

45. Which of the following is the correct cell diagram for the redox equation shown below?

$$Zn_{(s)} + CuSO_{4(aq)} \rightarrow ZnSO_{4(aq)} + Cu_{(s)}$$

A. $Cu_{(s)} \mid Cu^{2+}_{(aq)} \parallel Zn^{2+}_{(aq)} \mid Zn_{(s)}$
B. $Cu^{2+}_{(aq)} \mid Cu_{(s)} \parallel Zn_{(s)} \mid Zn^{2+}_{(aq)}$
C. $Zn_{(s)} \mid ZnSO_{4(aq)} \parallel CuSO_{4(aq)} \mid Cu_{(s)}$
D. $Zn^{2+}_{(aq)} \mid Zn_{(s)} \parallel Cu_{(s)} \mid Cu^{2+}_{(aq)}$
E. $\boldsymbol{Zn_{(s)} \mid Zn^{2+}_{(aq)} \parallel Cu^{2+}_{(aq)} \mid Cu_{(s)}}$

First write out the oxidation states of each element and identify the half-reactions:



The anode and cathode are always written on the leftmost and rightmost sides, respectively. In this case, the anode is $Zn_{(s)}$ while the cathode is $Cu_{(s)}$:

$Zn_{(s)} \mid \quad \parallel \quad \mid Cu_{(s)}$

In the middle, we write the electrolyte ions that complete the anode's oxidation and the cathode's reduction half-reactions:

$Zn_{(s)} \mid Zn^{2+}_{(aq)} \parallel Cu^{2+}_{(aq)} \mid Cu_{(s)}$

46. 58 grams of salt are added to 360 mL of water at 25°C. If the k_f and k_b of pure water is 1.86 and 0.512 °C · kg · mol^{-1} respectively, which of the following is expected to occur?

A. Osmotic pressure increases by $\dfrac{(298)(0.082)(2)}{0.36}$ kPa
B. Vapour pressure decreases by $\dfrac{1}{21}$
C. Freezing point deceases by $\dfrac{1.86}{0.36}$ °C
D. ***Vapour pressure decreases by*** $\boldsymbol{\dfrac{20}{21}}$
E. Boiling point increases by $\dfrac{(0.512)(2)}{0.36}$ °C · kg · L^{-1}

First, determine the number of moles of the solute (salt) and solvent (water):

$$n(\text{NaCl}) = \frac{58\text{ g}}{58\text{ g/mol}} = 1\text{ mol}$$

$$n(H_2O) = \frac{(360\text{ mL})(1\text{ g/mL})}{18\text{ g/mol}} = 20\text{ mol}$$

Calculate osmotic pressure:

$$\Pi = TRiM$$

$$\Pi = (273 + 25\text{ K})\left(8.3\text{ L} \cdot \text{kPa} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}\right)(2)\left(\frac{1\text{ mol}}{0.36\text{ L}}\right)$$

$$\Pi = \frac{(298)(8.3)(2)}{0.36}\text{ kPa}$$

Answer choice A) contains the incorrect ideal gas constant, and therefore is incorrect.

Write the equation for vapour pressure depression (Raoult's law) and rearrange for the ratio between the vapour pressure of the solution and that of the solvent:

$$P_{solution} = P_{solvent} \times X_{solvent}$$

$$\frac{P_{solution}}{P_{solvent}} = X_{solvent}$$

Substitute known values and solve:

$$\frac{P_{solution}}{P_{solvent}} = \frac{20\text{ mol}}{20\text{ mol} + 1\text{ mol}} = \frac{20}{21}$$

Answer choice B) contains the incorrect ratio, and is therefore incorrect. Answer choice D) appears correct.

Calculate freezing point depression:

$$\Delta T_f = -k_f i m$$

$$\Delta T_f = -(1.86\text{ °C} \cdot \text{kg} \cdot \text{mol}^{-1})(2)\left(\frac{1\text{ mol}}{0.36\text{ kg}}\right)$$

$$\Delta T_f = \frac{-(1.86)(2)}{0.36}\text{ °C}$$

Answer choice C) contains the wrong van't Hoff factor, and is therefore incorrect.

Calculate boiling point elevation:

$$\Delta T_b = k_b i m$$

$$\Delta T_b = (0.512\text{ °C} \cdot \text{kg} \cdot \text{mol}^{-1})(2)\left(\frac{1\text{ mol}}{0.36\text{ kg}}\right)$$

$$\Delta T_b = \frac{(0.512)(2)}{0.36}\text{ °C}$$

Answer choice E) contains the wrong units and is therefore incorrect.

47. The following list contains the equation and standard enthalpy change of several reactions. Using this information, what is the standard enthalpy change for reaction ④?

① $SrO + CO_2 \rightarrow SrCO_3$ $\quad \Delta H^\circ = -230$ kJ
② $2SrO \rightarrow 2Sr + O_2$ $\quad \Delta H^\circ = 1000$ kJ
③ $2SrCO_3 \rightarrow 2Sr + 2C + 3O_2$ $\quad \Delta H^\circ = 2500$ kJ
④ $C + O_2 \rightarrow CO_2$ $\quad \Delta H^\circ = ?$

A. − 980 kJ
B. + 520 kJ
C. + 980 kJ
D. −520 kJ
E. −1770 kJ

This is a Hess' Law problem.

First, we look at the reactants of equation ①. Notice how the CO_2 term is on the opposite side from where we want it. Thus, we add the reverse of equation ① to our summation:

$$-\mathbf{1} \times ① \; SrCO_3 \rightarrow SrO + CO_2 \qquad \Delta H^\circ = -\mathbf{1}(-230 \text{ kJ})$$

Next we need to cancel out the SrO term. Thus, we add ½×(equation ②) to our summation:

$$-1 \times ① \; SrCO_3 \rightarrow SrO + CO_2 \qquad \Delta H^\circ = -1(-230 \text{ kJ})$$
$$\mathbf{\frac{1}{2}} \times ② \; SrO \rightarrow Sr + \mathbf{\frac{1}{2}}O_2 \qquad \Delta H^\circ = \mathbf{\frac{1}{2}}(1000 \text{ kJ})$$

Next we need to cancel out the $SrCO_3$ term. Thus, we add the reverse of ½×(equation ③) to our summation:

$$-1 \times ① \; SrCO_3 \rightarrow SrO + CO_2 \qquad \Delta H^\circ = -1(-230 \text{ kJ})$$
$$\frac{1}{2} \times ② \; SrO \rightarrow Sr + \frac{1}{2}O_2 \qquad \Delta H^\circ = \frac{1}{2}(1000 \text{ kJ})$$
$$-\mathbf{\frac{1}{2}} \times ③ \; Sr + C + \mathbf{\frac{3}{2}}O_2 \rightarrow SrCO_3$$
$$\Delta H^\circ = -\mathbf{\frac{1}{2}}(2500 \text{ kJ})$$

Finally, we can combine all three equations and add up the ΔH° values:

$$① \; \cancel{SrCO_3} \rightarrow \cancel{SrO} + CO_2 \qquad \Delta H^\circ = -1(-230 \text{ kJ})$$
$$② \; \cancel{SrO} \rightarrow \cancel{Sr} + \cancel{\frac{1}{2}}O_2 \qquad \Delta H^\circ = \frac{1}{2}(1000 \text{ kJ})$$
$$③ \; \cancel{Sr} + C + \cancel{\frac{3}{2}}O_2 \rightarrow \cancel{SrCO_3} \qquad \Delta H^\circ = -\frac{1}{2}(2500 \text{ kJ})$$
$$④ \; C + O_2 \rightarrow CO_2 \qquad \Delta H^\circ = -520 \text{ kJ}$$

48. How much energy does it take to bring a 5 g sample of water from −5°C to 120°C? The specific heat capacity of water is 4 J/g°C. The latent heat of fusion and vaporization is 0.5 kJ/g and 2 kJ/g, respectively.

A. 2512.5 kJ
B. 15 kJ
C. 2500 kJ
D. 5 kJ
E. 12.5 kJ

First, use the heat transfer equation to calculate how much energy it takes to bring water from −5°C to 0°C:

$q = mc\Delta T$

$q = (5 \text{ g})(4 \text{ J/g°C})(0°\text{C} - (-5°\text{C}))$

$q = (5)(4)(5) = 100$ J

Next, use the heat transfer equation for a fusion phase change to calculate how much energy it takes to melt 5 g of water:

$q = m\Delta H_f$

$q = (5 \text{ g})(0.5 \text{ kJ/g})$

$q = (5)(0.5) = 2.5$ kJ

Then, use the heat transfer equation to calculate how much energy it takes to bring water from 0°C to 100°C:

$q = mc\Delta T$

$q = (5 \text{ g})(4 \text{ J/g°C})(100°\text{C} - 0°\text{C})$

$q = (5)(4)(100) = 2000$ J

Next, use the heat transfer equation for a vaporization phase change to calculate how much energy it takes to evaporate 5 g of water:

$q = m\Delta H_v$

$q = (5 \text{ g})(2 \text{ kJ/g})$

$q = (5)(2) = 10$ kJ

Then, use the heat transfer equation to calculate how much energy it takes to bring water from 100°C to 120°C:

$q = mc\Delta T$

$q = (5 \text{ g})(4 \text{ J/g°C})(120°\text{C} - 100°\text{C})$

$q = (5)(4)(20) = 400$ J

Finally, add up all of the calculated heat transfers. Remember to convert all values into kilojoules:

$q_{total} = 0.1 \text{ kJ} + 2.5 \text{ kJ} + 2 \text{ kJ} + 10 \text{ kJ} + 0.4 \text{ kJ} = 15 \text{ kJ}$

49. Which of the following compounds is INSOLUBLE in water?
    A. Potassium acetate ($KC_2H_3O_2$)
    B. Sodium nitrate ($NaNO_3$)
    C. Magnesium sulfate ($MgSO_4$)
    D. Ammonium chloride (NH_4Cl)
    E. Calcium sulfate ($CaSO_4$)

A → Incorrect. Group 1 elements and acetates are soluble
B → Incorrect. Group 1 elements and nitrates are soluble
C → Incorrect. Sulphates are soluble, unless combined with Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}, Hg^{2+}, or Ag^{+}
D → Incorrect. Ammonium and group 17 elements are soluble in water
E → Correct. Sulphates are soluble, except when combined with Ca^{2+}, Sr^{2+}, Ba^{2+}, Pb^{2+}, Hg^{2+}, or Ag^{+}

50. A 500 mL sample of nitric acid is titrated with 0.1 M calcium hydroxide. If it takes 100 mL of the titrant to reach the equivalence point, what is the initial concentration of the analyte?
    A. 0.025 M
    B. 0.05 M
    C. 0.1 M
    D. 0.25 M
    E. 0.5 M

This is a strong acid + strong base titration. First, write the balanced reaction equation for the neutralization of nitric acid (the analyte) with calcium hydroxide (the titrant):

$$Ca(OH)_2 + 2HNO_3 \rightarrow Ca(NO_3)_2 + 2H_2O$$

Next we calculate the number of moles of the titrant used:

$$n_{Ca(OH)_2} = \left(C_{Ca(OH)_2}\right)\left(V_{Ca(OH)_2}\right)$$

$$n_{Ca(OH)_2} = (0.500\ \text{L})(0.1\ \text{M}) = 0.05\ \text{mols}$$

Note that the stoichiometric ratio between H+ and OH− is 1:2, since there are two moles of H+ per HNO3 and two moles of OH− per Ca(OH)2. This means that the number of moles of analyte neutralized is equal to half the number of moles of titrant consumed:

$$n_{HNO_3} = \left(\frac{1}{2}\right)\left(n_{Ca(OH)_2}\right)$$

$$n_{HNO_3} = \left(\frac{1}{2}\right)\left(0.05\ \text{mols}\right) = 0.025\ \text{mols}$$

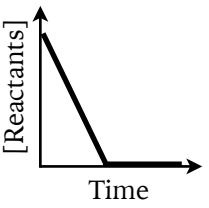
Now we can calculate the initial molarity of the analyte:

$$M = \frac{n_{HNO_3}}{V_{HNO_3}}$$

$$M = \frac{0.025\ \text{mols}}{0.500\ \text{L}}$$

$$M = 0.05\ \text{mol/L}$$

51. Which of the following statements is correct regarding the figure shown below?



    A. This illustrates a first-order reaction
    B. The rate law for this reaction is $r = k[A]^2$
    C. The units of the rate constant (k) for this reaction is 1/s
    D. The rate vs initial reactant concentration graph would be a horizontal line
    E. Rate is proportional to the concentration of the reactant

A → Incorrect. A first-order reaction would be illustrated with a downward-sloping exponential curve
B → Incorrect. This answer choice describes a second-order reaction. A zero-order reaction would have a rate law of $r = k$
C → Incorrect. This answer choice describes a first-order reaction. A zero-order reaction would have the units M/s
D → Correct. This is a zero-order reaction because rate (the slope of the presented graph) is constant and independent of initial reactant concentration
E → Incorrect. This answer choice describes a first-order reaction, an example of which would be radioactive decay, where the proportionality constant is half-life

52. The molecular formula for bromate is BrO_3^-. What is the molar ratio of Br to O in a molecule of hypobromite?
    A. 1:1
    B. 1:2
    C. 1:3
    D. 3:1
    E. 2:1

The molecular formula for many polyatomic ions are derived from the *"-ate"* form:

- The suffix *"-ite"* means one less oxygen than the *"-ate"* form
- The prefix *"hypo-"* means one less oxygen then *"-ite"*

Since brom*ate* has three oxygens, therefore brom*ite* must have two oxygens and *hypo*brom*ite* must have one.

53. If an orbital's principle quantum number is 3, then which of the following can NOT be its magnetic quantum number?

A. 1
B. 0
C. −2
D. 3
E. 2

The principle quantum number (n) dictates all possible values for the angular quantum number (l) and magnetic quantum number (m_l). The possible values for l range from 0 to $(n - 1)$, inclusive. Therefore if $n = 3$, then $0 \leq l \leq 2$. The possible values for m_l range from $-l$ to $+l$. Therefore if the largest possible value for l is 2, then $-2 \leq m_l \leq 2$. The only answer choice that falls outside of this range is D)

54. 5 grams of $C_6H_{10}O_5$, $C_6H_{12}O_6$, C_6H_6, $C_3H_8O_3$, and H_2O are each dissolved separately in 10 L of C_4H_{10}. Which solute would produce the solution with the lowest vapour pressure?

A. $C_6H_{10}O_5$
B. $C_6H_{12}O_6$
C. C_6H_6
D. $C_3H_8O_3$
E. H_2O

The vapour pressure of a solvent decreases after the addition of a non-volatile solute, according to the formula:

$$P_{solution} = P_{solvent} \times X_{solvent}$$

We can rewrite this equation to show how the magnitude of vapour pressure depression is dependent on the mole fraction of the solute:

$$\frac{P_{solution}}{P_{solvent}} = \frac{n_{solvent}}{n_{solute} + n_{solvent}}$$

Therefore, the lowest vapour pressure will result from the addition of the most moles of solute. Since 5 grams of each solute are dissolved, the solute with the lowest molar mass will result in the most number of moles. Answer choice E) has the lowest molar mass, and is therefore correct:

$C_6H_{10}O_5$: 6(12) + 10(1) + 5(16) = 162 g/mol

$C_6H_{12}O_6$: 6(12) + 12(1) + 6(16) = 180 g/mol

C_6H_6: 6(12) + 6(1) = 78 g/mol

$C_3H_8O_3$: 3(12) + 8(1) + 3(16) = 92 g/mol

H_2O: 2(1) + 1(16) = 18 g/mol

55. Which of the following is a valid measure of rate for the reaction shown below?

$$4FeS + 7O_2 \rightarrow 2Fe_2O_3 + 4SO_2$$

A. $\dfrac{\Delta[O_2]}{7\Delta t}$
B. $\boldsymbol{\dfrac{-\Delta[FeS]}{4\Delta t}}$
C. $\dfrac{-\Delta[Fe_2O_3]}{2\Delta t}$
D. $\dfrac{-\Delta[FeS]}{\Delta t}$
E. $\dfrac{\Delta[SO_2]}{\Delta t}$

A reaction's rate describes how fast the reaction occurs, and can be expressed in terms of the change in concentration of reactants/products divided by time. However, if the reactant/product has a coefficient, the rate expression must be divided by that coefficient. Furthermore, the rate must always be positive. This means that if a reactant concentration is used, a negative sign must be added

56. After centrifuging a solution, you notice the formation of a solid pellet at the bottom of the test tube. What is the liquid that rests on top?

A. Titrant
B. Organic phase
C. Supercritical fluid
D. Analyte
E. Supernatant

A → Incorrect. The titrant is an acid/base of known molarity used to titrate an unknown analyte
B → Incorrect. The organic phase is a non-polar layer in liquid-liquid extraction
C → Incorrect. A supercritical fluid is any substance that is at a temperature and pressure above its critical point. Supercritical fluids have properties of both liquids and gasses
D → Incorrect. The analyte is the unknown acid or base titrated against the titrant (an acid/base of known molarity)
E → Correct. The supernatant is the liquid found on top of a solid pellet after centrifugation

57. What form of radioactive decay does NOT involve the creation of a new neutron, proton, or photon?

A. Electron capture
B. Beta positive decay
C. Alpha decay
D. Beta negative decay
E. Gamma decay

A → Incorrect. In electron capture, a proton and electron combine to form a neutron
B → Incorrect. In beta positive decay, a proton decays into a neutron, releasing a positron and neutrino
C → Correct. In alpha decay, a $^{4}_{2}\mathrm{He}^{2+}$ particle containing two protons and two neutrons is simply released from the nucleus. It does not involve the formation of a new neutron, proton, nor photon
D → Incorrect. In beta negative decay, a neutron decays into a proton, releasing an electron and antineutrino
E → Incorrect. In gamma decay, the unstable nucleus dissipates excess energy by creating and releasing a γ particle (a high energy photon)

58. A 1 L tank containing 100 kPa of oxygen is connected via stopcock to a 4L tank containing 50 kPa of nitrogen. If the stopcock is opened while temperature is held constant, what is the final pressure?

A. 10 kPa
B. 20 kPa
C. 40 kPa
D. 60 kPa
E. 90 kPa

First, calculate the pressure change for oxygen:

$$P_1V_1 = P_2V_2$$

$$P_2 = \frac{P_1V_1}{V_2}$$

$$P_2 = \frac{(100\text{ kPa})(1\text{ L})}{5\text{ L}} = 20\text{ kPa}$$

Then, calculate the pressure change for nitrogen:

$$P_1V_1 = P_2V_2$$

$$P_2 = \frac{P_1V_1}{V_2}$$

$$P_2 = \frac{(50\text{ kPa})(4\text{ L})}{5\text{ L}} = 40\text{ kPa}$$

Finally, calculate the total pressure by adding up both partial pressures according to Dalton's law:

$$P_T = 20\text{ kPa} + 40\text{ kPa} = 60\text{ kPa}$$

59. Which of the following hybridization states describes the bonding orbitals in PF_5?

A. sp
B. sp^2
C. sp^3
D. sp^3d
E. sp^3d^2

Orbital hybridization occurs when two or more different atomic orbitals combine to form an equal number of identical hybrid orbitals. For instance, one s and two p orbitals can combine to form three sp^2 orbitals. A general rule-of-thumb for hybridization is that the number of hybrid orbitals will always be equal to the initial number of orbitals. Therefore, atoms with two regions of electron density are sp hybridized, atoms with three are sp^2, atoms with four are sp^3, and so on.

By drawing the lewis structure of PF_5, it is clear that the central atom has five regions of electron density:



Therefore, one s, three p, and one d orbitals combine to produce five sp^3d hybridized orbitals

60. The reaction shown below is allowed to reach equilibrium in a 2 L container. If the concentration of NO_2 at equilibrium is 4 M, how many grams of are N_2O_4 present?

$$N_2O_{4(g)} \rightleftharpoons 2NO_{2(g)} \quad K = 0.5$$

A. 16 g
B. 32g
C. 64 g
D. 2944 g
E. 5888 g

First, write out the equilibrium constant equation and rearrange for the concentration of N_2O_4:

$$K = \frac{[NO_2]^2}{[N_2O_4]}$$

$$[N_2O_4] = \frac{[NO_2]^2}{K}$$

Next, substitute known values and solve:

$$[N_2O_4] = \frac{(4\text{ M})^2}{0.5} = \frac{16}{0.5} = 32\text{ M}$$

Multiply molarity by volume to find the number of moles:

$$n_{N_2O_4} = 32\text{ mol/L} \times 2\text{ L} = 64\text{ mol}$$

Finally, multiply by molar mass to find the number of grams:

$$m_{N_2O_4} = 64\text{ mol} \times 92\text{ g/mol} = 5888\text{ g}$$

61. Which of the following is the correct electron configuration for chromium?

A. $1s^2, 2s^1, 2p^6, 3s^2, 3p^5, 4s^2, 3d^4$
B. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^4$
C. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 4d^4$
D. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, 3d^5$
E. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, 4d^5$

We start in the first row of the s-block and fill the first subshell ($1s^2$). Then we move to the next row and fill the next subshell ($2s^2$). Continue adding electrons to subshells until we reach $3d^4$. Normally, the electron configuration would be complete at this stage. However, chromium and copper are two important exceptions. In chromium, one 4s electron is promoted to the 3d subshell such that both the 4s and 3d subshells are exactly half-filled. This results in a more stable configuration: $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, 3d^5$

62. Given the standard cell potentials of the two half-reactions shown below, what is the change in Gibbs free energy?

$$Cu^{2+} + 2e^- \rightarrow Cu \quad E_r^\circ = 0.34 \text{ V}$$
$$Fe^{2+} + 2e^- \rightarrow Fe \quad E_r^\circ = -0.44 \text{ V}$$

A. $-(2)(9\times10^4)(0.10)$ J
B. $-(2)(9\times10^4)(0.78)$ J
C. $(2)(9\times10^4)(0.10)$ J
D. $(2)(9\times10^4)(0.78)$ J
E. $-(9\times10^4)(0.34)$ J

We can calculate ΔG by using the formula $\Delta G = -nFE_{cell}$. But first, we need to determine the cell potential.

E_{cell} is equal to the sum of the reduction (E_r) and oxidation (E_o) potentials of a cell's half-reactions. Reduction half-reactions always have a positive E_r while oxidation half-reactions always have a negative E_r. Since the Fe^{2+} half-reaction has a negative E_r, we can assume that Fe is oxidized. Therefore we can write our sum as follows:

$$\begin{array}{lll} & Cu^{2+} + 2e^- \rightarrow Cu & E_r^\circ = 0.34 \\ + & Fe \rightarrow Fe^{2+} + 2e^- & E_o^\circ = 0.44 \\ \hline & Cu^{2+} + Fe \rightarrow Cu + Fe^{2+} & E_{cell}^\circ = 0.78 \end{array}$$

Notice how we converted the E_r of the Fe^{2+} half-reaction into an E_o simply by changing the minus sign to a positive sign.

Now we can calculate ΔG:

$$\Delta G = -nFE_{cell}$$
$$\Delta G = -(2 \text{ mol})(9\times10^4 \text{ C/mol})(0.78 \text{ J/C})$$
$$\Delta G = -(2)(9\times10^4)(0.78) \text{ J}$$

63. 11.4 moles of $C_6H_{12}O_6$, $CaCl_2$, NaCl, $MgSO_4$, and $FeCl_3$ are each dissolved separately in 6 L of H_2O. Which solute would produce the solution with the lowest freezing point?

A. $C_6H_{12}O_6$
B. $CaCl_2$
C. NaCl
D. $FeCl_3$
E. $MgSO_4$

The freezing point of a liquid decreases after the addition of a solute, according to the formula:

$$\Delta T_f = -k_f i m$$

Since each solute is added to the same solvent, the freezing point depression constant (k_f) is identical for each answer choice. Furthermore, since the same number of moles of each solute is added to the same volume of solvent, the molality (m) term is also identical for each answer choice. The van't Hoff factor (i) is the only term that varies across the answer choices. The i term is equal to the number of particles formed after the dissociation of one solute particle. Since the formula states that i is directly proportional to ΔT_f, a larger i would result in a lower freezing point. Answer choice D) has the largest i, and is therefore correct:

$C_6H_{12}O_6$: $i = 1$
$CaCl_2$: $i = 3$
NaCl: $i = 2$
$FeCl_3$: $i = 4$
$MgSO_4$: $i = 2$

64. The following reaction is first order with respect to $TiCl_4$ and second order with respect to H_2O:

$$TiCl_4 + 2H_2O \rightarrow TiO_2 + 4HCl$$

If rate is equal to 4 M/s at 25°C and 2 M reactant concentrations, then what is the rate constant?

A. 0.5 s^{-1}
B. $0.5 \text{ M}^{-1} \cdot \text{s}^{-1}$
C. $0.5 \text{ M}^{-2} \cdot \text{s}^{-1}$
D. $1 \text{ M} \cdot \text{s}^{-1}$
E. $1 \text{ M}^{-2} \cdot \text{s}^{-1}$

First, write out the rate law and rearrange for k:

$$r = k[TiCl_4][H_2O]^2$$
$$k = \frac{r}{[TiCl_4][H_2O]^2}$$

Then, substitute known values:

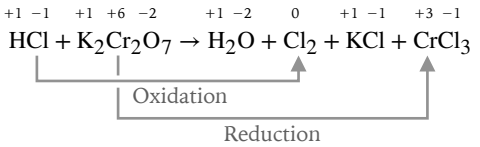
$$k = \frac{4 \text{ M/s}}{(2 \text{ M})(2 \text{ M})^2}$$
$$k = \frac{4}{(2)(4)} = 0.5 \text{ M}^{-2} \cdot \text{s}^{-1}$$

65. Which set of coefficients would balance the following reaction?

$$HCl + K_2Cr_2O_7 \rightarrow KCl + CrCl_3 + H_2O + Cl_2$$

A. 14, 1, 2, 2, 7, 3
B. 10, 1, 2, 2, 7, 1
C. 26, 3, 6, 6, 21, 1
D. 8, 1, 2, 2, 7, 3
E. 2, 1, 2, 2, 7, 3

First write out the oxidation states of each element and identify the half-reactions:



Since HCl is a reactant, we must balance the equation under acidic conditions. Write out the half-reactions:

$HCl \rightarrow Cl_2$

$HCl + K_2Cr_2O_7 \rightarrow KCl + CrCl_3$

Next we balance all non-oxygen and non-hydrogen elements:

$\mathbf{2}HCl \rightarrow Cl_2$

$\mathbf{8}HCl + K_2Cr_2O_7 \rightarrow \mathbf{2}KCl + \mathbf{2}CrCl_3$

Then we balance oxygens by adding water:

$2HCl \rightarrow Cl_2$

$8HCl + K_2Cr_2O_7 \rightarrow 2KCl + 2CrCl_3 + \mathbf{7H_2O}$

Since we are dealing with acidic conditions, balance hydrogens by adding protons:

$2HCl \rightarrow Cl_2 + \mathbf{2}H^+$

$8HCl + K_2Cr_2O_7 + \mathbf{6}H^+ \rightarrow 2KCl + 2CrCl_3 + 7H_2O$

Balance charges by adding electrons:

$2HCl + \mathbf{2}e^- \rightarrow Cl_2 + 2H^+$

$8HCl + K_2Cr_2O_7 + 6H^+ \rightarrow 2KCl + 2CrCl_3 + 7H_2O + \mathbf{6}e^-$

Multiply the oxidation half-reaction by 3 to make the number of electrons equal to the reduction half-reaction:

$\mathbf{6}HCl + \mathbf{6}e^- \rightarrow \mathbf{3}Cl_2 + \mathbf{6}H^+$

$8HCl + K_2Cr_2O_7 + 6H^+ \rightarrow 2KCl + 2CrCl_3 + 7H_2O + 6e^-$

Finally, add up the two half-reactions and eliminate or combine terms:

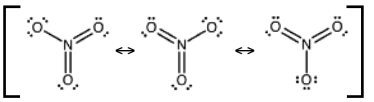
$6HCl + \cancel{6e^-} \rightarrow 3Cl_2 + \cancel{6H^+}$

$8HCl + K_2Cr_2O_7 + \cancel{6H^+} \rightarrow 2KCl + 2CrCl_3 + 7H_2O + \cancel{6e^-}$

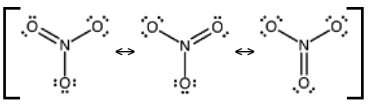
$14HCl + K_2Cr_2O_7 \rightarrow 2KCl + 2CrCl_3 + 7H_2O + 3Cl_2$

66. What is the correct lewis structure for NO_3^-?

A. 

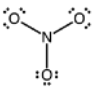
B. 

C. 

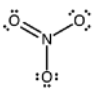
D. 

E. 

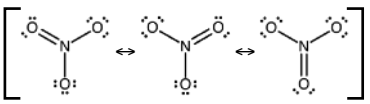
NO_3^- has a total of $5 + 3(6) + 1 = 24$ valence electrons. Nitrogen is the least electronegative element, so it is the central atom:



After we connect the three oxygens to nitrogen via single bonds, we are left with no remaining electrons. The next step is to check formal charges. Nitrogen has a $+1$ formal charge while each oxygen has a -1 formal charge. The sum of formal charges is $+1 -1 -1 -1 = -2$, which does not equal the overall charge of the molecule. This can be resolved by forming a single double bond:



Now the sum of formal charges is $+1 -1 -1 = -1$, which is consistent with the molecule's overall charge. However, this double bond can be formed with any of the three oxygens. Therefore, a resonance structure exists:



67. Which of the following statements regarding reaction coordinate diagrams is correct?
    A. The activation energy of forward and reverse reactions are equal
    B. Catalysts decrease the ΔH of a reaction
    C. Spontaneous reactions have a small E_a
    D. Potential energy peaks at the transition state
    E. In a spontaneous reaction, the lowest potential energy occurs at the intermediates

A → Incorrect. The reverse activation energy is equal to the forward activation energy plus the change in enthalpy
B → Incorrect. Catalysts increase the rate of a reaction by lowering activation energy. It does not alter the change in enthalpy nor the spontaneity of the reaction
C → Incorrect. The size of a reaction's activation energy is inversely correlated to rate, not spontaneity. Activation energy does not influence the thermodynamics of a reaction
D → Correct. The transition state is a transient, unstable form of the reactants prior to their conversion into products. Therefore, transition states are located at potential energy peaks in a reaction coordinate diagram
E → Incorrect. Intermediates are similar to transition states, except they are more stable and exist at local minimums in a reaction coordinate diagram. Despite this, the potential energy of products in a spontaneous reaction is always lower than both the transition state and the intermediates

68. What is the standard enthalpy of formation of N_2O, given the following reaction?

$$2N_2O_{(g)} \rightarrow 2N_{2(g)} + O_{2(g)} \quad \Delta H^\circ = -164 \text{ kJ}$$

    A. 164 kJ/mol
    B. 82 kJ/mol
    C. 55 kJ/mol
    D. −82 kJ/mol
    E. Cannot be determined

The standard enthalpy of formation (ΔH°_f) is defined as the enthalpy change that occurs when one mole of a substance is formed directly from its elements in their standard state. Therefore, the formation reaction of N_2O is:

$$N_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow N_2O_{(g)}$$

To transform the given reaction into the formation reaction, we must reverse it and multiply all coefficients by ½:

Original: $2N_2O_{(g)} \rightarrow 2N_{2(g)} + O_{2(g)} \quad \Delta H^\circ = -164 \text{ kJ}$

Reversed: $2N_{2(g)} + O_{2(g)} \rightarrow 2N_2O_{(g)} \quad \Delta H^\circ = +164 \text{ kJ}$

Times ½: $N_{2(g)} + \frac{1}{2}O_{2(g)} \rightarrow N_2O_{(g)} \quad \Delta H^\circ = +82 \text{ kJ}$

After making the appropriate adjustments, $\Delta H^\circ_f = 82$ kJ/mol

69. In which of the following reactions is $\Delta S < 0$?
    A. $CH_{4(g)} + 2H_2S_{(g)} \rightarrow CS_{2(g)} + 4H_{2(g)}$
    B. $K_2Cr_2O_{7(s)} \rightarrow 2K^+_{(aq)} + Cr_2O^{2-}_{7(aq)}$
    C. $\boldsymbol{CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(l)}}$
    D. $C_3H_8O_{(l)} \rightarrow C_3H_8O_{(g)}$
    E. $N_2H_4O_{3(s)} + \text{heat} \rightarrow N_2H_4O_{3(aq)}$

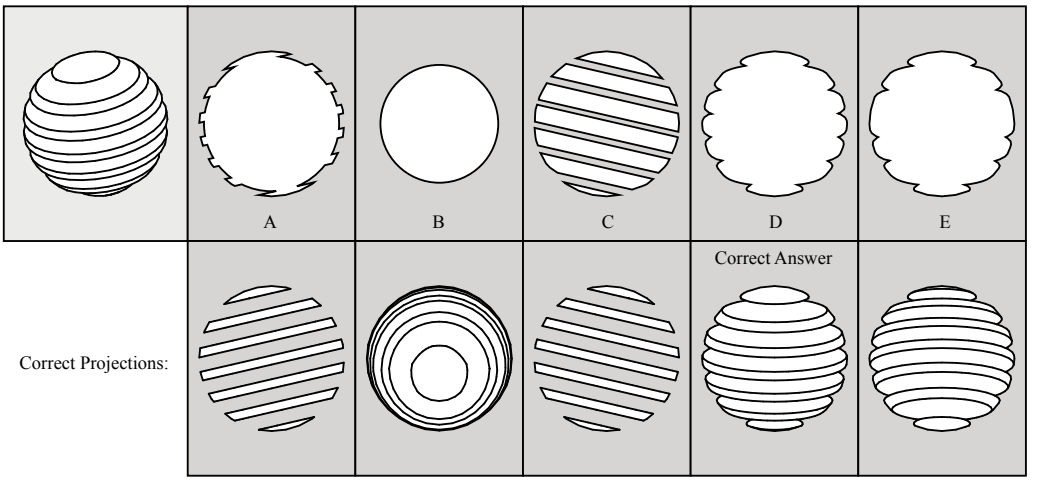
A → Incorrect. There are 3 moles of gas on the left and 5 moles on the right. Therefore disorder is increasing
B → Incorrect. This reaction describes the dissolution of solid $K_2Cr_2O_7$ into its aqueous form, thus increasing disorder
C → Correct. There are 3 moles of gas on the left and 1 mole on the right. Therefore disorder is decreasing and the change in entropy is negative
D → Incorrect. This equation describes the evaporation of liquid propanol into its gaseous form, increasing disorder
E → Incorrect. Although this reaction absorbs heat from its surroundings (endothermic, $\Delta H > 0$), the reaction itself actually has a positive change in entropy, since solid $N_2H_4O_3$ dissolves into its aqueous form and increases disorder

70. Decompression sickness is caused by dissolved gasses (primarily N_2) coming out of the blood upon rapid depressurization of the body. This phenomenon can be explained with:
    A. Boyle's law
    B. Charle's law
    C. Gay-Lussac's law
    D. Henry's law
    E. Avogadro's law

A → Incorrect. Boyle's law states that pressure and volume are inversely proportional under isothermal conditions. This does not explain the cause of decompression sickness because there is no mention of a change in volume
B → Incorrect. Charle's law states that volume and temperature are proportional under isobaric conditions. This does not explain the cause of decompression sickness because there is no mention of a change in volume or temperature
C → Incorrect. Gay-Lussac's law states that pressure and temperature are proportional under isochoric conditions. This does not explain the cause of decompression sickness because there is no mention of a change in temperature
D → Correct. Henry's law states that the amount of dissolved gas in a liquid is directly proportional to its partial pressure on the surface of that liquid. If the body is rapidly depressurized, the solubility of N_2 decreases and thus bubbles out of the blood. Henry's law also explains why soda drinks bubble when their pressurized containers are opened
E → Incorrect. Avogadro's law states that the number of moles is proportional to volume under isothermal and isobaric conditions. This does not explain the cause of decompression sickness because there is no mention of a change in volume or the number of moles

Solutions – Perceptual Ability Test

1.



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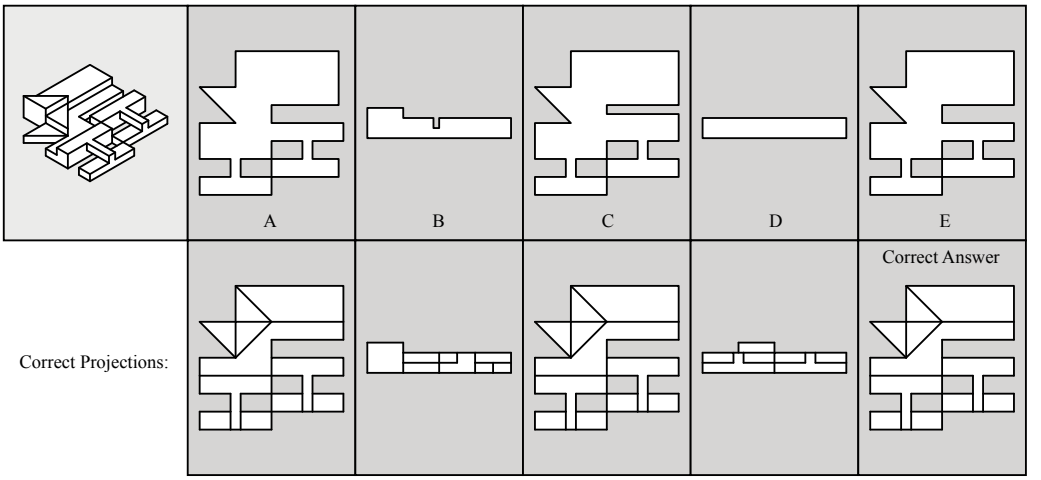

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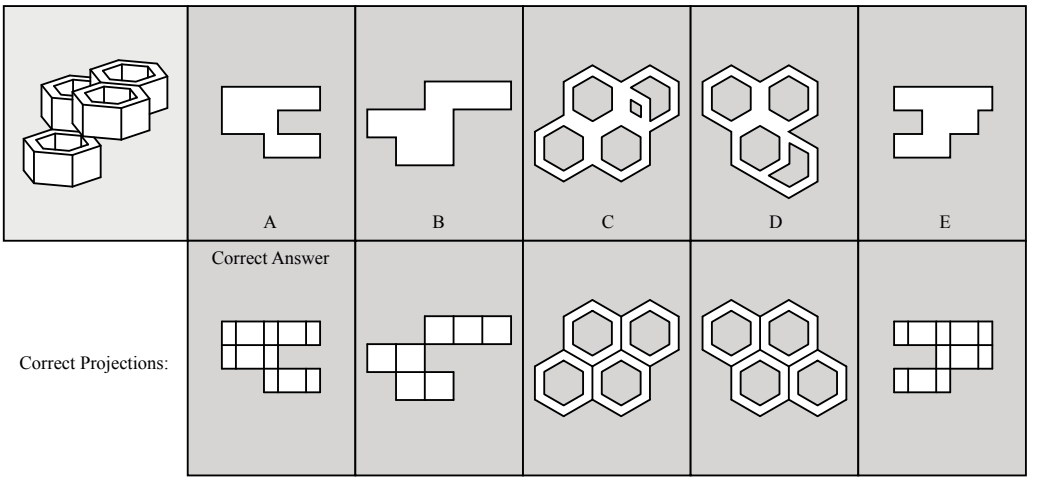

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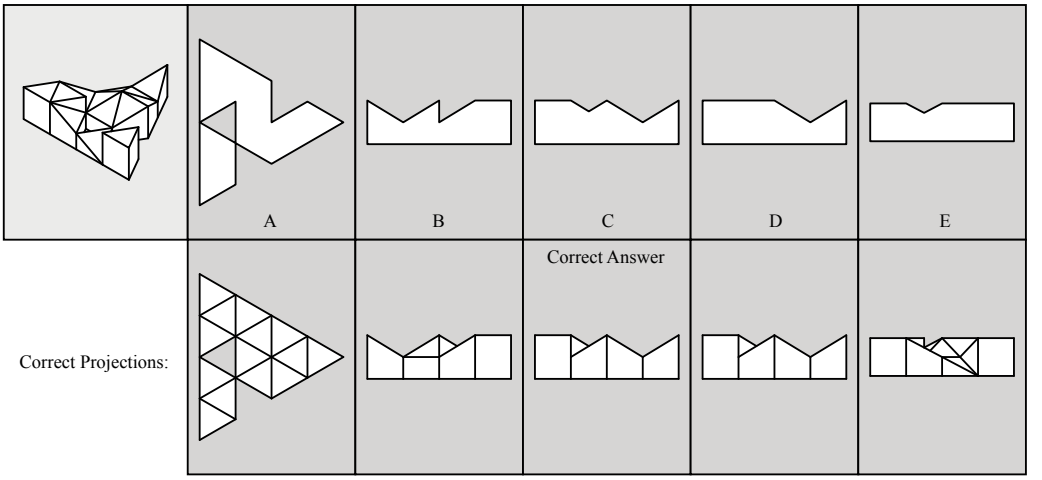
A
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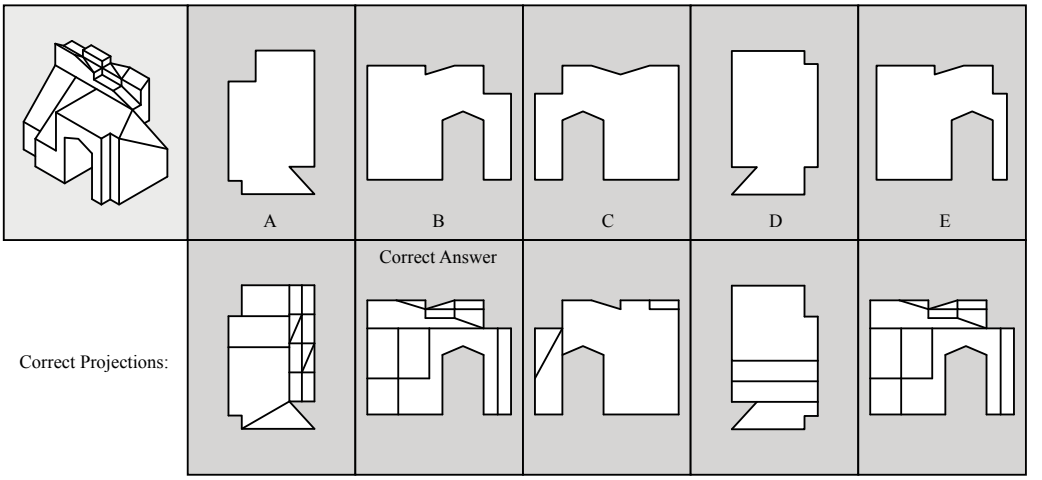
E
Correct Answer
Correct Projections:

5.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Correct Answer
Correct Projections:

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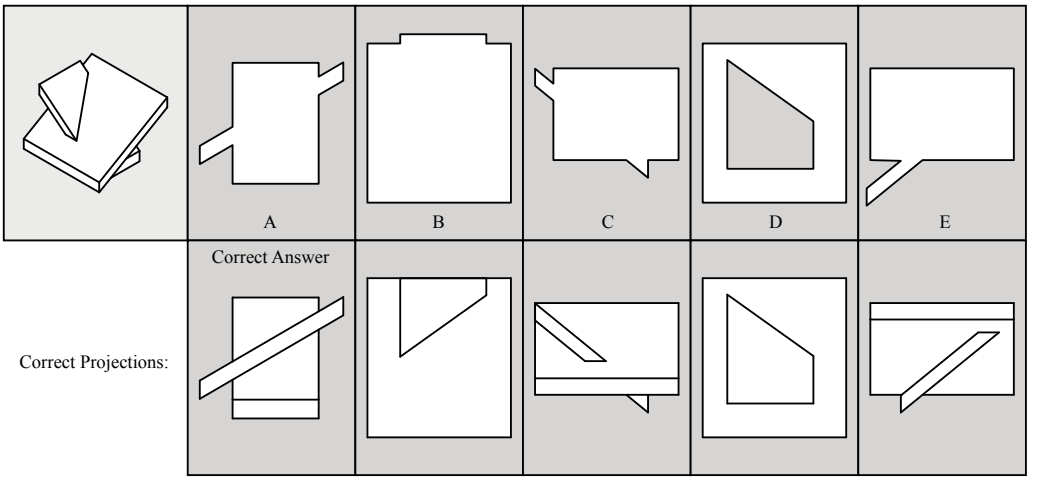
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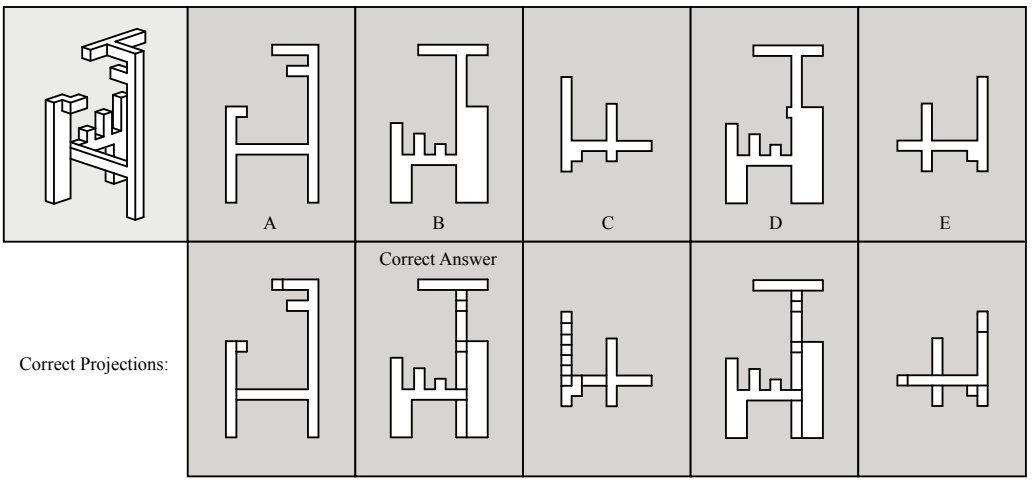
Correct Answer
Correct Projections:

7.


A
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Correct Answer
Correct Projections:

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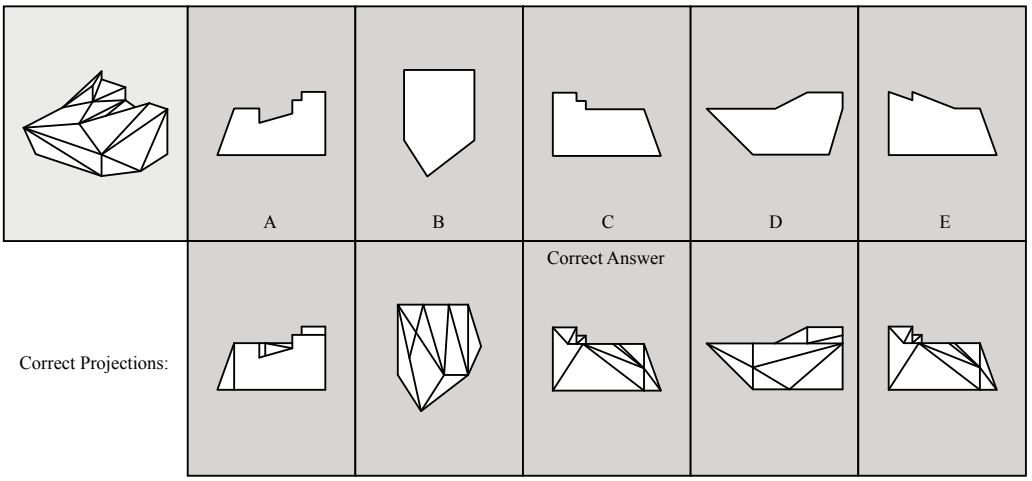
A
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Correct Answer
Correct Projections:

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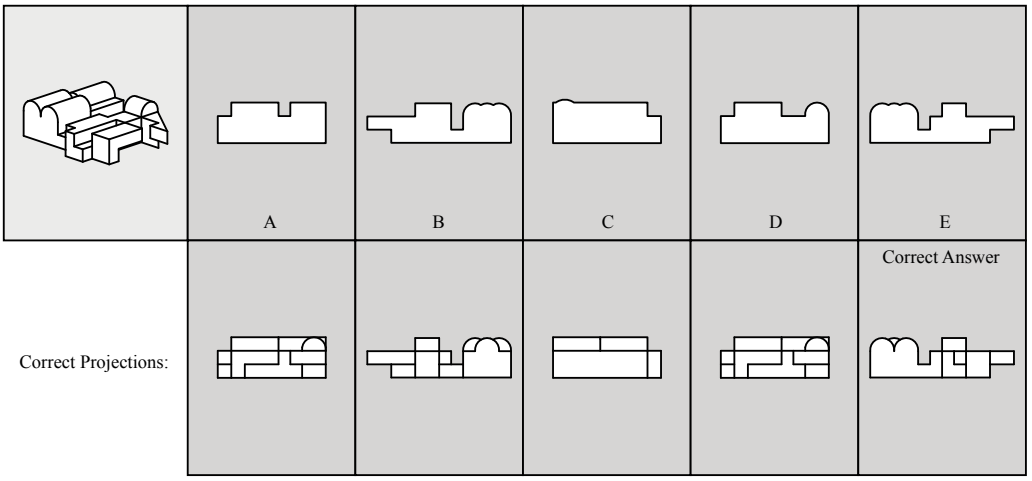
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Correct Answer
Correct Projections:

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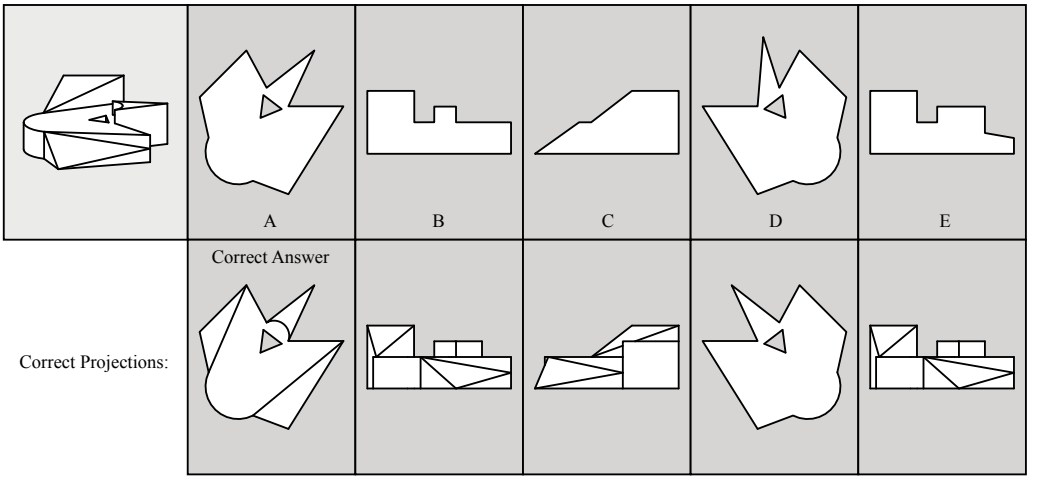
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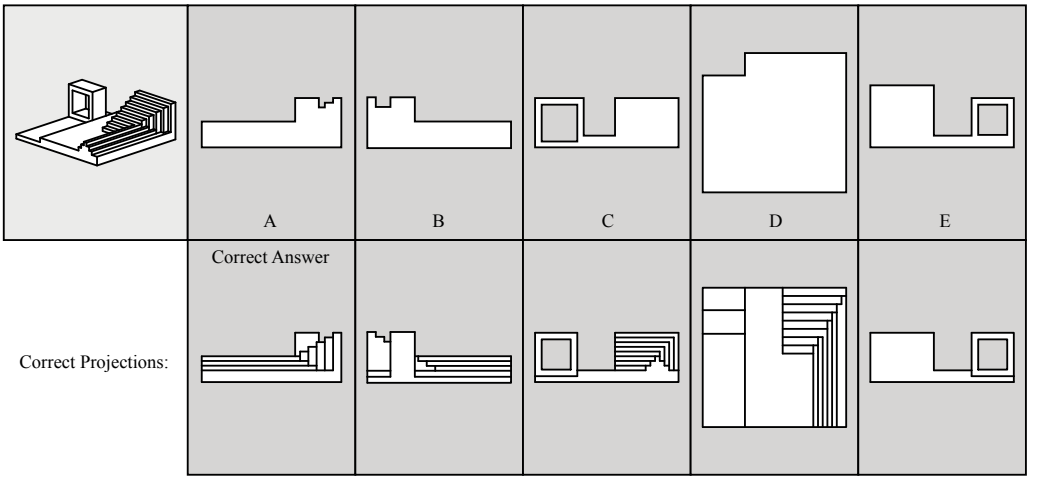
Correct Answer
Correct Projections:

11.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Correct Answer
Correct Projections:

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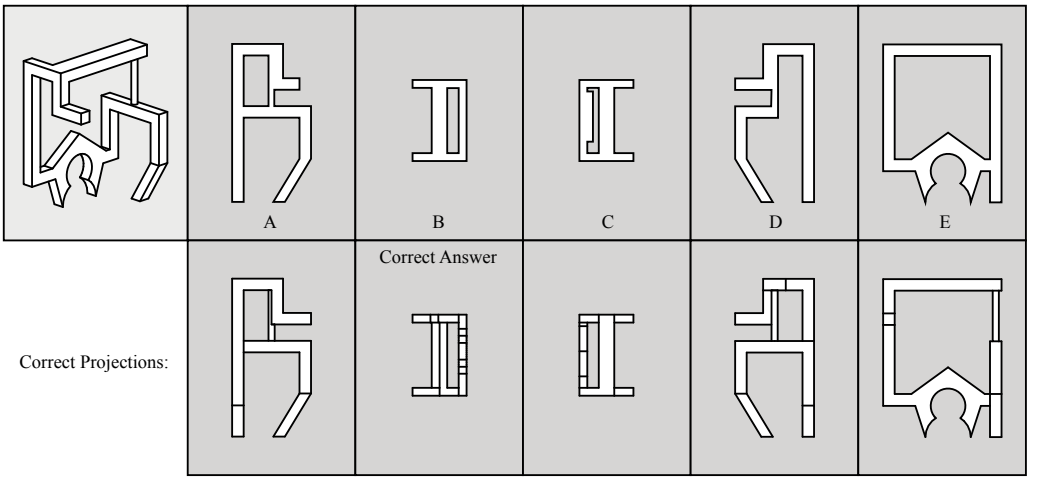
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Correct Answer
Correct Projections:

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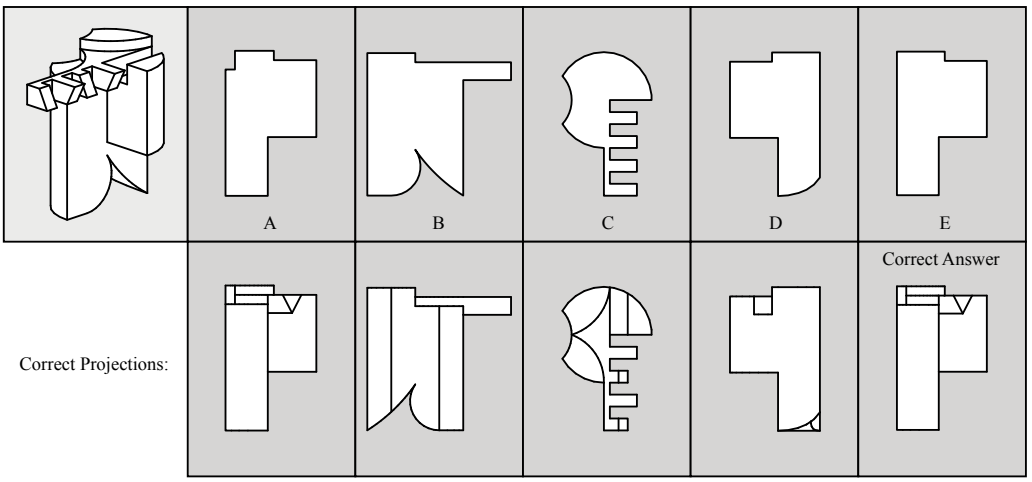
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Correct Answer
Correct Projections:

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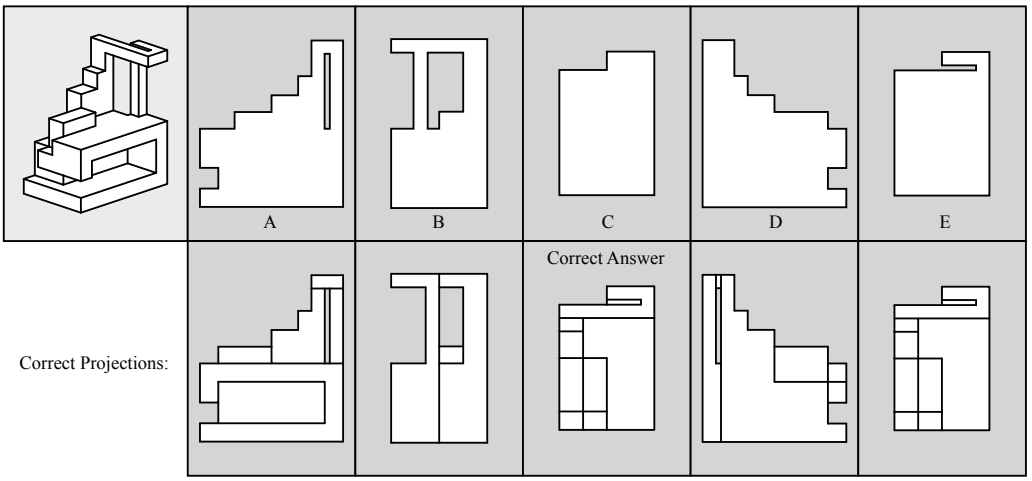
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Correct Answer
Correct Projections:

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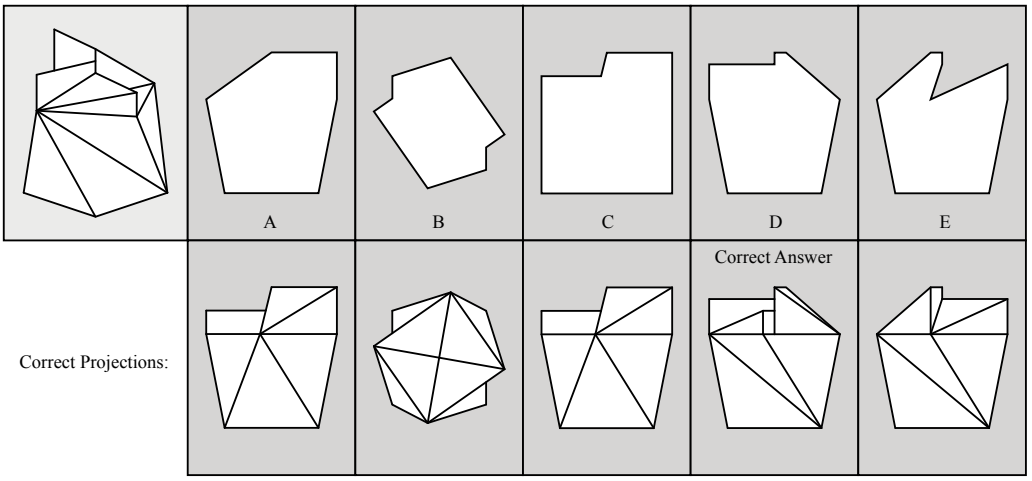
A
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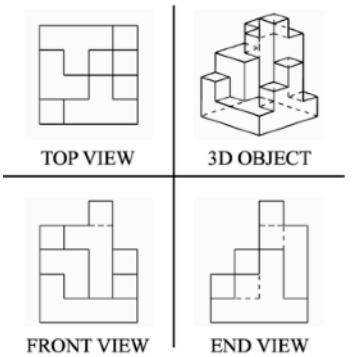
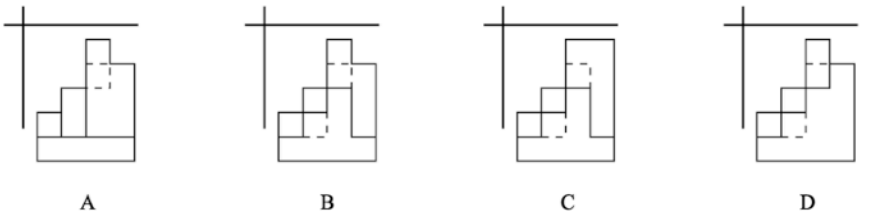
E
Correct Answer
Correct Projections:

16. Choose the correct END VIEW





Correct Answer

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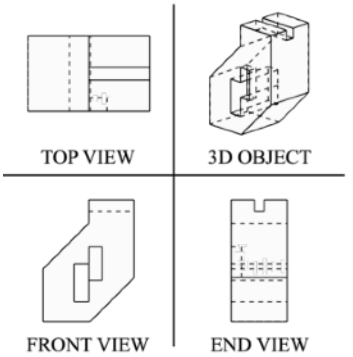
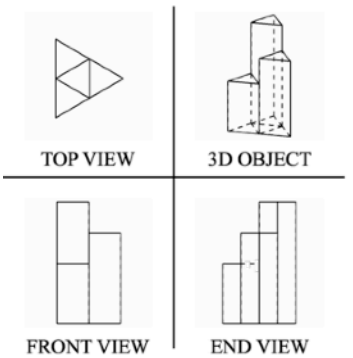
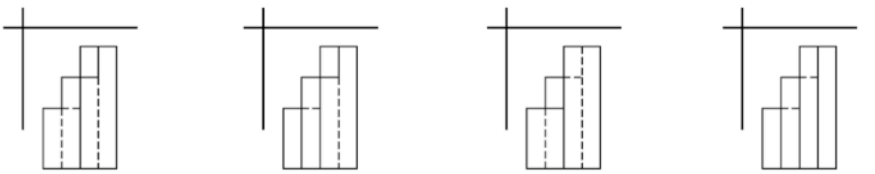




Correct Answer

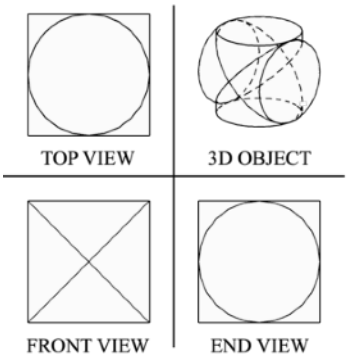
18. Choose the correct END VIEW

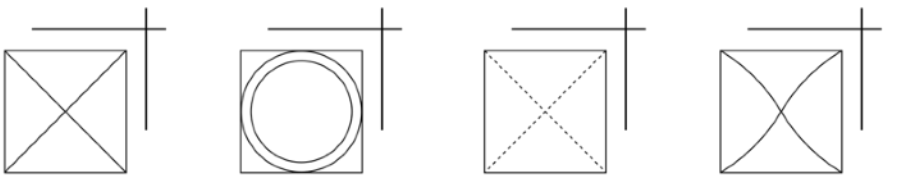




Correct Answer

19. Choose the correct FRONT VIEW





Correct Answer

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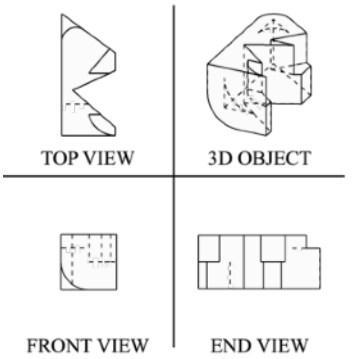

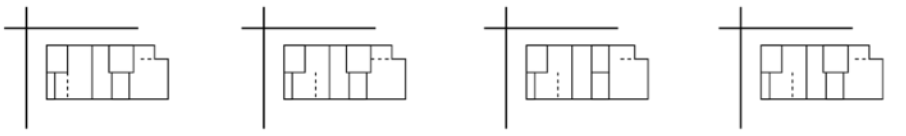

Correct Answer

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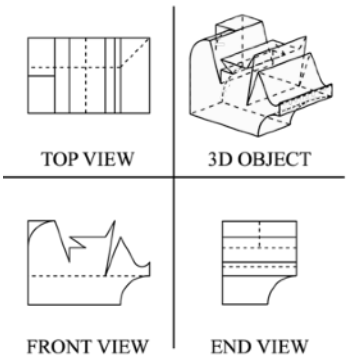

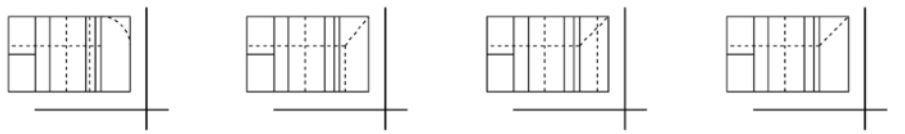

Correct Answer

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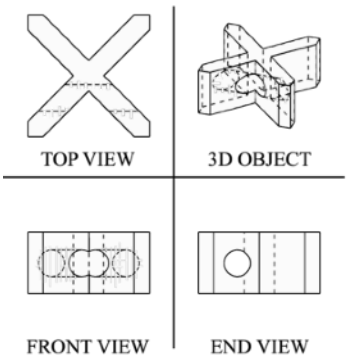

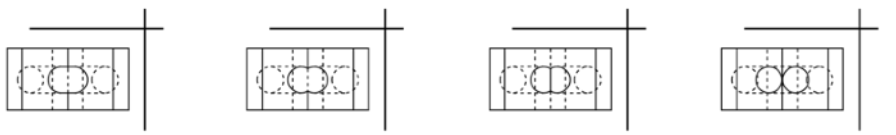

Correct Answer

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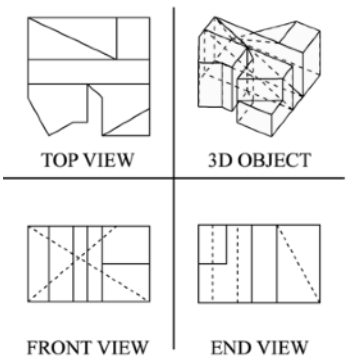

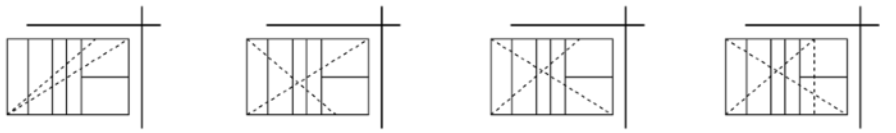

Correct Answer

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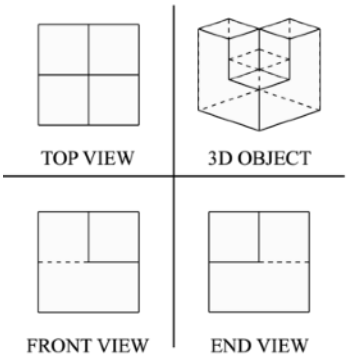
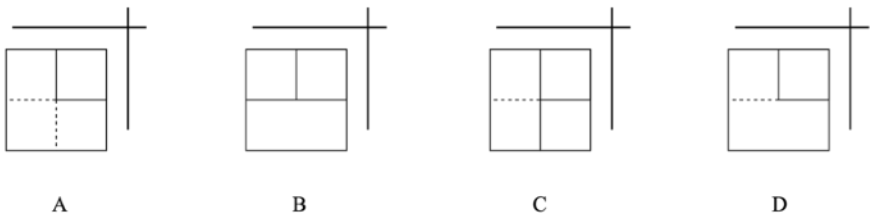
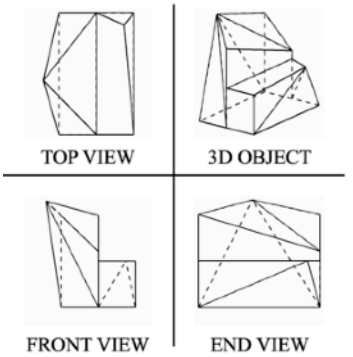
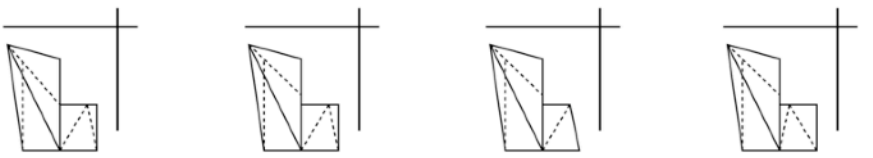




Correct Answer

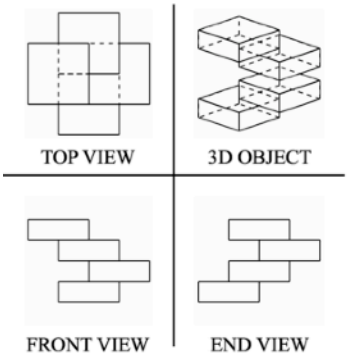
25. Choose the correct FRONT VIEW

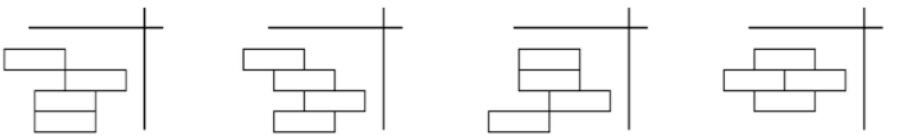




Correct Answer

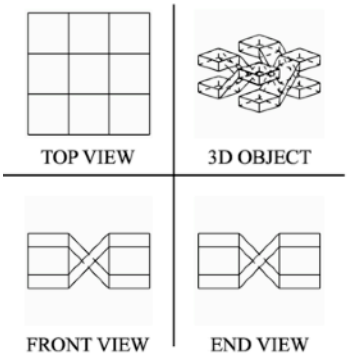
26. Choose the correct FRONT VIEW

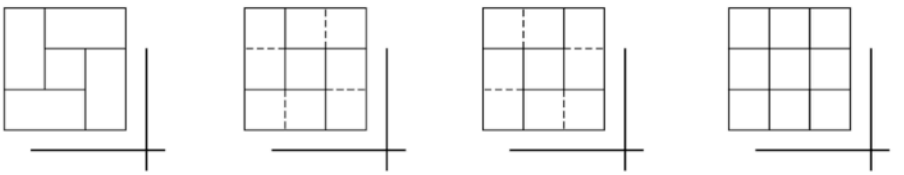




Correct Answer

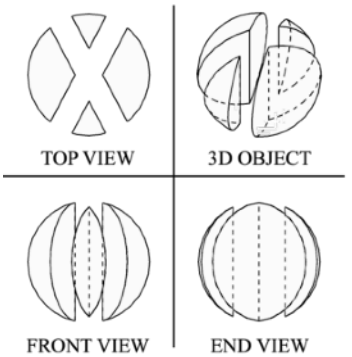
27. Choose the correct TOP VIEW

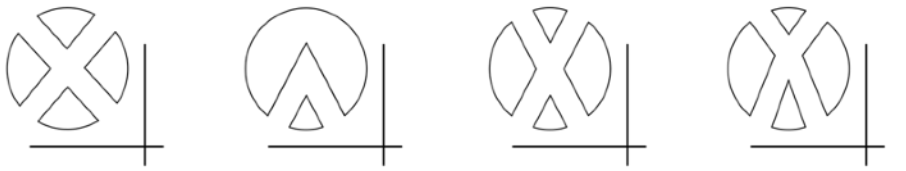




Correct Answer

28. Choose the correct TOP VIEW

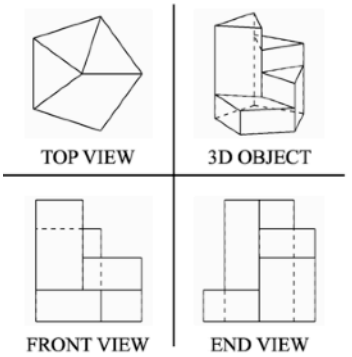


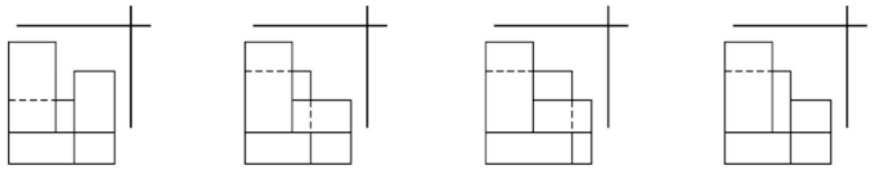


A B C D

Correct Answer

29. Choose the correct FRONT VIEW

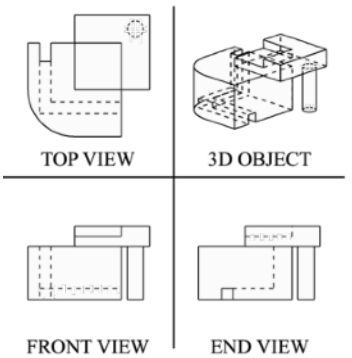


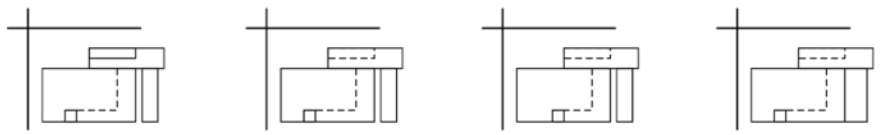


A B C D

Correct Answer

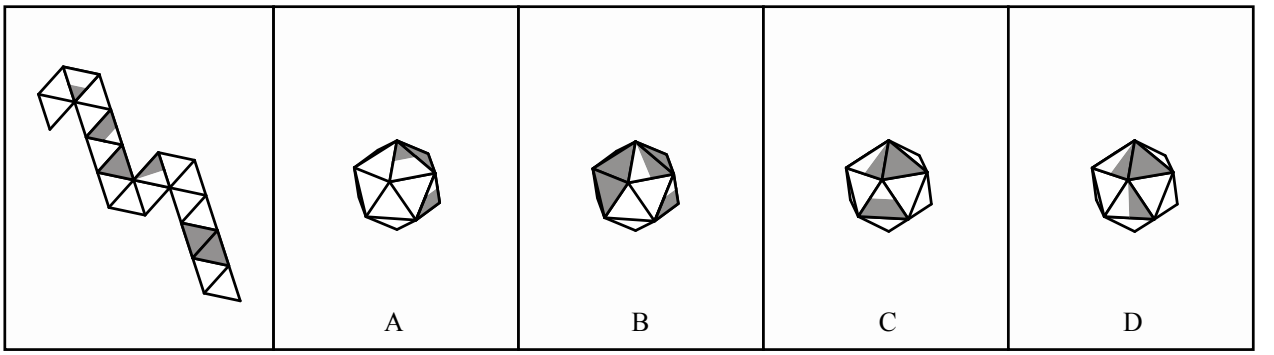
30. Choose the correct END VIEW





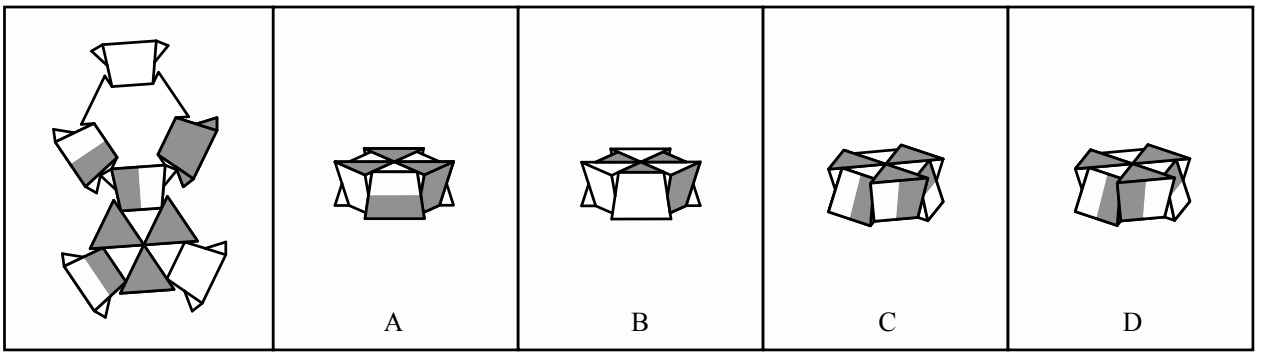
A B C D

Correct Answer



77. Correct Answer

77.



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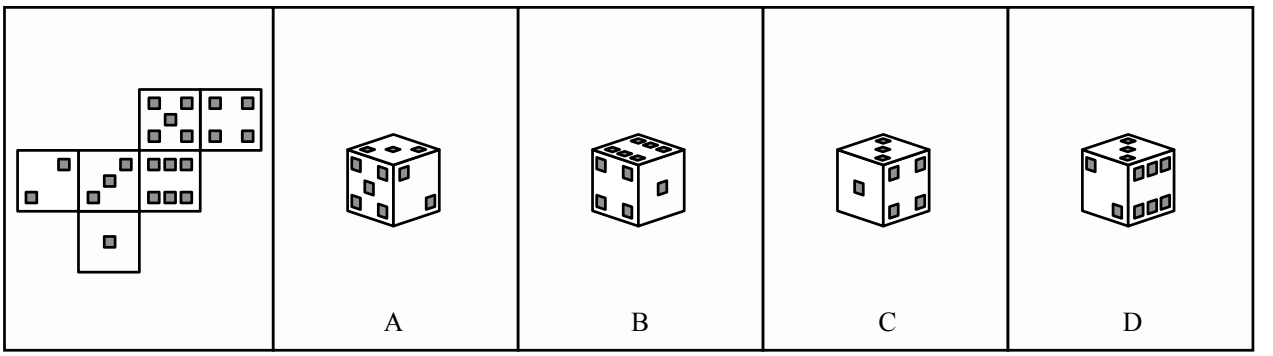

Correct Answer

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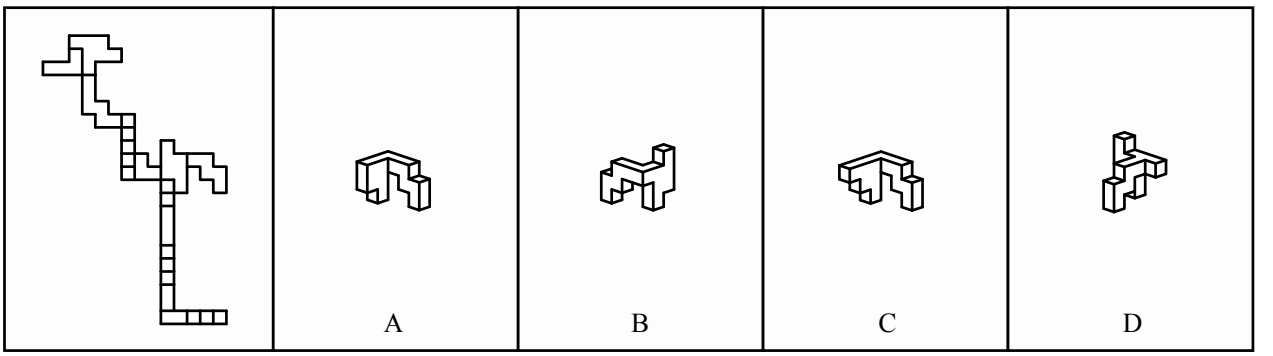

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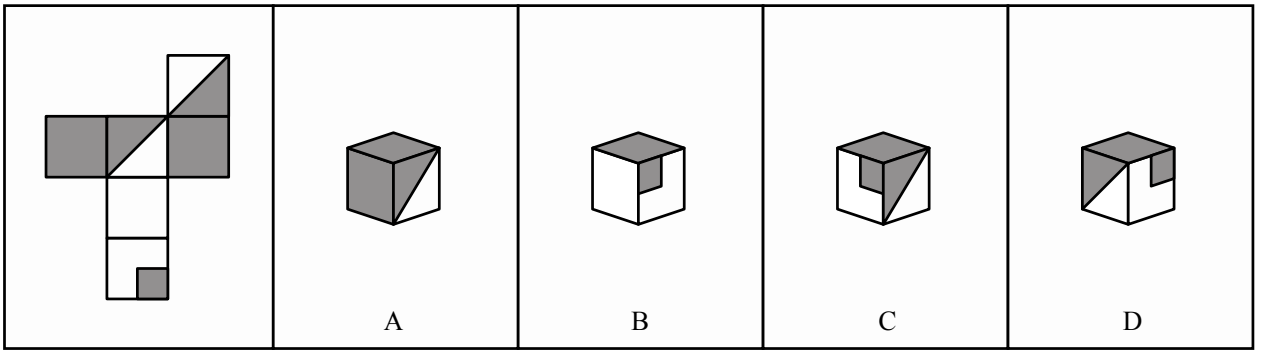

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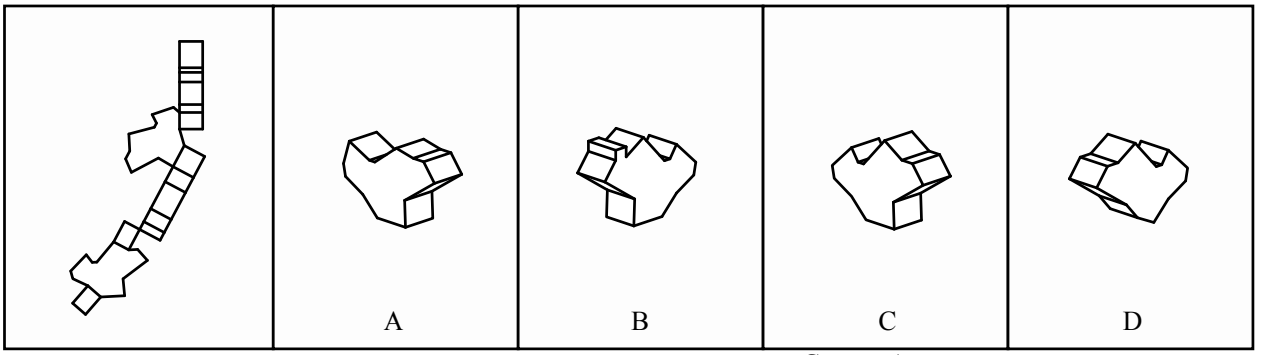

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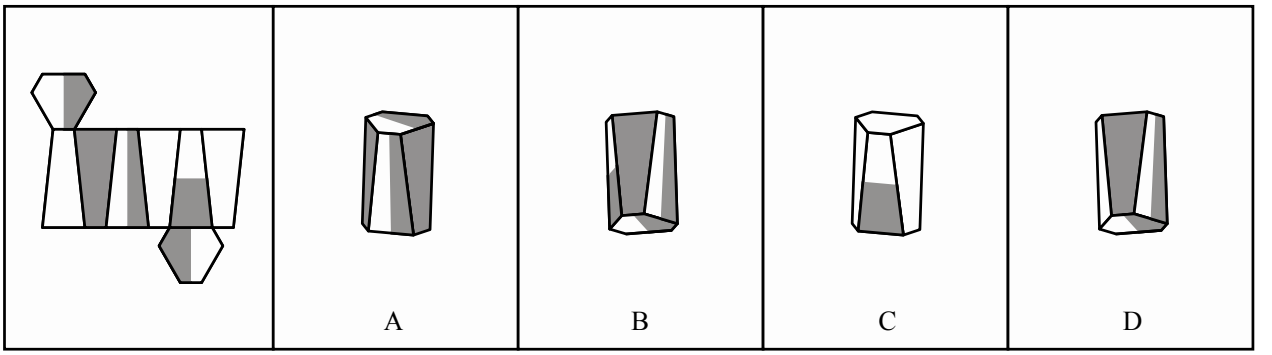

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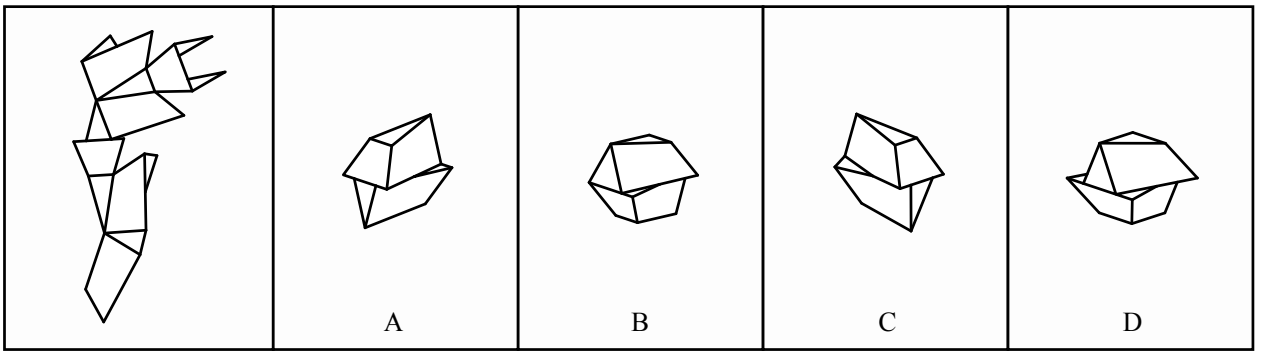

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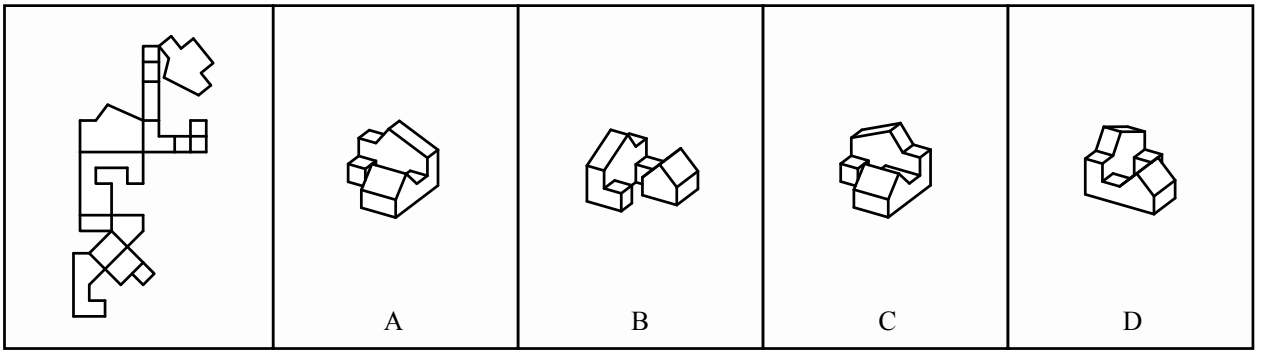

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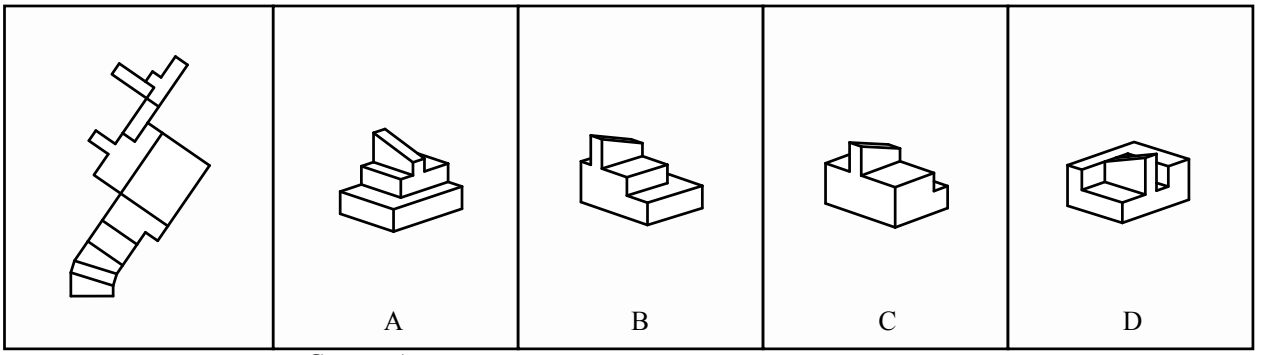

Correct Answer

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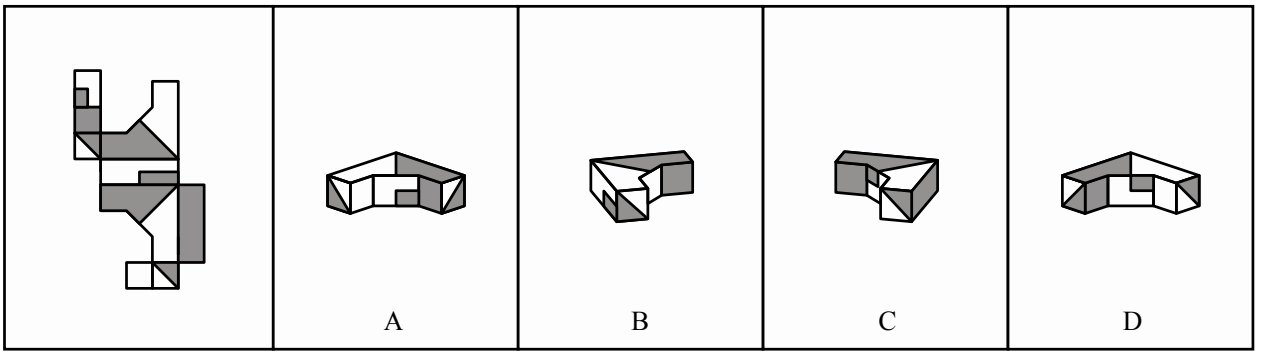

Correct Answer

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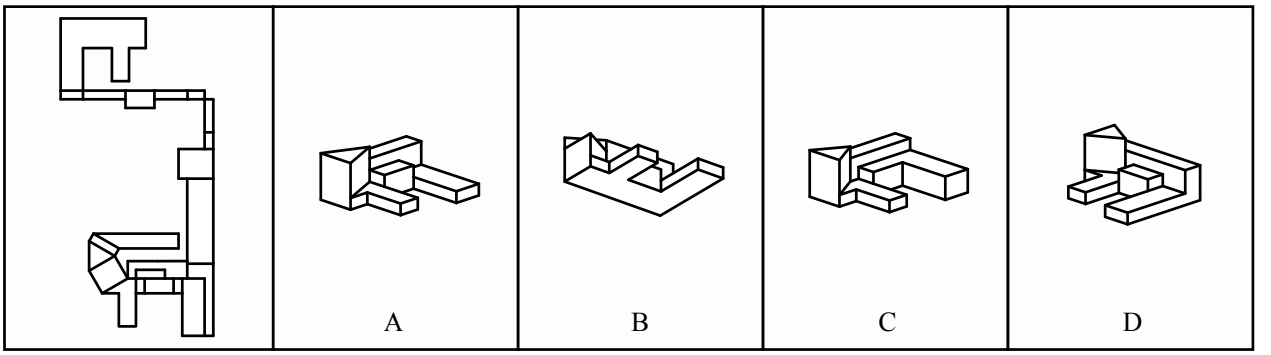

Correct Answer

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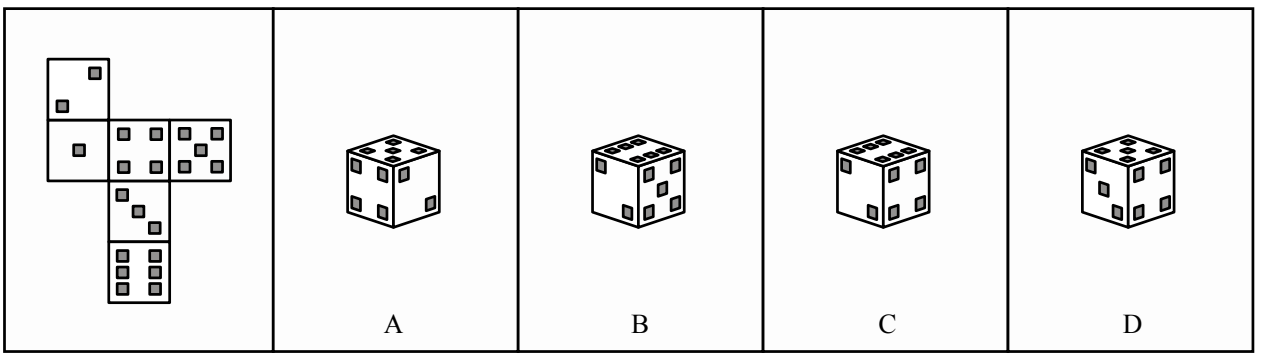

Correct Answer

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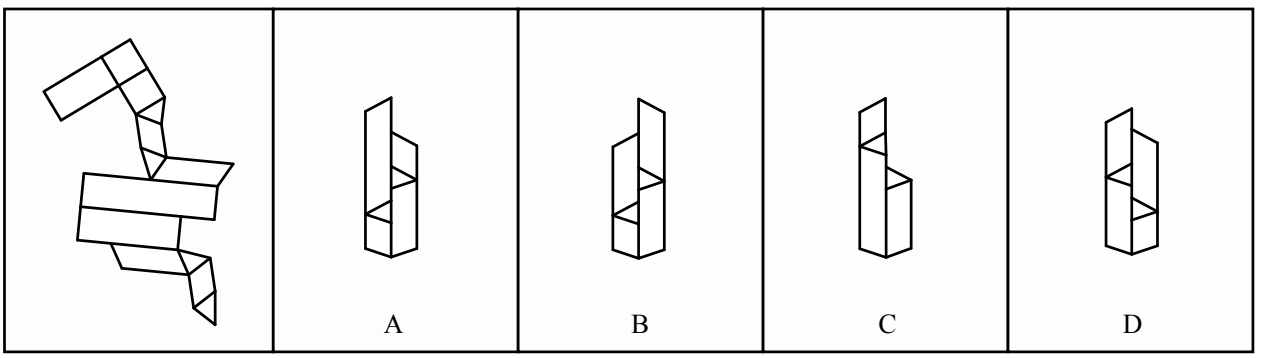
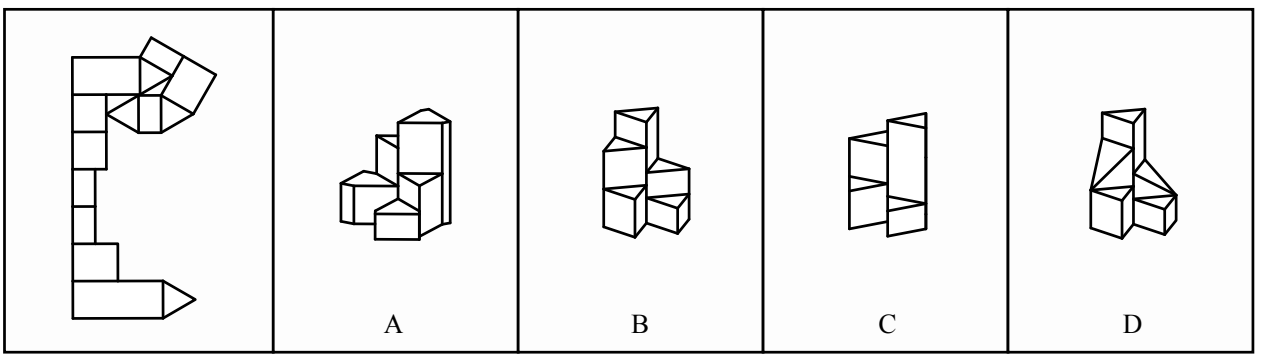


Correct Answer

90.



Correct Answer

Solutions – Reading Comprehension Test

1. Which of the following conditions does NOT result from the spontaneous hydrolysis of NO_2?
   A. Bronchitis
   B. Asthma
   C. Pneumonitis
   D. Pulmonary edema

   According to paragraph six, "… acute NO_2 poisoning is known to cause pulmonary edema, bronchitis, and pneumonitis when NO_2 is spontaneously hydrolyzed to nitrous and nitric acid upon contact with moisture in the lung". Option B) is the only condition not mentioned

2. Which of the following statements would the author most likely DISAGREE with?
   A. Improvements in safety technology has simply shifted the most common forms of occupational injury from acute to chronic
   B. It is difficult to fully protect coal miners from all hazards due to the diversity of exposures
   C. German regulations for maximum NO_2 exposure should be tightened
   D. Legislation is the most important factor in protecting workers from occupational hazards
   E. The significance of bioaerosols as an occupational hazard of coal mining has been historically under-appreciated

   A → Incorrect. In paragraph two, the author mentions "Although improved technology (i.e. handheld gas detectors) and government regulation has led to the reduction of many causes of acute injury to workers, modern miners are still burdened with chronic health issues". Therefore the author would most likely agree that this shift from acute to chronic conditions is at least partly due to technological advances
   B → Incorrect. In the first paragraph, the author mentions "… the occupational hazards associated with extraction and transportation are complex and varied, due to the plethora of different chemical, physical, and biological exposures generated from coal dust and mining paraphernalia". Therefore the author would likely agree with this statement
   C → Incorrect. In paragraph three, the author argues that toxic gases are a serious threat to worker health. He/she states that although NO_2 levels were found to be in compliance with German law in a 2009 study, they were still significantly higher than the long-term exposure threshold recommended by Zhang *et al*. Since the purpose of the article is to advocate for the protection of coalminers, we can infer that the author would agree with stronger NO_2 regulations
   D → Correct. Although in the last paragraph the author suggests that we should "… enact comprehensive laws that serve to protect our workers", this is prefaced by him/her advocating for "… a holistic approach if we wish to maximize the positive clinical outcomes of hazard management". Furthermore, the author argues that effective protection for workers can only be achieved by "… understanding the interplay of biological, environmental, and individual determinants of health …". Therefore the author would most likely disagree that legislation is the single most important factor in protecting workers from occupational hazards
   E → Incorrect. In paragraph five, the author mentions that "The role that microorganisms play in occupational health is a relatively novel field of research; one that has not yet been applied to the coal-mining industry until recently". Furthermore, the author argues that "This is incredibly relevant to occupational health given that in a 2018 study, 66.4% of miners with CWP were found to be comorbid with a latent TB infection". Therefore the author would most likely agree with this statement

3. Mycobacterium is a Proteobacteria that is known to cause tuberculosis.

   Macrophages and airborne particulates both play an important role in CWP.
   A. Both statements are TRUE
   B. Both statements are FALSE
   C. The first statement is TRUE, the second is FALSE
   D. The first statement is FALSE, the second is TRUE

   According to paragraph five, "Mycobacterium is an example of an Actinobacteria that is known to cause tuberculosis (TB)". Therefore the first statement is false.
   According to paragraph four, "Another major environmental hazard to coalminers is the generation of airborne particulates (coal dust, silica powder, etc.) during coal extraction. This results in a number of respiratory diseases, the most common being coal worker's pneumoconiosis (CWP) …". Later in paragraph seven, the author states "Alveolar macrophages (AM) cells play a major role in the pathophysiology of CWP". Therefore the second statement is true.

4. What was the concentration of archea found in the Wei *et al.* study?
   A. 9.60×10^4
   B. 1.44×10^8
   C. 1.44×10^4
   D. 1.02×10^4
   E. 1.02×10^8

   According to paragraph five, "The total concentrations of bacteria, archaea and fungi were 1.02×10^8, 1.44×10^8, and 9.60×10^4 cells/m^3 respectively"

5. Which of the following pulmonary diseases is not augmented with exposure to coal dust?
   A. Hypersensitivity pneumonitis
   B. Emphysema
   C. Asthma
   D. Bronchitis
   E. lung cancer

   According to paragraph four, "Other pulmonary diseases in which coal dust exposure has been shown to increase risk include: COPD, emphysema, lung cancer, hypersensitivity pneumonitis, and occupational asthma". Bronchitis is the only disease not mentioned in this list

6. Which of the following statements is most likely to be true?
   A. Oxidative stress and lipid peroxidation result from chronic NO_2 exposure
   B. Edema results from the destruction of type II pneumocytes
   C. Pulmonary edema, bronchitis, and pneumonitis, are risk factors for COPD
   D. Adding PDGF to a cell culture of fibroblasts will result in fibrosis
   E. IGF-1 converts fibroblasts into myofibroblasts in many human lung diseases

   A → Incorrect. According to paragraph six, *acute* NO_2 poisoning can cause chemical burns, oxidative stress, and lipid peroxidation. *Chronic* NO_2 exposure will likely have different consequences. In fact, the author mentions that "The pathogenesis of COPD in individuals chronically exposed to NO_2 remains unknown"
   B → Incorrect. According to paragraph six, "The respiratory epithelium becomes damaged due to destruction of type I pneumocytes, releasing fluid that results in edema". Therefore this answer choice statement is definitely false
   C → Incorrect. According to paragraph six, "… acute NO_2 poisoning is known to cause pulmonary edema, bronchitis, and pneumonitis …". We cannot assume the reverse causation relationship is true. Even if the reverse were true, acute NO_2 poisoning is not the same as COPD
   D → Correct. Paragraph seven describes how the binding of PDGF to the RTK receptor on fibroblasts will lead to overproduction of connective tissue, resulting in fibrosis. Since all fibroblasts possess RTK, this answer choice statement is the most likely to be true
   E → Incorrect. According to paragraph seven, IGF-1 stimulates differentiation of fibroblasts into a myofibroblast phenotype, but only in bleomycin-induced murine lung injury. Since this artificially-induced lung injury model does not accurately reflect the pathophysiology of human lung diseases, it is unlikely that IGF-1 also converts fibroblasts to myofibroblasts in humans

7. What is the standardized mortality ratio of coal worker's pneumoconiosis?
   A. 10×4
   B. 5×40
   C. 20×4
   D. 5×20
   E. 20×3

   According to paragraph four, coal worker's pneumoconiosis (CWP) "… demonstrated a standardized mortality ratio (SMR) of 79.70 …". The closest answer choice to this is C) $20 \times 4 = 80$

8. What is the author's tone in paragraph two?
   A. Agnostic
   B. Analytical
   C. Informative
   D. Melancholy
   E. Casual

   A → Incorrect. The author does not seem like he/she is unwilling to commit to an opinion about occupational health for coalminers. In fact, the author argues that although there is a reduction in acute injuries, miners are sill burdened with chronic health issues
   B → Correct. The author presents facts in the form of a case study, then proceeds to analyze the key points in order to form a conclusion
   C → Incorrect. Although this answer choice is very similar to option B), the key difference is that an informative tone will have considerably less analysis/inferencing done by the author. Instead, the text would read almost like a newspaper
   D → Incorrect. The author does not speak in a serious, formal, sad, or dignified manner
   E → Incorrect. The author presents many detailed pieces of evidence, and therefore does not seem relaxed or unconcerned about the topic

9. Which of the following techniques is NOT used to protect workers from airborne particulates or bioaerosols?
   A. Installing ventilation curtains
   B. Wearing N95 respirators
   C. Installing CAC technology
   D. Prophylactic vaccinations
   E. Spraying water over machinery

   A → Incorrect. This technique is discussed in paragraph ten
   B → Incorrect. Discussed in paragraph eleven
   C → Incorrect. This technique is discussed in paragraph ten
   D → Correct. According to paragraph eleven, prophylactic vaccinations protect an individual from M. tuberculosis, Staphylococcus, and Clostridium, not the actual bioaerosol particles themselves
   E → Incorrect. This technique is discussed in paragraph ten

10. Exposure to endotoxins are correlated with skin irritation.

    Exposure to exotoxins are are correlated with chronic airway obstruction and byssinosis.

    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

    According to the last paragraph, "… chronic exposure to exotoxins or endotoxins from bioaerosols are correlated with eye and skin irritation, as well as respiratory disorders such as allergic lung inflammation, chronic airway obstruction, byssinosis, bronchitis, tuberculosis, and asthma". Since the author uses "or" instead of "and", exposure to *either* exo- or endotoxins can result in any of the listed conditions

11. How did Wei et al. collect microorganism samples for pyrosequencing?
    A. N95 filters
    B. Nanopores
    C. Bioaerosol samplers
    D. Wired mesh
    E. Alveolar macrophages

    In paragraph five, the author states that "… pyrosequencing and real-time polymerase chain reaction (RT-PCR) was used to identify and classify 37,191 genomic DNA reads obtained from bioaerosol samplers fitted with 0.22 μm pore filters". Note that these filters are at the micro scale, not nano

12. Which of the following safety policies is the author most likely to implement in the USA?
    A. Mandatory gas masks for all coalminers
    B. Limit daily NO_2 exposure to 0.21 ppm
    C. Install gas detectors in every mineshaft
    D. Replacing diesel engines with electric motors
    E. Limit the allowable level of dust in coal mines

    A → Incorrect. In paragraph nine, the author states that "Personal protective equipment such as gas masks are effective but should only be used as last-resort measure …"
    B → Incorrect. In paragraph three, the author mentions that long-term exposure to NO_2 levels as low as 0.01 ppm can result in an increased risk for COPD
    C → Incorrect. In paragraph nine, the author argues that although gas detectors work effectively, they are expensive to acquire and maintain
    D → Correct. In paragraph nine, the author argues: "Personal protective equipment such as gas masks are effective but should only be used as last-resort measure, given that the majority of CO and NO2 emissions can be addressed directly by eliminating diesel-burning equipment from poorly ventilated areas and using electrical equipment instead"
    E → Incorrect. In the last paragraph, the author mentions that this safety policy already exists in the United States. It is called the 2014 "Dust Rule"

13. How many coalminers were involved in the 2014 study?
    A. 37,191
    B. 8,829
    C. 1,748
    D. 1,369
    E. 8,892

    According to paragraph four, "… [CWP] demonstrated a standardized mortality ratio (SMR) of 79.70 (95% CI 72.1 to 87.67) in a 2014 prospective cohort study of 8,829 America coalminers with a follow-up of 37 years"

14. What message is the author trying to convey in paragraph three?
    A. There is no "safe" level of NO_2 exposure
    B. The use of diesel machinery should be limited in underground mines
    C. There should be a limit for the number of hours coalminers are allowed to work per day
    D. The long-term dangers of exposure to toxic gasses such as NO and NO_2 often first manifest through warning signs
    E. The long-term consequences of toxic gasses such as NO and NO_2 are under-appreciated and under-regulated

    A → Incorrect. Although the author does argue in paragraph three that current German regulation for NO_2 exposure is not strict enough, there is no evidence that *all* concentrations of NO_2 are unsafe. Despite the study by Zhang *et al.* demonstrating a 2% increase in risk for COPD with exposure to 0.01 ppm of NO_2, we cannot assume that even lower NO_2 concentrations will have the same harmful effects
    B → Incorrect. Although the author advocates for the elimination of diesel-burning equipment in poorly ventilated areas near the end of the passage, this is not the focus of paragraph three. Despite the author's statement that "… the main sources of exposure to carbon monoxide and nitrogen oxides were from diesel engines …", we cannot assume he/she supports their elimination from this paragraph alone
    C → Incorrect. The author does mention that Zhang *et al.* studied NO_2 exposure over an 8-hour workday, but we cannot assume that he/she supports the reduction of work hours based on the evidence presented
    D → Incorrect. At the beginning of the paragraph, the author states "Although the hazards of mining are obvious even to the untrained eye, one of the most serious dangers is invisible – the insidious effects of toxic gases". The word *insidious* implies that the damaging health effects of toxic gasses progress in a gradual, subtle manner, showing no signs or symptoms until it is too late. Therefore we would not expect any warning signs to manifest until the disease is already in an advanced stage
    E → Correct. The author states that the insidious effects of toxic gases is one of the most serious dangers that is often invisible to the untrained eye. Furthermore, he/she presents evidence that implies that the current German legislation for NO_2 exposure is not strict enough

15. Which of the following techniques was used to analyze DNA from bioaerosol samplers?
    A. Next-generation sequencing
    B. Gel electrophoresis
    C. Restriction digest
    D. Polymerase chain reaction
    E. Molecular cloning

    According to paragraph five, "In a landmark paper by Wei *et al.*, pyrosequencing and real-time polymerase chain reaction (RT-PCR) was used to identify and classify 37,191 genomic DNA reads obtained from bioaerosol samplers fitted with 0.22 μm pore filters"

16. Which of the following describes the Mycobacterium tuberculosis complex?
    A. A collection of clinical signs and symptoms
    B. A protein-substrate complex
    C. A group of evolutionarily related bacteria
    D. A lesion formed by calcified granulomas
    E. An assembly of a mature phagosome, lysosome, and hydrolytic enzymes

    According to paragraph eight, "MTC is a phylogenetically related group of Mycobacteria that cause TB in humans and animals"

17. In the study by *Wei et al.*, what percentage of potentially pathogenic bacterial sequences were related to Actinobacteria?
    A. $\boldsymbol{\frac{0.02}{1.87}\%}$
    B. $\frac{1.12}{1.87}\%$
    C. $\frac{0.73}{1.87}\%$
    D. $\frac{0.02}{1.12}\%$
    E. $\frac{0.73}{1.12}\%$

    The question is asking for the percentage of Actinobacteria sequences out of all *pathogenic* sequences. Since we know that 0.02% of all sequences were Actinobacteria, and that 1.87% of all sequences were pathogenic, we can simply divide to find the percent of pathogenic sequences that were Actinobacteria

18. How is methane different from carbon monoxide?
    A. Methane is more dangerous to coalminers
    B. Methane can be more easily detected
    C. Carbon monoxide is explosive
    D. Carbon monoxide is produced via electrical equipment
    E. Methane can cause asphyxiation

A → Incorrect. This is never stated nor implied
B → Correct. According to paragraph nine, "Reduction in occupational exposure to explosive gases such as methane have been greatly reduced through the introduction of safety lamps. However, toxic levels of insidious gases like CO and NO_2 are much harder to detect in an economical manner"
C → Incorrect. This is never stated nor implied
D → Incorrect. According to paragraph nine, "… the majority of CO and NO_2 emissions can be addressed directly by eliminating diesel-burning equipment from poorly ventilated areas and using electrical equipment instead"
E → Incorrect. It is true that methane can cause asphyxiation, but so can carbon monoxide. Paragraph three calls carbon monoxide a toxic gas, while paragraph two describes a case of methane asphyxiation

19. What does MSHA stand for?
    A. Mine Security and Health Alliance
    B. Municipal Social Housing Association
    C. Mineable Sulphur, Hassium, and Antimony
    D. Mine Safety and Health Administration
    E. Municipal Safety and Health Association

According to the last paragraph, "Most governments have implemented legislation that controls the level of occupational hazards coalminers are exposed to. For instance, the Mine Safety and Health Administration (MSHA) of the United States enacted the 2014 'Dust Rule' …"

20. Which of the following factors does the author NOT mention as important for occupational health in coalminers?
    A. Socioeconomic factors
    B. Environmental hazards
    C. Biological hazards
    D. Abiotic dangers
    E. Genetic factors

A → Correct. The author does not mention the socioeconomic determinants of health, such as income, minority status, education, etc.
B → Incorrect. The author discusses many environmental hazards such as bioaerosols and airborne particulates
C → Incorrect. The author mentions biological hazards such as M. tuberculosis, Staphylococcus, and Clostridium
D → Incorrect. In the last paragraph, the author states "As more research is conducted in this field, it becomes clear that abiotic dangers are not the only issues that warrant our attention". This implies that abiotic dangers *are* important for occupational health, in addition to other factors
E → Incorrect. In the last paragraph, the author states "Only by better understanding the interplay of biological, environmental, and individual determinants of health will we be able to enact comprehensive laws that serve to protect our workers". Genetic factors are specific to an individual, and therefore is an individual determinant of health

21. Which of the following statements would the author most likely agree with?
    A. Controlling the HIV/AIDS pandemic largely depends on limiting the spread of the disease in regions such as Europe and America
    B. Vertical transmission of HIV from mother to newborn has been virtually eliminated thanks to highly sensitive and specific screening tests
    C. Nevirapine treatment may be harmful to the mother and newborn
    D. The global response to the lack of adequate prevention and treatment interventions has been rapid and effective
    E. Zidovudine is often more effective when used independently, rather than in combination with other antiretroviral drugs

A → Incorrect. According to the second paragraph, "Prevention and treatment efforts in Sub-Saharan Africa and Asia—regions that together represent 85 percent of all current infections—have dictated, and will continue to dictate, global trends in the burden of HIV- and AIDS-related mortality"
B → Incorrect. The author states in paragraph four that infection from the *blood supply* has been virtually eliminated thanks to highly sensitive and specific HIV screening tests
C → Correct. According to paragraph four, "… the administration of a short course of nevirapine to mothers during labor and to newborns postpartum reduces the risk of mother-to-child transmission (MTCT) by as much as 47 percent. However, recent data suggest that such short-term successes may be at the expense of resistance and viral failure once treatment is introduced after delivery". Therefore, although nevirapine may reduce the risk of HIV transmission to the newborn, it also decreases the effectiveness of antiretroviral treatment after delivery
D → Incorrect. According to paragraph seven, "Current coverage shortfalls, combined with the relentless expansion of the epidemic, underscore the acute need for rapid scale-up of prevention and treatment interventions—an imperative that the international community has acknowledged but that remains to be realized after more than 15 years"

E → Incorrect. According to paragraph five, "The most notable advance on the treatment front is the use of combination antiretroviral therapy, which is far more effective than monotherapy (zidovudine or AZT), the previous 'gold standard'"

22. Which of the following countries does NOT provide universal coverage for antiretroviral therapy?
    A. Brazil
    B. Argentina
    C. India
    D. Mexico

According to paragraph eight, "Because antiretroviral therapy has historically been unavailable in most developing countries, national programs have lacked the means to undertake a comprehensive approach to HIV/AIDS (notable exceptions are Argentina, Brazil, and Mexico, which provide universal coverage for antiretroviral therapy)"

23. Which of the following regions has the highest burden of HIV/AIDS?
    A. Asia
    B. South Africa
    C. Eastern Europe
    D. Sub-Saharan Africa
    E. Western Europe

According to the first paragraph, "Sub-Saharan Africa remains the region most affected by HIV/AIDS; however, the virus is now spreading rapidly in Asia and parts of Eastern Europe"

24. The impact of antiretroviral drugs on HIV treatment is similar in magnitude to the impact of penicillin on the treatment of bacterial infections.

    The current allocation of resources for HIV/AIDs prevention is based on the results of many studies and expert recommendations.
    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

According to paragraph five, "The advent of antiretroviral drugs in the late 1980s began a revolution in the management of HIV, which can be seen as analogous to the use of penicillin for treating bacterial infections in the 1940s". Therefore the first statement is true.

According to paragraph nine, "Currently, the allocation of resources for HIV/AIDS prevention is seldom evidence based, primarily because of a lack of data on both the effectiveness and the cost of interventions". Therefore the second statement is false.

25. How many HIV infections does the Emergency Plan for AIDS Relief program estimate itself to be able to prevent?
    A. 2 million
    B. 4 million
    C. 7 million
    D. 10 million
    E. 15 million

According to paragraph seven, "The [AIDS Relief program] aims to provide antiretroviral drugs for 2 million HIV-infected people, to prevent 7 million new infections, to provide care for 10 million individuals, and to develop health system capacity in Vietnam and in Africa and the Caribbean"

26. What is the purpose of the passage?
    A. To advocate for increased research in the public health responses for HIV and AIDS
    B. To advocate for the de-stigmatization of sexually transmitted diseases
    C. To inform the reader of current public health measures to combat HIV/AIDS
    D. To describe how HIV/AIDS grew to a pandemic of massive proportions
    E. To advocate for the withdrawal of government funding until all HIV prevention decisions are evidence-based

A → Correct. The author emphasizes how an information deficit is resulting in misguided public health decisions and the poor allocation of resources. In the final paragraph, the author describes the current situation as having a "glaring deficit in AIDS research"
B → Incorrect. Although the author does mention stigmatization as a factor that causes aid agencies to avoid HIV prevention, he/she does not advocate for the reduction of such stigma
C → Incorrect. The passage is not objective enough to simply serve as an informative piece of literature. The author has a very clear opinion on the state of HIV/AIDS research
D → Incorrect. The author does not discuss the history or epidemiology of HIV/AIDS
E → Incorrect. Although the author does advocate for increased HIV/AIDS research, this answer choice is too extreme. The author never expresses his/her opinion that government funding should be withdrawn at all

27. Why is it difficult for HIV prevention programs to identify and self-correct ineffective policies?
    A. Because prevention programs are relatively underfunded, compared to HIV treatment
    B. Because there is social stigma surrounding HIV prevention
    C. Because there is a research deficit
    D. Because it is difficult to distinguish success from failure
    E. Because such policies are dictated by governments and international agencies

A → Incorrect. The author does not differentiate between prevention and treatment programs on the basis of funding
B → Incorrect. Although this statement is factually correct, it is not the *reason* why prevention programs find it difficult to correct ineffective policies
C → Incorrect. According to paragraph nine, the lack of research prevents the effective allocation of resources for HIV/AIDS prevention, not the ability to self-correct ineffective policies
D → Correct. According to the second last paragraph, success is easily distinguishable from failure in HIV treatment, since failure leads to death. This allows treatment programs to self-correct any ineffective policies. However, it is much more difficult for HIV prevention programs to estimate how many lives they save, and thus it is more difficult to self-correct and optimize their policies
E → Incorrect. There is no evidence in the passage that this statement is true

28. Mother-to-child transmission of HIV/AIDS has declined by as much as 47 percent because HIV screening tests have successfully been developed.
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

According to paragraph four, the risk of mother-to-child transmission (MTCT) has declined by as much as 47 percent. Therefore the statement is correct.

Furthermore, the paragraph states that highly sensitive and specific HIV screening tests have been successfully developed. Therefore the reason is factually correct.

However, the decline in MTCT is due to the administration of nevirapine, not HIV screening tests. Therefore the reason is not related to the statement.

29. Which of the following is NOT considered a basic prevention service for HIV?
    A. Education
    B. Counselling and testing
    C. Safe injection sites
    D. Harm reduction
    E. Condoms

According to paragraph six, "… a 2003 survey of coverage revealed that fewer than one in five people at high risk of infection had access to the most basic prevention services, including condoms, AIDS education, MTCT prevention, voluntary counselling and testing (VCT), and harm reduction programs". Since safe injection sites are not listed, it is not considered by the passage to be a basic prevention service

30. According to the author, which of the following is a valid criticism of the US President's Emergency Plan for AIDS Relief ?
    A. It ignores the needs of countries with a high HIV/AIDS burden, such as Malawi
    B. It does not address the current research deficit and lack of public health data
    C. It is a short-term solution focused on diplomatic vanity rather than improving the health system of countries
    D. It is funded by federal lobbyists who have electoral conflicts of interest
    E. It undermines efforts made by local charities and agencies

A → Correct. According to paragraph seven, "Even though 15 countries are currently slated to receive support from the President's Emergency Plan, many of the countries most affected by HIV/AIDS—including Lesotho, Malawi, Swaziland, and Zimbabwe—are not included in the list of beneficiary countries"
B → Incorrect. Although the author does mention that there is a research deficit, it is not clear based on the passage whether the Emergency Plan for AIDS Relief is ignoring the issue. Therefore this criticism is unfounded
C → Incorrect. It is unlikely that the author would make this critique, as he/she mentions in paragraph seven that the program aims "… to develop health system capacity in Vietnam and in Africa and the Caribbean"
D → Incorrect. There is no evidence that suggests the author would make this critique
E → Incorrect. There is no evidence that suggests the author would make this critique

31. What is the purpose of the last paragraph?
    A. To make an appeal for scientists to prioritize HIV/AIDS research
    B. To give the reader a sense of hope despite the many problems in the field of HIV prevention and treatment
    C. To explain why auto-correction of ineffective policies is more difficult in HIV prevention
    D. To discuss the efforts and challenges of HIV prevention and treatment in various countries
    E. To warn the reader of the consequences for public health in the absence of research data

    A → Incorrect. Although the author is an advocate for increased research for HIV/AIDS, he/she does not call for scientists to prioritize the topic. In fact, it seems like the author recommends that we focus on other factors: "Despite the glaring deficits in AIDS research, the magnitude and seriousness of the global pandemic calls for action in the absence of definitive data"
    B → Incorrect. The last paragraph does not provide an optimistic view of the issue at all
    C → Incorrect. This is the purpose of the second last paragraph
    D → Incorrect. This answer choice is too broad to be the purpose of the last paragraph. It is more suitable to describe the entire passage
    E → Correct. Emphasizing the "glaring deficits" in HIV/AIDS research, the author paints a grim picture of the future of prevention and care. He/she argues that without data, we cannot accurately guide program objectives and make effective investments. This is made clear in the final sentence: "This waste [of resources] undoubtedly exacerbates funding shortfalls and results in unnecessary HIV infections and premature deaths"

32. Which of the following countries is mismatched with its corresponding program/initiative?
    A. Uganda – Decreasing HIV prevalence
    B. USA – Emergency Plan for AIDS Relief
    C. Thailand – 100 Percent Condom Program
    D. Swaziland – Community-Based Syndromic Management of STIs

    According to paragraph three, "The extraordinary potential of HIV prevention is exemplified by such diverse efforts as Thailand's 100 percent condom program, Uganda's remarkable decrease in HIV prevalence, and the community-based syndromic management of sexually transmitted infections (STIs) in Mwanza, Tanzania"

33. Prevention and treatment efforts in Sub-Saharan Africa dictate global trends in HIV/AIDS-related mortality because it accounts for more than 75 percent of all HIV infections worldwide.
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

    According to the second paragraph, "… Sub-Saharan Africa remains by far the hardest hit region. With only 10 percent of the world's population, it accounts for more than 75 percent of all HIV infections worldwide and more than 75 percent of AIDS-related deaths estimated for 2003 … Prevention and treatment efforts in Sub-Saharan Africa and Asia … have dictated, and will continue to dictate, global trends in the burden of HIV- and AIDS-related mortality"

34. Which of the following recommendations would the author make to improve HIV control?
    A. Conduct research to develop new control technologies and strategies
    B. Lobby governments to start providing free condoms, testing, and counselling
    C. Privatize the production of antiretroviral drugs to lower prices
    D. Randomize the distribution of basic prevention services

    A → Incorrect. According to paragraph six, the existing control strategies are sufficient enough to "… prevent 63 percent of all infections projected to occur between 2002 and 2010". The problem is concerning accessibility, not the actual strategies themselves: "Most people who could benefit from available control strategies, including treatment, do not have access to them". Therefore the author would not make this recommendation
    B → Correct. The author argues in paragraph six that a lack of accessibility is causing the unnecessary infection of individuals and spread of HIV. Providing free basic prevention services would increase accessibility and protect more people
    C → Incorrect. According to paragraph five, "Recent declines in the price of combination antiretroviral therapy in developing countries from US$15,000 per year to less than US$150 in some countries have prompted numerous developing countries to introduce antiretroviral therapy through the public sector". Therefore the author would likely view this recommendation as ineffective

D → Incorrect. There is nothing to suggest that the author would support this recommendation. In fact, the author would probably be against random distribution, since he/she supports "evidence-based" decision making

35. The prevalence of major depressive disorder in women has been consistently measured to be 1.5 times greater than the prevalence in men.

    Worldwide, around 18.9 million people have some form of depressive disorder.

    A. Both statements are TRUE
    B. Both statements are FALSE
    C. The first statement is TRUE, the second is FALSE
    D. The first statement is FALSE, the second is TRUE

According to paragraph three, the prevalence of major depressive disorder in women is "… roughly 1.5 to 3 times greater than prevalence in men (depending on the time period and methodology of the study)". This means that the value of "1.5 times greater" is not consistently measured. Therefore, the first statement is false.
Also in paragraph three, the author states "Globally, it's estimated that 300 million people are afflicted with depressive disorders". Thus, the second statement is false.

36. A patient with a history of chronic depression, smoking, insomnia, and bipolar disorder is on "day one" after recovering from a major depressive episode. Which of the following is most likely to happen within the next week?

    A. Spontaneous remission
    B. Suicide
    C. Catatonia
    D. Relapse
    E. Psychosis

A → Incorrect. According to paragraph five, "spontaneous remission occurs when a patient recovers from an illness without receiving formal treatment". Given that the patient has already recovered from a major depressive episode, spontaneous remission is impossible
B → Incorrect. Although the author mentions in paragraph two that depression "… often entails an increased suicide risk", it is not clear whether this risk persists after recovery. Therefore, this is not the *most* likely answer choice
C → Incorrect. Although the author mentions in paragraph two that catatonia is an aspect of severe depression, he/she does not discuss the risk of catatonia after recovery. Therefore, this is not the *most* likely answer choice
D → Correct. According to paragraph four, "… the risk of relapse decreases the longer the period a person remains remitted". Since the patient is on "day one", the likelihood of relapse is at its highest. In addition, the author mentions that dispositional, lifestyle, and environmental factors can contribute to chronicity. Since the patient has many risk factors including smoking and insomnia, the risk of relapse is augmented. Furthermore, the author states that comorbid mental health conditions such as bipolar disorder can again increase the risk of relapse. Considering all these factors, relapse is the most likely answer choice
E → Incorrect. Psychosis is not mentioned in the passage. Therefore this answer choice is out of scope

37. Which of the following statements is TRUE?

    A. The prognosis of major depressive disorder is relatively consistent from patient to patient
    B. Older patients have a greater risk of developing a major depressive disorder
    C. Recent studies on spontaneous remission are more consistent than early studies
    D. Spontaneous remission was first demonstrated in 1997
    E. The prevalence of major depressive disorder is higher in African Americans

A → Incorrect. According to paragraph four, "The DSM-5 notes that the prognosis of major depressive disorder is fairly variable and susceptible to influence from a number of personal factors"
B → Incorrect. According to paragraph three, "In the United States, young adults aged 18 to 29 years old have a threefold higher prevalence of major depressive disorder than adults 60 years and above"
C → Correct. According to paragraph seven, "More recent studies on spontaneous remission have been more successful at converging on a base rate". In other words, the discrepancy between recent studies on the rate of spontaneous remission is lower than that of early studies (30-50% vs 37-65.3%)
D → Incorrect. According to paragraph five, "The first major examination of spontaneous remission was in 1952 …"
E → Incorrect. According to paragraph three, "Ethnic studies have also found a higher prevalence of major depressive disorder in biracial, First Nations, and white Americans"

38. Which of the following is the most common mental health disorder?
    A. Bipolar disorder
    B. Depression
    C. Schizophrenia
    D. Obsessive-compulsive disorder
    E. Anxiety disorders

    According to the first paragraph, "In North America, an estimated 18.9 million people experience at least one major depressive episode per year, making depression the second most common mental health disorder after anxiety disorders"

39. A significant portion of depression patients recover during the disproportionately short period of 3 months because their condition developed from a previously healthy state
    A. Both the statement and reason are correct and related
    B. Both the statement and reason are correct but NOT related
    C. The statement is correct but the reason is NOT
    D. The statement is NOT correct, but the reason is correct
    E. NEITHER the statement NOR the reason is correct

    According to paragraph four, "… the immediate likelihood of remission decreases the longer a patient remains depressed, hence why a significant portion of patients recover during the disproportionately short period of 3 months". Therefore the statement is correct but the reason is not

40. Why was Eysenck's 1952 paper on spontaneous remission provocative?
    A. It provided support for behaviour therapy
    B. It undermined the legitimacy of psychoanalysis
    C. It attacked the beliefs of the majority
    D. The results were not reproducible
    E. It demonstrated extremely high remission rates in patients who underwent psychiatric treatment

    A → Incorrect. Although Eysenck was a proponent of behaviour therapy, the 1952 paper did not explicitly provide any evidence that would support this form of psychotherapy
    B → Correct. According to paragraph five, "… not only did Eysenck bring spontaneous remission into the academic limelight, he also immediately established the partisan paradigm of the topic by using his paper to attack the psychoanalytical method …"
    C → Incorrect. Although Eysenck's paper was an attack on the psychoanalytical method, there is no evidence for us to conclude that this was the majority belief at the time
    D → Incorrect. Although paragraph six states that "… early researchers were unable to determine a base rate for spontaneous remission …", this is not the reason for the controversy of his 1952 paper
    E → Incorrect. In fact, Eysenck demonstrated the exact opposite of this. According to paragraph five, "… he found that patients who received psychiatric treatment … had a lower rate of remission than patients who received minimal, non-psychological treatment from general practitioners—44% compared to 72%, respectively"

41. Which of the following statements best describes the concept of "low mastery"?
    A. The belief that one's depression is a helpless situation that cannot be resolved
    B. The lack of self-confidence in accomplishing a task or goal
    C. The diminished interest or pleasure in all or almost all activities
    D. The belief that the circumstances of one's life are out of his/her control
    E. Complete incapacitation or catatonia

    A → Incorrect. This answer is an extremely specific version of the actual definition for "low mastery", which is described in paragraph four as "believing that the circumstances of one's life are determined by external factors"
    B → Incorrect. The author does not discuss self-confidence anywhere in the passage. This answer is out of scope
    C → Incorrect. This statement describes the symptoms of depression, rather than the concept of "low mastery"
    D → Correct. According to paragraph four, "An example of a dispositional factor [of depression] is low mastery—believing that the circumstances of one's life are determined by external factors"
    E → Incorrect. This statement describes the most severe form of depression, rather than the concept of "low mastery"

42. Which of the following words can be used to replace "remission" throughout the passage?
    A. Resistance
    B. Progression
    C. Recovery
    D. Exacerbation
    E. Relapse

    In the context of this passage, the word "remission" refers to a temporary recovery from disease. All other answer choices carry either the opposite meaning or a neutral connotation

43. What was the title of Eysenck's paper?
    A. Spontaneous Remission: An Evaluation
    B. Major Depressive Disorder and Spontaneous Remission
    C. Psychoanalysis and Spontaneous Remission
    D. The Effects of Psychotherapy: An Evaluation
    E. The Effects of Psychoanalysis

    According to paragraph five, "The first major examination of spontaneous remission was in 1952, with the publication of Hans Eysenck's provocative paper *The Effects of Psychotherapy: An Evaluation*"

44. How did Wallace and Whyte measure the rate of spontaneous remission in neurotic patients?
    A. Self-reporting
    B. Interviews
    C. Medical examination
    D. Retrospective survey
    E. Psychoanalysis

    According to paragraph six, "… Wallace and Whyte found that 65.3% of neurotic patients who had been on waitlists for 3-7 years had improved without treatment (as judged in interviews with psychiatrists)"

45. Which of the following best describes why full remission is difficult for patients with a form of depression that arises from an exacerbation of previous, sub-clinical depressive state?
    A. These patients are more likely to have lifestyle, environmental, and dispositional risk factors
    B. These patients are more likely to have a genetic basis behind the disorder
    C. The immediate likelihood of remission decreases the longer a patient remains depressed
    D. These patients often present with comorbid mental health disorders

    A → Correct. Paragraph four states that "… in some patients a major depressive episode develops from a previously healthy state, whereas in other patients a major depressive episode represents an exacerbation of previous, sub-clinical depressive symptoms. Those in the latter category are much more likely to have the dispositional, lifestyle, and environmental factors that make full symptom remission unlikely"
    B → Incorrect. While the statement is true, it is not comprehensive and thus not most correct answer. See answer choice A)
    C → Incorrect. Although this statement is true, it describes depression as a whole and is not specific to the form of depression that arises from an exacerbation of previous state
    D → Incorrect. Although comorbid mental health disorders do increase the risk of relapse, there is no evidence to show that they prevent remission, nor that they are correlated with this specific form of depression

46. What does the author describe with the phrase "partisan paradigm" in paragraph five?
    A. The strong support of many scientists for psychoanalysis
    B. The catalyst for disagreement between many prominent psychologists
    C. Eysenck's prejudice against psychoanalysis in favour of behaviour therapy
    D. The rising popularity of spontaneous remission within academic circles
    E. The contentious but well-documented nature of spontaneous remission

    A → Incorrect. This is only one aspect of the situation that "partisan paradigm" describes. See answer choice B)
    B → Correct. The author is trying to describe how Eysenck generated controversy within the scientific community through his 1952 paper. In this sense, "partisan paradigm" can be paraphrased as a "catalyst for disagreement"
    C → Incorrect. Although it is possible that Eysenck was prejudiced against psychoanalysis, the author indicates that this is a point of uncertainty: "In publishing his paper, … he also immediately established the partisan paradigm of the topic due to his attack—intended or otherwise—on the psychoanalytical method …". Additionally, the author uses the term "partisan paradigm" to describe the general controversy surrounding Eysenck's paper, not his specific beliefs and prejudices
    D → Incorrect. The author uses the phrase "academic limelight" to describe this phenomenon
    E → Incorrect. Although this is factually true, it is not what the author is trying to describe

47. Which of the following statements would the author most likely agree with?
    A. The definition for a major depressive episode is broad and subjective
    B. Factors associated with the rate of relapse for untreated depression are well understood
    C. Work stress is a lifestyle factor that is strongly correlated with relapse
    D. Research into the potential effect of spontaneous remission on the prognosis of depression will be beneficial regardless of the actual outcome
    E. Heart disease is the leading cause of disability worldwide

A → Incorrect. According to the second paragraph, "The Diagnostic and Statistical Manual of Mental Disorders defines a major depressive episode as a period longer than two weeks during which a person experiences the symptoms of major depressive disorder. To be diagnosed with major depressive disorder, a person must meet at least five of nine diagnostic criteria". This is a very specific definition
B → Incorrect. According to the second last paragraph, "… one aspect lacking attention is the rate of relapse for untreated depression. The factors associated with relapse of treated depression are well understood, but it is unclear if these same factors apply to untreated populations"
C → Incorrect. According to paragraph four, work stress is classified as an *environmental* factor
D → Correct. In the second last paragraph, the author explains that if spontaneous remission was found to be associated with a positive prognosis, the information can be used to improve psychotherapy. On the other hand, if spontaneous remission is associated with a negative prognosis, the research would emphasize the importance of delivering accessible psychotherapy. This message is repeated and summarized in the final paragraph
E → Incorrect. Heart disease is never mentioned in the passage. This answer choice is out of scope

48. What is the tone of the passage?
    A. Critical
    B. Serious
    C. Sympathetic
    D. Informative
    E. Casual

A → Incorrect. The author does not aim to criticize any particular argument or aspect of spontaneous remission or depression
B → Incorrect. The author does not imply that the need for research into spontaneous remission is urgent or has profound implications
C → Incorrect. The author does not openly show pity, understanding, or support for patients with depression
D → Correct. The author is seeking to inform the reader about spontaneous remission and depression in an objective, nonjudgemental way. The text reads like an academic article
E → Incorrect. The author does not sound relaxed, unconcerned, or nonchalant about the topic

49. In which of the following contexts would you most expect to find this passage?
    A. An informational pamphlet for patients
    B. An academic thesis
    C. A magazine in popular science
    D. A book about the social determinants of depressive disorders
    E. A news release from the World Health Organization

A → Incorrect. The passage contains information and details that a patient would likely not be interested in or understand
B → Correct. The author writes with an informative tone and focuses on an area for further research. In the final paragraph, he/she proposes the closing of this knowledge gap
C → Incorrect. The scope of this passage seems too niche for a popular science magazine. Furthermore, the heavy jargon used suggests that it is written for a professional or academic audience, rather than for the average consumer
D → Incorrect. The passage does discuss the social determinants of health, but this is not its main focus. Its scope does not fall within the context of this book
E → Incorrect. The passage is not written in the clear and concise language found in press releases. Rather, it seems to target an academic audience

50. Which of the following best describes a "dispositional factor"?
    A. The outward appearance of an individual
    B. A quality or characteristic that is associated with an individual's surroundings
    C. The mood or attitude of an individual
    D. A quality or characteristic that is associated with a particular individual
    E. The diet and exercise of an individual

A → Incorrect. The author does not mention the significance of outward appearances anywhere in the passage
B → Incorrect. This describes environmental factors (i.e. work stress, family conditions, homelessness, etc.)
C → Incorrect. This describes "low mastery", which is only one example or aspect of a dispositional trait. Therefore, the description is too narrow in scope. See paragraph four
D → Correct. In paragraph four, the author states that "An example of a dispositional factor is low mastery …". Since low mastery is later described as a state of mind, we can infer that dispositional factors are "internal" traits that are tied to an individual and influence their behaviour/actions
E → Incorrect. This describes lifestyle factors (i.e. smoking, drinking, sleep habits, meditation, etc.)

FULL-LENGTH 4 HIGHER DIFFICULTY

SCORE CONVERSION SCALE

Biology		Chemistry		PAT		RCT	
Percent	DAT Score	Percent	DAT Score	Percent	DAT Score	Percent	DAT Score
1–5%	0	1–5%	0	1–5%	0	1–5%	0
5–10%	1–3	5–10%	1–3	5–10%	1–3	5–10%	1–3
10–15%	3–5	10–15%	3–5	10–15%	3–5	10–15%	3–5
15–20%	5–8	15–20%	5–8	15–20%	5–8	15–20%	5–8
20–25%	8–11	20–25%	8–11	20–25%	8–11	20–25%	8–11
25–30%	12	25–30%	12	25–30%	11–14	25–30%	12
30–35%	14	30–35%	14	30–35%	14–16	30–35%	13
35–40%	16	35–40%	16	35–40%	17	35–40%	14
40–45%	17	40–45%	17	40–45%	18	40–45%	15
45–50%	18	45–50%	18	45–50%	19	45–50%	17
50–55%	19	50–55%	19	50–55%	20	50–55%	18
55–60%	20	55–60%	20	55–60%	21	55–60%	19
60–65%	21	60–65%	21	60–65%	22	60–65%	20
65–70%	22	65–70%	22	65–70%	24	65–70%	21
70–75%	24	70–75%	24	70–75%	25	70–75%	23
75–80%	25	75–80%	25	75–80%	26	75–80%	24
80–85%	27	80–85%	27	80–85%	27	80–85%	26
85–90%	28	85–90%	28	85–90%	29	85–90%	28
90–95%	29	90–95%	29	90–95%	30	90–95%	29
95–100%	30	95–100%	30	95–100%	30	95–100%	30

END OF PREPRINT #4112583

648/773

ISBN-13: 978-1-7771052-0-4

First Edition

26 25 24 23 22 21 20 / 10 9 8 7 6 5 4 3 2 1

London Press