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Poincaré's ''Les conceptions nouvelles de la matière''

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ABSTRACT

We present a translation of Poincaré's hitherto untranslated 1912 essay together with a brief introduction describing the essay's contemporary interest, both for Poincaré scholarship and for the history and philosophy of atomism. In the introduction we distinguish two easily conflated strands in Poincaré's thinking about atomism, one focused on the possibility of deciding the atomic hypothesis, the other focused on the question whether it can ever be determined that the analysis of matter has a finite bound. We show that Poincaré admitted the decisiveness of Perrin's investigations for the existence of atoms; he did not, however, anticipate the kind of resolution of which the second question is susceptible in light of recent developments.

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Editor's introduction

One hundred years ago, the towering figure of Henri Poincaré passed away. Poincaré workshops and conferences are accordingly being held all over the world, and it is only fitting that we at *Studies in History and Philosophy of Modern Physics* also devote attention to Poincaré's path-breaking work in theoretical physics and the philosophy of science. We therefore plan to publish a special Poincaré issue. Given that the majority of the papers in this special issue will originate from meetings taking place in 2012, however, its publication can only take place in 2013. So as a taste of what is in store, and as a timely homage to Poincaré, we are publishing the first English translation of a 1912 essay by Poincaré about atomism.

Introduction to Poincaré's "The new conceptions of matter"

William Demopoulos, Melanie Frappier and Jeffrey Bub

"The new conceptions of matter"[1] was first delivered as a lecture on March 7, 1912[2]. It is interesting for many reasons, most importantly for what it tells us about Poincaré's evolving views on the subject of atomism. Poincaré was a witness to the great discoveries of Perrin and Planck. The essay is particularly instructive in connection with his reaction to the work of Perrin.[3] A casual acquaintance with Poincaré's writings can suggest a recalcitrant and unjustifiable skepticism about the atomic hypothesis. "New conceptions" calls into question any such evaluation by bringing out a subtlety in Poincaré's view. Unfortunately, this subtlety has been missed, even by commentators who are acquainted with the essay. As we approach Poincaré's centenary, it seems only appropriate that there should be an English translation of this hitherto untranslated text together with a brief clarification of its content.

In an essay[4] written before Perrin's investigations into Brownian motion and the nature of "molecular reality" Poincaré distinguished between hypotheses which are "natural and necessary," such as the suppositions "that the influence of very distant bodies is quite negligible, that small movements obey a

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[1] "Les conceptions nouvelles de la matière," *Foi et Vie* **15** (1912): 185–191. Reprinted in Henri Bergson (et al.) *Le Matérialisme Actuel*, (Paris: E. Flammarion Éditeur, 1933): 49–67.

[2] See E. Lebon, *Henri Poincaré. Biographie, Bibliographie Analytique des Écrits* (Paris: Gauthier-Villars, 1912, 2nd ed.), p. 92 for the dating of the lecture (and its initial printed distribution).

[3] The lecture also includes a brief discussion of Planck's contribution to the first Solvay conference which occurred only four months earlier.

[4] "Les relations entre la physique expérimentale et la physique mathématique," *Revue Générale des Sciences Pures et Appliquées* **11** (1900): 1163–1175; reprinted under the English title, "Hypotheses in physics," as Chapter IX of *Science and Hypothesis* and collected in Henri Poincaré, *The Foundations of Science*, George Bruce Halsted translation (Lancaster PA: The Science Press, 1913): 127–139. Quotations are from the essay's authorized English translation and reprinting in *The Foundations of Science*. See page 1166 of the original publication for the corresponding French text.

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linear law, and that [an] effect is a continuous function of its cause," and those that should be qualified as "neutral." He then argued that the atomic hypothesis falls into the second category:

> In most questions the analyst assumes, at the beginning of his calculations, either that matter is continuous, or on the contrary, that it is formed of atoms. He might have made the opposite assumption without changing his results. He would only have had more trouble to obtain them—that is all (p. 135).

Regarding an analyst whose calculations assume the atomic hypothesis, Poincaré continues, "If…experiment confirms [such an analyst's] conclusions, will he suppose that he has proved, for example, the real existence of atoms?" The clear suggestion of "Hypotheses in physics" is that no respectable analyst would make such a supposition because he would recognize that the hypothesis is merely a convenient aid to his calculations.

But in "New conceptions" the atomic hypothesis is decidedly not neutral.[5] Here Poincaré distinguishes two issues that the question of atomism raises. The first is the familiar one which we associate with thermodynamics and the nineteenth century controversy between atomists and energeticists over the status of the kinetic theory and the existence of atoms. Regarding this question, Poincaré remarks that for a long time the atomic hypothesis was at best a convenience because the question of its truth was not susceptible to resolution by our methods of proof and evidence. But more recently advances of importance have occurred that allow us to transcend this situation, and we can now confidently assert that we have abundant proof—in the form of Perrin's results—that the atomic hypothesis is correct. This is emphasized in 'New conceptions" with an appeal to the variety of independent sources of evidence for the hypothesis:

> …more than a dozen entirely independent processes, that I would not be able to enumerate without tiring you, lead us to the same result. If there were more or fewer molecules per gram, the brightness of the blue sky would be entirely different; incandescent bodies would radiate more or radiate less, and so on. There is no denying it, we see atoms.

The point is reiterated—and the general methodological principle on which it is based is formulated—shortly afterwards when, discussing different kinds of confirmation which may attach to a hypothesis, Poincaré considers the case where the novelty of a phenomenon is only apparent because its connection with those for which the hypothesis was originally adduced is so close that any hypothesis which accounts for the one, must necessarily account for the other. He then continues,

> [this] is not so when experience reveals a coincidence which could have been anticipated and could not be due to chance, *and particularly when a numerical coincidence is involved*. Now, coincidences of this type have, in recent times, confirmed the atomistic concepts.[6]

The second issue atomism raises—and the issue Poincaré is particularly concerned to formulate in "New conceptions"—concerns the nature of the analysis of matter. Are there, Poincaré asks, atoms within atoms without end? In other words, allowing that matter is in some sense atomic, does its analysis into constituents have a finite bound or is it capable of indefinite continuation? The answer to this question is left open by investigations like Perrin's. Moreover, vacillation in this case is entirely acceptable, since each swing of the pendulum will typically be associated with a discovery of importance. Thus when Poincaré says[7] that the struggle between atomists and the "…proponents of continuity and the infinite…will last as long as we do science…because it is due to the opposition of two irreconcilable needs of the human mind," he is referring to the struggle between the two approaches to matter's analysis that he has distinguished. He is *not* suggesting that the atomic hypothesis which was successfully addressed by Perrin is intractable to our methods of proof and evidence. For Poincaré the irreconcilable opposition between atomists and the proponents of continuity is entirely compatible with the assessment that Perrin's results regarding the atomic hypothesis are definitive. The issue that remains unresolved—and for Poincaré not resolvable—is the methodological one about the nature of analysis.

We would like to conclude by noting that the thermodynamics of black holes suggests that there is an absolute limit on the information content of a region of space or a quantity of matter or energy. With reference to Poincaré's remark about "atoms within atoms without end," there is an *information-theoretic sense* in which this process has to stop somewhere, because a *complete* description of the piece of matter can be achieved with less than $A/4$ bits of information, where A is the surface area of the piece of matter in Planck units (the Planck length is approximately 10^{-33} cm).[8] There must be a last information-theoretic level which cannot be field-theoretic because that would involve an infinite number of degrees of freedom, and hence, infinitely many bits. Moreover, contrary to what Poincaré would almost certainly have supposed, the argument to such a conclusion is independent of the constitution of the system and does not rest on the rejection of the continuum. This is why an appeal to the physics of black holes in connection with the information-theoretic formulation of the question of atomism can be held to address Poincaré's view without simply begging the question of the continuum versus atomistic conceptions. So in one sense, though perhaps not the sense envisaged by Poincaré, current physics has resolved the issue in favor of the atomist, and in a surprising way. Notice, finally, that not only is the bound on the number of bits required for an informationally complete description of a piece of matter finite, it is also much smaller than one would have expected, depending as it does on the surface area of the boundary of the region the piece of matter occupies, rather than its volume.

[5] This is not to say that it is "necessary," since Poincaré's distinction does not purport to partition the class of all possible hypotheses.

[6] From "The relations between matter and ether" in Henri Poincaré, *Mathematics and Science: Last Essays*, translated by John W. Bolduc (New York: Dover Publications, 1963): 89–101, p. 90, emphasis added. The essay is based on a lecture of April 11, 1912. (The French text reads: "Il n'en est plus de même quand l'expérience nous révèle une coincidence que l'on aurait pu prévoir et qui ne saurait être due au hazard et surtout quand il s'agit d'une coincidence numérique. Or ce sont des coincidences de ce genre qui sont venues dans ces derniers temps confirmer les idées atomistes." See "Les rapports de la matière et

(*footnote continued*)
de l'éther," in Henri Poincaré, *Œuvres*, vol.9 (Paris, Gauthier-Villars, 1954): pp. 669–682, p. 670.)

[7] In the penultimate paragraph of "The new conceptions of matter."

[8] This is the holographic bound for the amount of information in a region of space. The universal entropy bound for the amount of information in a mass m of a certain size is in general tighter than the holographic bound, except when the mass is as dense as a black hole, when the two bounds coincide. See Jacob D. Beckenstein, 'Information in the Holographic Universe,' *Scientific American* **289** (August, 2003): 58–65 for an elementary discussion, and Raphael Bousso, "The holographic principle," *Reviews of Modern Physics* **74** (2002): 825–887 for a review of the relevant literature and a statement of the more general covariant bound.

A translation of Poincaré's "Les conceptions nouvelles de la matière"

Melanie Frappier and Jeffrey Bub

The New Conceptions of Matter

Henri Poincaré

Since this lecture is part of a series on materialism, some of you are perhaps expecting from me an answer to a question society people often ask scientists: "Is Science leading us to materialism?" Well…such a question does not have a satisfactory answer and I admit that I do not quite understand its meaning. I do not really know what the word 'materialist' means; if you are a materialist each time you accord matter a paramount role, it is clear that Science is materialist, since the Natural Sciences, especially physics and chemistry, have matter as their specific subject matter; this is not to say that scientists are all materialists since their science is not their entire life. I understand somewhat better what the word 'determinist' denotes, although when I consider it a little more closely, I am no longer so sure I quite understand it. Oh, in this case, yes, science is deterministic; it is so by definition; a science that is not deterministic would not be a science anymore; a world not ruled by determinism would be closed to scientists; and to ask what the limits of determinism are, is to ask how far the domain of science will be able to spread, or where its uncrossable boundaries are.

If we look at it in this way, every new achievement of science is a victory for determinism: and as the scientists' conquests will never stop, we are tempted to conclude that there will be no place left for free will or, consequently, for the mind. This is a little hasty; as long as science is imperfect, a small place will be preserved for free will and while this place continually shrinks, there will nevertheless be enough of it left for free will to be able to direct everything from there; now, science will always be imperfect, and not just because of our deficient faculties; but by its very definition; to speak of science is to speak of the duality between the mind that knows and the object that is known, and as long as this duality remains, as long as the mind distinguishes itself from its object, it will not know its object perfectly because it will never see anything but its exterior. Therefore, neither the question of materialism, nor that of determinism which I do not separate from it, will be once and for all resolved by science.

Despite these reservations, it is nonetheless the case that, if I dare say so, there are some physical theories that smack particularly of materialism; they are precisely those that are most dear to physicists because they tend to simplify everything, to clarify everything, and to remove as much mystery as possible. These theories are those tied to atomism and mechanism. Since Democritus, atomism has always had proponents, and it is admittedly quite seductive. The mind does not like to pursue analysis indefinitely without any hope of ever reaching an end; it prefers to think that it will one day manage to discover the ultimate elements and will then not have anything further to do but rest. There are however two ways to understand atomism. As the word's etymological meaning requires atoms may be elements in the absolute sense of the word, they may be perfectly indivisible; in this case, upon reaching the atom, we could effectively rest and we would reach complete metaphysical peace of mind. Unfortunately this peace of mind would never last; the fundamental need of our understanding, that of discovering elementary units, would have been satisfied; but we have other needs. It is not sufficient for us to understand, we want to see: it is not sufficient for us to count the atoms, we want to represent them to ourselves, to give them a form, and this is enough to prevent us from viewing them as indivisible, if not by the means at our disposal, at least by more powerful means, which we are able imagine; this is enough to force upon us the question whether or not there are elements of atoms, atoms of atoms so to speak.

The same applies to mechanism: we believe that we understand impacts better than action at a distance, which has something mysterious about it that naturally suggests the idea of an intervention exterior to the world, and this is why I said earlier that mechanism smacks of materialism; but scientists are cut out for removing mysteries, which, of course, they always find a little farther away; but they nonetheless prefer them to be farther off; and this is why almost all scientists, even when their personal philosophical convictions are very far from materialism, have always had a weakness for mechanistic explanations. When we find an action at a distance somewhere, we readily imagine an intervening medium to transmit this action step by step; only this does not get us much further; if this medium is continuous, it gives no satisfaction to our love for simplicity, i.e., to our need to understand; if it is made up of atoms, the latter could not possibly touch; they could be very close to one another, perhaps a billionth of a millimeter; but a billionth of a millimeter is still a distance, the same way a kilometer is; for the philosopher, it is the same thing; the action will have to pass from one atom to the next and it will again become an action at a distance; sooner or later, it will be necessary to imagine, between the atoms of our first medium, a second, more subtle medium intended to act as the vehicle of action.

These reasons explain why *science is condemned to oscillate constantly from mechanism to continuism*,[9] *from mechanism to dynamism* and vice versa, and why *these oscillations will never end*. But that should not prevent us from examining the present state of affairs and from asking ourselves what phase of the oscillation has been reached, even if we are certain that one day we will find ourselves in the opposite phase.

I do not hesitate: at present we are going towards atomism; the mechanism is changing, but also becoming clearer and taking shape, we will soon see to what extent. Thirty years ago, my conclusions would have been completely different; at that time it appeared we had returned from the enthusiasms of the previous period; they even appeared a little naive to us. The reasons that had led us to conclude to the discontinuity of matter retained their value, in the sense that they supplied us with a set of convenient hypotheses to which, however, we no longer attributed any convincing power; we were already trying to do without them; disposed to follow M. Duhem who wanted to establish a thermodynamics free of hypotheses and exclusively based on experience, [a case of] *hypotheses non fingo*; a thermodynamics where there were lots of integrals but no atoms at all. What has happened since then?

The great stronghold of mechanism is the kinetic theory of gases. What is a gas? Some answer: "I have no idea," this is of course the most cautious answer, but it leads nowhere; it safeguards us from error only by leaving us absolutely no chance to discover the truth; not to move on the pretext that we could mistake the road is not the way to achieve one's goal. So those who respond this way are less and less numerous and the others all say the same thing: a gas is an innumerable multitude of molecules that circulate in all directions at high speeds, colliding with the walls and colliding with one another. Like a swarm of gnats locked up in a room and flying aimlessly until they hit the walls, the ceiling, or the windows. In colliding with the walls, these molecules push them, and these walls would give way under this pressure if they were not solidly fixed; if density

[9] Here Poincaré uses the French neologism 'continuisme,' a term apparently built from a Latin root to which a Greek ending is added. By analogy, we have chosen to use, in accordance with some earlier translators, the English neologism, 'continuism.' We also follow G. B. Halsted's convention of indicating in square brackets those places where Poincaré uses 'force vive' for kinetic energy.

increases, so does the number of impacts, because more gnats are colliding with the walls, and so pressure increases: this is Mariotte's law; if the gas heats up, the velocity of the molecules increases and their collisions become more violent and so, unless the walls give way and allow the gas to expand, pressure increases once more: this is Gay-Lussac's law.

In summary, the general properties of gases were explained easily in this way, but there remained in the details many difficulties which stopped some minds; moreover we wanted to see and wondered if the explanation was not a little simplistic. The study of solutions, such as salted water, led to an unexpected parallel: we saw that salt molecules dissolved in water behave in a glass of water like gas molecules in a vessel, that is to say like gnats in a room; some numerical agreements could not be attributed to chance; this was already a confirmation; but we were not yet seeing the salt molecules because, like gas molecules, they were too small.

Some time ago, a naturalist examined organic liquids with a microscope: he saw particles animated with disordered and very rapid motions; what we have called Brownian motion. For him, this was life; but it was not long before it was noticed that inert particles, for example carmine granules, thrash about with no less ardor. The naturalists abandoned the question, thinking that it was a matter for physicists; on their side, the physicists did not deign to look. "These naturalists," they no doubt said, "do not know how to reason; they strongly illuminate their microscope preparation; by illuminating it they heat it and the heat causes irregular currents in the liquid." Finally, M. Gouy decided to look; it was not that at all, it really was a new phenomenon. The visible particles move and at first sight it is possible to believe that they are not responding to any motive force and that this is a perpetual motion; in reality, it is the impacts of the dissolved and invisible molecules that set them in motion. Thus, coming back to our gnats, if we do not have eyes good enough to see them, and if among them there are a few large flies, we will be able to observe the flies' motions and come to a conclusion about the motions of the gnats on the condition that the flies do not deviate from their routes on a whim, but to avoid or follow smaller insects that we cannot see.

This time we could see, and I would like to explain to you how we thus had the means of counting the molecules. Theory teaches us that owing to their incessant collisions, molecules exchange their velocities until an average distribution of these velocities is reached, a distribution which then maintains itself indefinitely, the large molecules moving more slowly than the small ones in such a way that the kinetic energy [force vive] of the large molecules is on average the same as that of the small ones. Our visible particles subject to Brownian motion, our large flies from a moment ago, are in reality very large molecules. We know their velocities because we observe their motions, we know their dimensions because we see them. On the other hand, theory makes known to us the velocities of the small molecules; and, since the kinetic energy [force vive] of the one must be the same as that of the other, a simple rule of three will give us the mass of the small molecules, the molecules properly speaking.

This is not quite the way M. Perrin did it. Let us imagine the terrestrial atmosphere; as we rise in it, air pressure and density decrease; temperature decreases as well; however in the following arguments we will assume that, by some heating process, the atmosphere is maintained at a uniform and constant temperature. You quite understand that with the help of the elementary laws of physics, it is easy to calculate how our atmosphere would behave if its temperature were maintained at a constant level, even if our real atmosphere does not behave quite like this. If our atmosphere, always at the same temperature, were formed of hydrogen, density would decrease less rapidly because hydrogen molecules are smaller than those of oxygen or nitrogen; the dimensions of our atmosphere would be increased by a known amount; they would, by contrast, decrease, if we took bigger molecules; let us therefore take some visible particles, some big flies, Brownian particles suspended in water; we will then have an atmosphere in miniature that we will be able to study; it is truly at a constant temperature, since it is immersed in water; by comparing it to what a hydrogen atmosphere at the same temperature would be like, we will see in what proportion it is scaled-down, that is to say how many times our particles are bigger than hydrogen molecules.

This is how M. Perrin was able to tell us how many atoms there are in a gram of hydrogen; there are a lot less than we might be tempted to believe; there are only 683 thousand billion billion. Nevertheless, let us not yet say: "we see the atoms since we can count them," when we embark upon a calculation we do know in advance that we will find a number, some result; we should not marvel at the fact that we obtain one. This is not yet a proof that atoms exist.

But here is something more serious. We have another means of seeing the atoms, what is called a spinthariscope. Consider this instrument: a few traces of radium and at some distance a bit of phosphorescent substance, for example zinc sulfur; when looking in it, we see a glimmer from time to time, a sort of spark and we can distinguish and count these sparks. Sir W. Crookes said that each spark is a helium molecule that detaches itself from the radium and goes and hits the sulfur; but some remained skeptical; could this not be a property of sulfur when it undergoes a discontinuous variation after a sufficient quantity of energy has slowly accumulated in it when, so to speak, it breaks after having been heated long enough, which would not mean that the sulfur receives all the heat at one stroke?

Nevertheless, let us see: since we have a second means to count molecules, absolutely independent from that of M. Perrin, let us compare them; this time we find 650 thousand billion. This is a surprising agreement, quite unexpected. You can well understand that a few thousand billion billion doesn't make a difference.

This time, there is cause for wonder, especially since more than a dozen entirely independent processes that I would not be able to enumerate without tiring you lead us to the same result. If there were more or fewer molecules per gram, the brightness of the blue sky would be entirely different; incandescent bodies would radiate more or radiate less, and so on. There is no denying it, we see atoms.

Let me pause to make a remark here. Imagine a giant armed with an enormous telescope. He arrives from the depths of the dark abyss of the sky and is heading towards a sort of cloud that shines with a milky glare. It is our Milky Way. We know what it is because we are inside it, we know that it is formed of a billion worlds similar to ours. Our giant, however, is reduced to conjectures; he asks himself, with many supporting arguments, if this cloud is made of continuous matter or if it is formed of atoms. Nevertheless he approaches and one fine day his telescope shows him myriads of luminous dots in this cloud. "Ah! this time, this is it," he says to himself, "here they are, I've caught the atoms." The poor soul does not know that these atoms are suns, that each of them is the center of a system of planets, that on each planet there are millions of beings who constantly discuss whether they are themselves composed of atoms.

Well, this is where we stand; we have just caught a glimpse of the atoms and already the same problem arises for these atoms as for the coarse bodies our senses show us. Is not each of them a world? And of what elements is each of these worlds made? Or rather, we are already more advanced than our giant, we already discern in each atom a rich diversity; we are beginning to see some details there, and every scientist would welcome with a shrug of the shoulders anyone who would want to make them believe that the chemist's atoms, those we have just counted, are mathematical points, indivisible beings as the Greeks would demand.

For a start, we see our former atoms disintegrate before our eyes; radioactive substances, through their very own activity, are constantly transforming themselves: beginning with uranium, we see that it constantly loses helium and it is this continuous emission that gives it its radiant properties; it transforms into radium, which in turn loses some helium and after several steps we would end up with polonium; and without a doubt we would not stop there, and we would ultimately arrive at a simple common body with no radioactivity. But this is still only an ordinary chemical decomposition, differing from those we are accustomed to only by its slowness, the enormous heat it gives off, and the strange phenomena accompanying it, but it can still be expressed, like all chemical reactions, through an equation, since the decomposition products are tangible, known, and cataloged bodies. Certain of the bodies that we believed were simple ones are compounds, that is all; the old atomic doctrine remains intact.

But let us look more closely: we will see the atoms decompose into much smaller pieces, called electrons. You know all the tubes physicists or physicians use to produce X-rays and perform radiography. These are large glass vials where a vacuum has been produced and where electrodes are located, linked to a source of electricity; when the current flows, the glass becomes luminous and shines with a greenish glare; it is because the negative electrode, the cathode, emits a distinctive radiation called cathode rays; it is these rays that render the glass luminous by striking it. When they strike the anticathode, that is to say the electrode opposite the cathode, these rays produce the X-rays which I do not want to deal with for the moment. What then is a cathode ray? It is a stream of extremely small, negatively charged particles that can be collected; these particles are called electrons. By studying the action of magnetism and electricity on these cathode rays, the velocity of these particles—which is enormous—as well as their charge to mass ratio can be measured; we have reason to believe that this charge is the same as that carried by an atom in the decomposition of saline solutions by electric currents; and we must conclude that the mass of an electron is a thousand times smaller than that of a hydrogen atom. We are thus led to represent an atom as a sort of solar system; at the center a relatively large body carrying a positive charge and, orbiting around this central star, some types of much smaller and negatively charged planets, the electrons. The central sun attracts these planets because it is positively charged and positive electricity attracts negative electricity; we thus have the image of Newtonian gravitation governing our solar system. Besides, for us who are seeing the atom from the outside, this atom does not even appear charged, because there is precisely as much positive electricity on the sun as there is negative electricity on the planets.

This new step forward is another victory for atomism. It is not only matter, but electricity that ceases to be infinitely divisible, that reduces to irreducible elements; we have no means to cut an electron in two, to take half of its charge away and transport it elsewhere; the electron is a true atom of electricity.

However, we cannot stop at this stage, where the ultimate elements are small corpuscles possessing a little mass and an invariable electric charge. Some people have had the curiosity to search for the origin of this mass and they have demonstrated that it does not exist, that it is only an appearance, that it is due solely to electromagnetic phenomena caused by the surrounding ether by the displacement of electric charges. I cannot consider the gist of their arguments here, so I retain only the result. If there was an attribute that seemed to belong exclusively to matter, it truly was mass, to the extent that the words "mass" and "matter" seemed almost synonymous. Lavoisier, with scales in hand, demonstrated the indestructibility of matter by demonstrating the invariability of mass.

Well, here is a mass that is only an appearance, that a multitude of circumstances, especially velocity, can change. At a stroke, the active role is taken away from matter, to be transferred to the ether, the true seat of the phenomena attributed to mass. There is no more matter, there are only holes in the ether; however, since these holes cannot move without disturbing the ether that surrounds them, it takes some effort to move them and they appear to be endowed with inertia, while in reality this inertia belongs to the ether.

This reminds us of the ether that we had forgotten. Now, the ether appears to us as a continuous medium; it is possible that it is made up of atoms; but this is only an empty hypothesis; these atoms cannot be seen as we now see those of the chemist—far from it: we can only dream of them; and here continuity is installed, at least provisionally, in the ethereal medium, the only truly active one.

To conclude, I must say a word about the last incident in the struggle between the atomists and the proponents of continuity, and this incident has certainly been the most unexpected and surprising episode of this whole story. M. Planck believes he has reason to conclude that heat exchanges between neighboring bodies, exchanges realized through radiation, can only happen by jumps, by discontinuous degrees. It is what he calls the theory of Quanta. I do not know if you truly realize how strange this hypothesis is, and to help you understand better, I will push it to the extreme consequences to which I believe it must inevitably lead us. The world would no longer vary in a continuous manner as if by imperceptible degrees; it would vary by jumps; these jumps would be very small for the eyes of beings as myopic as man, and thus give us the illusion of continuity; we know that when they see a printed page at a certain distance, myopic people no longer distinguish black and white, but only see a uniformly gray surface. We could no longer say: *Natura non facit saltus*: on the contrary she would do only this. It would not only be matter that would be reduced to atoms, but the history of the world itself; that is to say it would be time itself, for two moments included in the same interval between two jumps would not be discernible anymore, since they would correspond to the same state of the world.

Let us not go so fast; you see only that we are not close to an end in the struggle between the two modes of thought, that of the atomists—who believe in the existence of ultimate elements, the combinations of which would, in a finite but very large number, suffice to explain the various aspects of the universe—and that of the proponents of continuity and the infinite. This struggle will last as long as we do science, as long as humanity will think, because it is due to the opposition of two irreconcilable needs of the human mind, that this mind cannot shed without ceasing to be; that of understanding—and we can only understand the finite—and that of seeing—and we can only see extension which is infinite.

This war will not end with the definitive victory of one of the combatants, which is not to say that it is sterile; at each new battle, the battlefield changes; so each time it is a step forward, a conquest not for one of the two warring parties, but for humanity.

Henri Poincaré
of the Académie française.

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