Reading Howard Stein

Book Review for *Reading Natural Philosophy: Essays in the History and Philosophy of Science and Mathematics*, La Salle, IL: Open Court, 2002. Edited by David Malament. 424 pages, including index and bibliography of Stein's works.

This volume is a fitting tribute to Howard Stein. It includes thirteen original essays of remarkably high quality, most of which were presented at Steinfest, a celebration of Stein's seventieth birthday held at the University of Chicago in 1999. The essays span a range of topics that Stein has written about with characteristic passion and insight, and they illustrate the influence of Stein's body of work, both in terms of their subject matter and their methodology. Like Gaul the volume is divided into three parts: ancient and 17th century science, 19th and 20th century science, and general epistemology and the philosophy of mathematics. Since I have neither the space nor the expertise to comment on all of these essays, this review will focus on the essays devoted to history and philosophy of physics.

Abner Shimony's introduction aptly describes what is so striking about Stein's work. Reading Howard Stein is difficult but rewarding. Difficult because he typically examines a problem from many different angles; Stein's papers usually combine, as Shimony emphasizes, an incredibly careful exegesis of the texts at hand, the judicious use of modern mathematics and physics, and a study of the broader intellectual context (whether in philosophy, mathematics, or the sciences). The ability to draw on such a wide variety of intellectual resources contributes to the richness of Stein's essays. Stein does not simplify or reduce the problems he discusses; instead, his papers give a patient reader a full sense of the texture and subtlety of the problems at hand. Readers with the intellectual agility to follow Stein's lead are rewarded with fresh insights, and in several cases Stein's careful work has overturned the conventional wisdom.

Stein's several papers regarding Newton undermined the mid-20th century received view that Newton's metaphysics and methodology were unoriginal and misguided. The series began with a classic paper (Stein 1967) that treated Newton's famous scholium as an analysis of the spacetime structure implicit in any adequate science of dynamics, and subsequent papers have further clarified Newton's argument for universal gravitation and the relation of his views to those of Descartes, Huygens, Leibniz and Locke. The essays by George Smith and Bill Harper both build on Stein's enlightening reassessment of Newton's philosophy. Like Stein's work, both of these articles draw out a number of insights related to perennial issues in philosophy of science.

Harper responds to Stein's challenge (Stein 1990): is Newton's appeal to the third law of motion in the argument for universal gravitation based upon an illicit hypothesis about the nature of gravitation? Newton's editor Roger Cotes was the first to raise the issue. Cotes accepted Newton's argument that a force directed toward the sun deflects the planets from inertial trajectories, but objected to the further claim that this force is matched by an equal and opposite force acting on the sun. As Cotes put it (pp. 76-77), the third law justifies the claim that there is such a force, but this force could be a pressure on an "invisible hand" (or aetherial fluid) holding the planet in orbit. Is Newton guilty of feigning hypotheses? Harper clarifies the limitations Newton faced in deducing gravitation from orbital phenomena; in particular, for bodies interacting purely gravitationally the product GM (where G is the gravitational constant and M is the mass of the attracting body) can be measured, but not G and M separately. The orbital phenomena are compatible with a theory in which the third law fails and the celestial bodies have acceleration fields with different values of G. This alternative theory would fall short of universal gravitation with respect to Newton's "ideal of empirical success." Harper glosses this as a robustness requirement, roughly that parameters appearing in theoretical descriptions (such as the masses of the planets) can be measured in a variety of ways and that these measurements converge on stable values. This is an interesting proposal that deserves careful scrutiny, although it is not clear how Harper would defend the Newtonian ideal against, for example, a constructive empiricist.

George Smith's essay begins with a deceptively straightforward question: why didn't Newton infer the inverse square dependence of the gravitational force directly from the elliptical orbits of the planets? Contrary to the textbook tradition, Newton's argument for universal gravitation relies on Kepler's second and third laws rather than the first law. Smith convincingly argues against various explanations of Newton's approach, such as respect for the state of contemporary astronomical observations; in fact, the harmonic law was *more* controversial than elliptical orbits. Smith's subtle answer highlights an unappreciated aspect of Newton's methodology: his sensitivity to inferences that are valid even if the antecedent conditions hold only approximately. The inference from elliptical orbits and the area law to an inverse square force does *not* hold if there is uncertainty regarding the force center. Newton derives two distinct force laws for an object moving along an elliptical orbit: for a force directed at a *focus*, $f \propto r^{-2}$, and at the *center*, $f \propto r$. For an ellipse with eccentricity very close to 1 (such as the planetary orbits), the foci nearly overlap with the center. The inference from an elliptical orbit to an inverse square force clearly does not hold "approximately." As Smith shows, the same problem does not arise for Newton's actual argument using the harmonic law and the precession theorem. Smith builds on this assessment of *quam proxime* reasoning with an insightful discussion of idealizations and evidence. Newton recognized that the planetary orbits could not be described by a simple closed curve, since perturbing forces lead to much more complex motions. Treating these dauntingly complex motions via a series of successively more sophisticated approximations was a crucial aspect of Newton's methodology. Smith emphasizes the importance of seeking systematic discrepancies at each stage of approximation as an evidential strategy; continuing success in handling discrepancies without fundamentally altering the theory indicates that one has not gone down an unproductive garden path, to use Smith's phrase. Smith reads Newton's bold inductive generalizations in Book III as an attempt to turn up possible discrepancies indicative of an overall failure of the framework. Although the focus is primarily on Newton, Smith's essay introduces a number of promising ideas for a more general treatment of methodology and idealizations that philosophers of science would do well to consider.

Stein's positive reassessment of Newton was coupled with a forceful criticism of Mach and his "abusive empiricism" (Stein 1977). Unlike Reichenbach and Einstein, Stein found in Mach a confused jumble rather than a clear diagnosis of an epistemological defect in Newtonian mechanics. di Salle argues that some of the apparent confusion is an artifact of revisions to *Die Mechanik*. On di Salle's reading, in the first edition Mach preferred an understanding of inertia closely tied to the actual practice of constructing an inertial frame using the fixed stars, shying away from an abstract formulation of Newton's laws and the assessment of counterfactuals involving, for example, rotating globes in an otherwise empty universe. In later editions Mach more carefully distinguished skepticism regarding the validity of Newton's laws from questions about their meaning, and, ironically, he arrived at an understanding of inertia and relativity that was quite sympathetic to Newton. Mach's contribution is then a modest part of the late 19^{th} century clarification of the concept of an inertial frame. di Salle goes on to trenchantly criticize many arguments offered by latter day Machians. For example, di Salle questions Einstein's "Machian" argument that Newtonian mechanics introduces a "factitious cause" – absolute space – to explain the bulge of a rotating sphere. Rather than treating this as an unsatisfying causal account, where the cause is an unobservable entity that acts but is not acted upon, di Salle follows Stein in reading Newton as introducing a satisfactory *definition* of rotation. di Salle acknowledges the important heuristic role of Machian ideas, but chides contemporary Machians for expressing philosophical prejudices for or against particular theories rather than offering compelling arguments. In the process of prying Mach away from his epigones and reassessing his real contribution, di Salle offers a number of fresh insights into the development of different conceptions of the geometrical structure of spacetime.

Einstein considered the status of geometry at length in his famous lecture "Geometry and Experience," the focus of Friedman's essay. The lecture is vintage Einstein: eminently quotable, and presented with a clarity that reflects Einstein's good judgment in drawing ideas from different lines of thought, despite underlying tensions among them. In his rich and detailed essay, Friedman argues that Einstein's approach to debates about geometry, while certainly fruitful, ends up obscuring the novel status of geometry in general relativity. To draw out one theme, Friedman advocates kicking away the ladder provided by "rigid bodies." Einstein's appeal to rigid bodies was part of a delicate response to Poincaré and Helmholtz, and neither of their approaches was perfectly apt for the new conception of geometry in general relativity. Einstein agreed with Poincaré that measuring rods and clocks could not be introduced as primitive elements of a theory, yet following Helmholtz's idea of using rigid bodies to probe the geometry of space led to the introduction of non-Euclidean geometry. According to Friedman, Einstein disagreed with Poincaré regarding the significance of results regarding rigid bodies for different "levels" in the hierarchy of the sciences. Poincaré placed geometry at the same level as the general laws of mechanics, above any detailed physical account of the rigid bodies, and prefered to modify the lower-level dynamics of the rigid bodies rather than introducing non-Euclidean geometry. Einstein, by way of contrast, took Lorentz contraction in special relativity and the rotating disk in general relativity to have direct geometrical consequences, completely sidestepping a detailed structural account of rods and clocks. Einstein later had qualms about this, which Friedman regards as misplaced – he argues that the empirical content of the geometrical structure of spacetime is fully captured by two coordinating principles, namely that light rays trace out the null cone structure and freely falling particles move along geodesics. Friedman concludes that Poincaré's conventionalism does not carry over to general relativity.

Friedman and Di Salle both mention the importance of the problem of rotation in Einstein's discovery of general relativity. Malament's contribution, on the other hand, clarifies the difficulty in giving a criterion of rotation applicable in the dynamical spacetimes allowed in that theory. Like energy, angular momentum and its associated conservation law share the familiar properties of the Newtonian analog in some highly symmetric spacetimes or in regions "far away" from an isolated mass. Malament's discussion illustrates the surprising difficulty in extending a local definition of angular momentum to extended objects. In general relativity there is a natural definition of "non-rotation" applicable to an infinitesimal ring – the spatial vectors fixed to the ring are Fermi transported along the ring's worldline. But this infinitesimal notion cannot be consistently extended to a criterion of non-rotation for finite objects that applies in all spacetimes. As Malament proves, any criterion that coincides with the infinitesimal notion in the limit runs afoul of a natural adequacy condition, namely that a ring whose points are at fixed distances from a non-rotating ring is also non-rotating. Roughly put, the essential technical result is that in Kerr or Gödel spacetime, for example, rings at different locations that satisfy the infinitesimal non-rotating criterion "in the limit" rotate relative to each other. Malament brings out this counterintuitive feature of general relativity with his characteristic care and rigor. He carefully distinguishes this problem from the traditional debates regarding "absolute" vs. "relative" rotation, but a point from an earlier paper of his is worth repeating here. Two spacetimes with the same causal structure will agree in their determinations of whether or not a given body is rotating; this undercuts Reichenbach's combination of a causal theory of space-time structure with conventionalism regarding rotation.

The hole argument has been a fixture of the philosophy of space and time literature for the past two decades. Stachel's essay extends the argument to cover any theory in which the basic entities are individuated only in terms of the relations in which they are embedded. The original hole argument brings out the problems that arise if one takes spacetime points to be individuated independently of the spacetime metric. Can the physical state of a solution be fully specified by fixing the solution outside of a hole H, a vacuum region? If one takes spacetime points to be independently individuated, then the answer is no; the field equations are compatible with a class of solutions that agree outside the hole but disagree within it. (More precisely, the solutions are related by a diffeomorphism ϕ that reduces to the identity on $M - H$ but not on H, and in general for $p \in H$, $g_{ab}(p) \neq \phi * g_{ab}(p)$.) The standard response is to wash away the identity of spacetime points and treat the equivalence class of solutions related by diffeomorphisms as representing a single physical solution. In version 2.0 of the hole argument, Stachel replaces the differentiable manifolds, diffeomorphisms, and solutions of general relativity with sets, permutations, and "relational structures" $R, R', R'', ...$, respectively. For a permutable theory the space of solutions is closed under permutations. The corresponding question is whether one can fully fix R by stating how elements of the set "fill" some subset of its "slots". If, like spacetime points, the elements of the set are *not* independently individuated, then one does not need to specify how the elements fill the relational structures to identify the solution. On the other hand, if the elements of the set are defined independently of the ensemble of relations then one can distinguish between cases where the elements fill different slots. Stachel's detailed discussion of this alternative hole argument closes with brief provocative remarks regarding structuralism; if the basic entities of our fundamental theories have their identity conferred only by their place in relation structures, as Stachel suggest they should, then individuality is "an emergent property."

From the comments above it should be clear that these essays are all excellent contributions to central issues in the philosophy of physics. The other papers in the volume meet the same high standard. Nersessian's study emphasizes the central role of the "method of physical analogy" in Maxwell's discovery of the electromagnetic field equations and draws on cognitive science literature regarding the use of mental models. Tait argues that Plato's famous discussion of the divided line should be read as an argument in favor of the deductive method in the exact sciences. Palter's odd essay tracing the impact of Newton's apple and other philosophical fruits on poets' imaginations is like an apple among oranges. A pair of papers from Shimony and Levi provide brief discussions of epistemological naturalism and confirmation theory. The volume concludes with two papers devoted to philosophy of mathematics. Hellman assesses a recent categoricity theorem due to McGee as a way of resolving Zermelo's dilemma, roughly how to balance determinateness vs. open-endedness in set theory, before suggesting an alternative modal-structural approach. Sieg's paper gives a detailed assessment of the foundational disputes of the 1920s, emphasizing aspects of Hilbert's programmatic vision that have continued to exert an influence.

To sum up, these papers break new ground in areas of history and philosophy of science and mathematics that have been benefitted from Stein's insightful contributions. Hopefully Shimony is correct that this volume will introduce more historians and philosophers of science to the rewards of reading Howard Stein. In any case, I am sure that I am not the only reader who eagerly awaits the publication of Stein's collected papers, to which this volume is a fitting companion.

References

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