Integrating History of Philosophy with History of Science after Kant

Michael Friedman

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I shall begin by saying a few words, as background, about my own approach to integrating history of philosophy with history of science in my research. The idea that the history of early modern philosophy should give a central place to the contemporary context provided by early modern science has now become widespread and well established, thanks to the work of Margaret Wilson, Daniel Garber, and others.[1] My own work in the history of modern philosophy concerns primarily Kant, and here, unfortunately, the idea that the contemporary (18th-century) scientific context is centrally important to Kant's philosophy in general is not yet so widely accepted. Building on the work of Gerd Buchdahl and others,[2] I have tried to give this scientific context a central place in Kant-interpretation as well. I have focused, in particular, on Kant's philosophy of mathematics and mathematical physics—wherein the primary paradigm in mathematics was of course Euclid's Elements and the primary paradigm in mathematical physics was of course Newton's *Principia.* In connection with the latter, more specifically, I have tried to show how Newton's argument for universal gravitation in book III of the *Principia* provides Kant with his model for how laws of nature—and therefore causal connections—are grounded in and made possible by the necessary principles of the human understanding. And this same procedure provides Kant with a model, as well, for how the objectivity of scientific knowledge is grounded in universally intersubjective principles common to all rational human beings. The universality and necessity of this conception are then threatened by later developments within the sciences—principally, the development of non-Euclidean geometries and non-Newtonian foundations for physics—and these developments have their origins in the early years of the 19th century. Indeed, it is possible to show that Kant's own struggles with late-18th-century scientific innovations—primarily Lavoisier's new chemistry—already led him, in the so-called *Opus postumum*, to undertake a profound reconsideration of the basic principles of his critical philosophy.[3]

The second main focus of my historical research is on the development of logical empiricism in the early years of the 20th century. Here, once again, the contemporary scientific context is of central importance—especially the development of Einstein's theories of relativity and parallel developments in the foundations of modern mathematics and modern logic. It was precisely these developments, of course, that seemed to cause the biggest problems for Kant's original conception of scientific knowledge, and it was precisely this situation, in particular, that provided the logical empiricists with their most important philosophical motivation. Indeed, it is not too much to say that logical empiricist philosophers such as Moritz Schlick, Rudolf Carnap, and Hans Reichenbach took as their primary philosophical mission to do for modern mathematics and modern physics what Kant had done for the mathematics and physics bequeathed to the 18th century by the work of Newton. In this way, they hoped, one could fashion a parallel revolution in "scientific philosophy" appropriate to the revolution in the foundations of mathematics and mathematical physics associated with Einstein's work—wherein the relevant developments in mathematics especially involved revolutionary changes in the foundations of geometry due to the articulation and development of non-Euclidean systems throughout the 19th century.[4]

The logical empiricists, not surprisingly, took substantial philosophical inspiration from these 19th-century developments. Indeed, they explicitly appealed to earlier work in "scientific philosophy" by such 19th-century thinkers as Hermann von Helmholtz, Ernst Mach, and Henri Poincaré—where these thinkers, of course, were primarily professional scientists rather than professional philosophers. Indeed, in the cases of Helmholtz and Poincaré, in particular, the work we now take as important contributions to scientific epistemology was intimately connected with their own more properly scientific contributions concerning the foundations of the new non-Euclidean geometries. This work had already led them to attempt to modify Kant's original conception of the necessary character of specifically Euclidean geometry as grounded in the fundamental form of our human sensibility (our perception of space), so as to provide a more general conception adequate to the new non-Euclidean geometries to which they themselves were then making important mathematical contributions. This led, both for the 19th-century thinkers in question and for the logical empiricist philosophers who were inspired by them, to a new view of scientific epistemology capable of competing with, and eventually replacing, the Kantian system. The fact that Einstein himself, in developing his theories of relativity, also took inspiration from the thought of precisely these 19th-century thinkers, provided further confirmation for this new philosophical ambition.[5]

A third focus of my historical research, accordingly, concerns the developments in 19th-century "scientific philosophy" that formed the bridge, as it were, between Kant's original philosophical synthesis in the late 18th century and the philosophical revolution wrought by logical empiricism at the beginning of the 20th. What we see here, I want to suggest, is really a continuously evolving sequence of interactions between successively revolutionary philosophical innovations and a parallel set of revolutionary developments within the sciences. The 19th-century scientific innovations in question include the developments in the foundations of geometry indicated earlier, but they also include a complex web of related developments in such sciences as chemistry, the theory of heat, thermodynamics, electricity and magnetism, and psychophysics—together with evolutionary and developmental biology. Indeed, in some of my most recent work, I have attempted to articulate the very beginnings of these post-Kantian scientific and philosophical developments in the first modifications of Kant's so-called dynamical theory of matter by Friedrich Schelling—which were undertaken in the course of Schelling's deep immersion in the new discoveries in electro-chemistry at the turn of the century. These discoveries led Schelling to introduce an essentially developmental and dialectical dimension into Kant's original theory of matter, and this essential feature of Schelling's *Naturphilosophie* proved decisive in both the further development of German philosophy within the tradition of post-

Kantian idealism and the further development of German science in such areas as chemistry, electricity and magnetism, and evolutionary and developmental biology.[6]

My picture of how the history of philosophy and the history of science relate to one another, therefore, is one of thoroughgoing developmental interaction. It is not just that contemporary science, in any given period, provides an important part of the background to whatever is happening within philosophy during that same period. It is, rather, that both the scientific context and the philosophical context are continuously evolving, and a continual interaction between the two is a primary stimulus for both developmental processes. Kant's original synthesis is a reflection of 18th-century Newtonianism, of course, but Kant also attempts to adapt his ongoing philosophical thinking to post-Newtonian scientific developments. Moreover, certain post-Newtonian developments, like those in the foundations of geometry or electricity and magnetism, for example, explicitly take their starting points from Kant's original conception, while simultaneously attempting to transform this conception in a way Kant himself never envisioned.[7] These developments then led 19th-century scientific thinkers like Helmholtz, Mach, and Poincaré—with one foot in science and one in philosophy—to undertake parallel reconceptualizations in both fields. Their work, in turn, influenced both Einstein and the philosophy of logical empiricism; Einstein and the logical empiricists interacted with one another against this common background; and so on.

One final point before I turn to teaching: This interaction between the history of philosophy and the history of science is important, in my view, not only for properly historical research into the evolution of philosophy as a discipline (and, by implication, into the evolution of the sciences as well); it is also centrally important for contemporary work in the philosophy of science. For one of the central intellectual developments framing contemporary philosophy of science is of course Thomas Kuhn's theory of scientific revolutions, and this theory, as is well known, gives overriding importance to the history of science in fashioning an adequate philosophical understanding of the nature of science. Moreover, some of Kuhn's main examples of revolutionary scientific change are drawn from precisely the developments sketched earlier: Einstein's theory of relativity, Lavoisier's chemical revolution, the articulation of thermodynamics in the context of the discovery of the conservation of energy, and so on. But Kuhn, in my view, gives insufficient attention to the contemporaneous philosophical developments associated with these revolutionary changes, and he is thereby led to both an inadequate understanding of the true philosophical sources of the challenges to scientific objectivity that have resulted from his historiographical work and a fundamental inability to adequately respond to these challenges. The true philosophical sources, in my view, derive from the way in which Kant's original conception of the necessary intersubjectivity of scientific reason has been successively challenged by subsequent developments within both philosophy and the sciences. And an adequate response to these developments involves both a full appreciation of the "relativized a priori" exhibited by successively articulated mathematical-physical conceptual frameworks (or Kuhnian "paradigms") and an understanding of how such successively articulated conceptual frameworks are nevertheless continuously—and rationally—connected with one another through precisely the *interaction* between philosophy and the sciences I am emphasizing here.[8]

With this general viewpoint on the relationship between the history of philosophy and the history of science as background, I shall now describe two of the courses I have been teaching recently: a course on Kant's theoretical philosophy and a course on the development of the philosophy of science "from Kant to Carnap." The first is primarily a graduate course; the second is for both graduate and undergraduate students. Since philosophy after Kant is our primary focus here, I shall give only a brief description of the first course and devote more space, accordingly, to the second. The first course does contain some of the essential background for the second, however.

In teaching Kant's theoretical philosophy, I give special emphasis, of course, to his philosophy of mathematics and physical science. In connection with the latter, in particular, I discuss in some detail a relatively less well-known work of Kant's—his *Metaphysical Foundations of Natural Science*—which appeared in 1786, between the first (1781) and second (1787) editions of the *Critique of Pure Reason* (the *Prolegomena* appeared in 1783).[9] It is in this work that the dynamical theory of matter mentioned earlier is developed, where this theory portrays matter as constituted out of the two "fundamental forces" of attraction and repulsion rather than as a primitively hard and absolutely impenetrable solid. Thus, the fundamental force of repulsion is responsible for relative solidity or resistance to compression, whereas the fundamental force of attraction is responsible for universal gravitation. On my reading, moreover, the fundamental force of attraction, in the guise of Newtonian universal gravitation, involves Kant in a profound reconceptualization of Newtonian absolute space and time. Kant understands them, specifically, not as great empty "containers" existing prior to matter and motion but, rather, as concepts we successively construct as we apply the Newtonian laws of motion to the observed "phenomena" or planetary motions with which Newton himself begins the argument of book III of the *Principia*. We thereby obtain both the law of universal gravitation (as noted earlier) and a privileged frame of reference—determined by the center of mass of the solar system—for defining the "true" or "absolute" motions in this system. And, in this way, Kant's critical dynamical theory of matter essentially involves Kant's more global views on the nature of space and time, as well as his more local views on the structure of material substance and its causal interactions.

In the first part of the course, therefore, we discuss the *Metaphysical Foundations* in the context of both Kant's more general critical philosophy expounded in the *Critique of Pure Reason* and the *Prolegomena* and in the context of contemporary scientific works—principally, Newton's *Principia*, but also the *Opticks*, parts of the *Leibniz-Clarke Correspondence*, and some of the works of Euler, Lambert, and others. We also pay attention to some of Kant's earlier precritical scientific works, such as the *Physical Monadology* (1756) and *Theory of the Heavens* (1755). In the second part of the course, we then read the main theoretical argument of the *Critique of Pure Reason*, as expounded in the transcendental analytic—including the metaphysical and transcendental deductions of the categories—and the chapter on the corresponding principles of pure understanding. The main strategy of this approach is to read the transcendental analytic backward: starting with the picture of material or physical nature presented in the *Metaphysical Foundations*, we view the discussion in the analytic in terms of successively more abstract conceptions of nature read from the end of the analytic to the beginning—from the more concrete picture of nature in general presented in the principles of pure understanding to the highly abstract discussion of the pure concepts of the understanding found in the metaphysical and transcendental deductions. The leading idea is to view the procedure by which Newton derives both the law of universal gravitation and a privileged frame of reference or absolute space for describing the true motions in the solar system as a model for Kant's more general conception, central to the analytic, of how phenomena or perceptions are successively transformed into what he calls objective experience.

The hope is that this way of presenting the main argument of the *Critique of Pure Reason* helps clarify and make more concrete the excessively abstract and abstruse argumentation of the earlier parts of the analytic by reference to a much more specific realization or application of this argumentation provided by the scientific context Kant has prominently in mind. We are also able to shed light, I believe, on Kant's specific place as a philosopher of modern science against the background of such early modern thinkers as Descartes, Locke, Leibniz, and Hume: Kant's specific contribution is fully to assimilate the depth of Newton's mathematical and physical innovations against the background of a broadly Leibnizean approach to fundamental metaphysical concepts or categories such as substance, causality, and interaction.

The guiding idea of the second course, on the development of the philosophy of science from Kant to Carnap, is to introduce students to 20th-century philosophy of science by looking in detail at its historical background. I take the development of logical empiricism in the early years of the century (that is, before the migration to the United States occasioned by the Nazi seizure of power and World War II) to be the pivotal event in the development of 20th-century philosophy of science. My primary goal, accordingly, is to depict the Vienna Circle period—primarily, the 1920s—as the high point of logical empiricism and to examine the 19th-century background to the formation of the Vienna Circle from this point of view. In this way, in particular, we are able to transcend conventional stereotypical characterizations of logical empiricism by concentrating on its actual historical context and background. The phrase *from Kant to Carnap* is taken from a now classic treatment by Alberto Coffa that functions as one of the main recommended secondary sources for the course.[10] My own aim is to cover roughly the same body of material as does Coffa, although from a rather different (and more Kantian) point of view. The full syllabus for the course, which goes under the more prosaic title of The Development of Modern Philosophy of Science, is reproduced in the Appendix.

The main primary sources for the course are drawn from five key figures in the development of scientific philosophy: Hermann von Helmholtz, Ernst Mach, Henri Poincaré, Moritz Schlick (founder of the Vienna Circle and first "professional philosopher of science"), and Rudolf Carnap. The culmination of the course is a reading of Carnap's *Der logische Aufbau der Welt*, one of the twin testaments, along with Wittgenstein's *Tractatus Logico-Philosophicus*, of the philosophy of the Vienna Circle. The aim, throughout, is to depict a continuous series of transformations of the philosophical perspective on fundamentally Newtonian science originally articulated by Kant—stimulated by, and interacting with, 19th-century scientific developments such as the discovery of non-Euclidean geometries; innovations in the sciences of heat, light, and matter; and (with reference to Schlick and Carnap) Einstein's theories of relativity and related developments in modern mathematics and mathematical logic. We begin with a couple of weeks on Kant, Newton, and some main post-Newtonian scientific developments from the early years of the 19th century. This background is provided by secondary literature and lectures rather than primary sources. We then proceed to a more detailed and more focused reading of our five primary scientific philosophers.

In discussing Helmholtz, we focus on his early work on the conservation of energy, his work on the foundations and philosophy of non-Euclidean geometries, and his work in the psychophysiology of perception. The last topic includes his main contribution to scientific epistemology, "The Facts of Perception," which concludes our treatment of Helmholtz. Our aim is to exhibit the complex interactions among all of these different facets of Helmholtz's thought and to show how they all contributed, in particular, to his reformulation of some basic Kantian themes. Thus, his early work on the conservation of energy was associated with a kind of atomism of point centers of force, which Helmholtz himself explicitly linked to Kant's dynamical theory of matter in the *Metaphysical Foundations* and Kant's more general views on the principle of causality. In his later work, connected more explicitly with psychophysiology, Helmholtz gradually transformed this initial point of view so that the principle of causality, in particular, had more to do with lawlike relations among phenomena than with an underlying atomism of substantial causes. Moreover, this work in psychophysiology prominently concerned space perception, which led him, in turn, to an interest in the new foundations for non-Euclidean geometries recently provided by Bernhard Riemann in the context (for Helmholtz) of a reconsideration of Kant's basic doctrine that space is a "necessary form of our (outer) sensible intuition." In "The Facts of Perception" Helmholtz then puts these pieces together in his celebrated sign theory of perception—according to which both external physical bodies in space, and this (three-dimensional) space itself, are generated or constructed from lawlike relations among our sensations.

When we turn to Mach, our main emphasis is on his *Analysis of Sensations*, which, as in the case of Helmholtz, presents a new scientific epistemology in intimate connection with recent work in the psychophysiology of perception. We also discuss, in this context, Mach's opposition to mechanism and atomism in the philosophy of physical science and his historicocritical expository method for demystifying such physical concepts. The basic line of thought we pursue is that Mach's fundamental concern is with what he calls the unity of science rather than the philosophical-epistemological obsessions (with skepticism, certainty, etc.) stereotypically associated with the empiricist tradition. In particular, Mach wants a point of view suitable for a unified presentation of both the physical and the life sciences (including psychology), and he finds this point of view in a neutral monism of sensations or elements rather than in mechanistic atomism. Moreover, Mach's perspective on the psychophysiology of perception, under the explicit influence of Ewald Hering, has a decidedly evolutionary dimension missing from the work of Helmholtz: whereas, according to Helmholtz's sign theory of perception, the acquisition of our representations of space and of the external world is an *individual* adaptation made in response to the lawlike patterns in the sensations of a single organism, Mach and Hering view it as an evolutionary adaptation extending over many generations that then becomes wired in to individual organisms.[11] This gives Mach's scientific epistemology a parallel evolutionary dimension in the guise of his notorious principle of economy. We conclude by looking at the famous exchange between Mach and Planck at the beginning of the 20th century from this point of view.

Our treatment of Poincaré emphasizes his celebrated geometrical conventionalism, of course, and also his closely related work on electrodynamics and the foundations of what we now call the special theory of relativity. Our primary reading is *Science and Hypothesis*, and we pay special attention to the sequence or hierarchy of sciences he presents there: arithmetic, the theory of continuous magnitude, geometry, mechanics, and properly physical theories of force (such as gravity and electromagnetism). We use Poincaré's work in the foundations of arithmetic and geometry to introduce the characteristically modern conception of mathematics as dealing with what we would now call abstract structures (the number series, groups of transformations, and so on). (This conception is entirely missing from Mach, for example, who has a much more empirical conception of mathematics essentially tied to calculation and measurement.) We then look at Poincaré's geometrical conventionalism against the background of Helmholtz's earlier work on what we now call the Helmholtz-Lie theorem characterizing the geometry of space in terms of groups of transformations or bodily motions subject to a condition of free mobility. In particular, whereas Poincaré follows Helmholtz's basic ideas about how the representation of space is acquired (with a bit of an evolutionary twist derived from later work in the tradition of Hering and Mach), he takes the Helmholtz-Lie theorem, in this context, to indicate a fundamental freedom left over in the choice between Euclidean and non-Euclidean representations of the same empirical facts. We conclude by embedding Poincaré's work on special relativity within this same point of view, and we attempt to depict the differences between Poincaré and Einstein against this general background.

The discussion of Schlick, the first 20th-century *philosopher* of science, concentrates on his first major work, *General Theory of Knowledge,* published in 1918—and thus before he moved to Vienna in 1922 and founded the Vienna Circle. Here Schlick is deeply influenced by the three 19th-century thinkers we have been discussing so far, although he is here more negative toward Mach's subjectivism or sensationism than he is during the period of the Vienna Circle. But Schlick is also working against the background of two decisive new influences: David Hilbert's axiomatization of (Euclidean) geometry first published in 1899 and Einstein's creation of the general theory of relativity in 1915–16.[12] Hilbert's axiomatization solidified the modern conception of geometry as dealing with an abstract formal structure having no intrinsic connection with space perception or any other intuitive experiences. (This contrasts sharply with the view of Poincaré, for example, who still worked in the earlier group-theoretical conception due to Felix Klein, on which geometry retains an essential link with spatial intuition.) Moreover, Einstein's creation of the general theory of relativity contributed important confirmation of this idea—since it uses a geometry of variable curvature to represent gravitational phenomena and thus breaks away from the framework of the classical non-Euclidean geometries of constant curvature that formed the background for Helmholtz's and Poincaré's work. The space(-time) of Einstein's general theory, therefore, is an entirely abstract and nonintuitive representation in the same spirit as Hilbert's conception of the axiomatic foundations of (Euclidean) geometry. Schlick then generalizes this conception of axiomatic or implicit definitions to embrace all of the concepts of mathematical-physical science, which are now viewed in terms of purely formal systems of logical relationships as described in one or another Hilbert-style axiomatic system.

Our final work, Carnap's *Aufbau*, represents the high point of Vienna Circle logical empiricism, and it is viewed as taking its starting point from Schlick's conception of purely formal implicit definitions presented in *General Theory of Knowledge*. However, whereas Schlick himself has a fundamental problem in explaining how purely formal axiomatic systems can apply to or designate empirical physical reality, Carnap obviates this entire problematic by beginning his logical constitution of the world from a Machian subjective starting point in the elementary experiences of a single (representative) cognitive subject. Carnap employs "purely structural definite descriptions," using the language and logical resources of Whitehead's and Russell's *Principia Mathematica* (1910–13), to constitute or construct all of the concepts of empirical science step by step: first, the autopsychological realm of the full subjective experiential world (as described, ideally, by Gestalt psychology); then the physical realm of the external world (as given to commonsense perception and as described by modern abstract mathematical physics); and, finally, the heteropsychological realm of the totality of cognitive subjects (including the "cultural sciences" of sociology, history, political theory, and so on). Carnap thereby hopes to embrace *all* of empirical science while simultaneously doing justice to Schlick's emphasis on the importance of purely formal logical structure and the complementary emphasis of Machian positivism on the necessary subjective starting point of all human knowledge, no matter how refined. Here, at last, we have the characteristic conception of logical empiricism, according to which modern science is represented, at its best, as a combination or synthesis of a priori rational form (now captured entirely within the new mathematical logic) with uncontroversially empirical content. Indeed, in the preface to the second (1961) edition of the *Aufbau*, Carnap himself explains this view, clearly echoing Kant, as a synthesis of rationalism and empiricism. It is also clear in the context of the historical developments we have been studying that Carnap conceives this new synthesis of rationalism and empiricism as the final replacement for Kant's original conception of scientific objectivity based on the *synthetic* (and therefore nonlogical) a priori.

As the conclusion of the course, we look at one of Carnap's applications of the new type of philosophy he dubs "constitutional theory" to a central traditional problem of philosophy at the time Carnap calls "the problem of reality." This involves a debate between realism, idealism (both transcendental and subjective), and what was then termed phenomenalism—that is, Kant's version of transcendental idealism retaining unknowable things-in-themselves behind the phenomena. Carnap's aims are twofold. In the first place, he distinguishes constitutional and metaphysical versions of the problem of reality, where the first rises within rational science as the question of which entities, according to this science, actually exist, and the second arises outside rational science as the question of which entities, already recognized by this science, are "really real" in some extrascientific or distinctively philosophical sense. So here the materialist, for example, contends that only physical objects are real, whereas the subjective idealist contends that only psychic objects are real. Both are wrong from the point of view of constitutional theory, because both types of objects in fact occur in the constitutional system. Moreover, it is perfectly possible to take psychological (or even autopsychological) objects as basic and define everything else (including physical objects) from them, and it is equally possible to take physical objects as basic and define everything else (including psychological objects) from them. Indeed, according to Carnap, this extra, metaphysical problem of reality cannot be rationally stated or answered at all, because the metaphysical concept of reality cannot itself be constituted or defined in any legitimate constitutional system.

In the second place, however, Carnap is also concerned to show that the traditional debate between the various epistemological schools can be dissolved by showing that they all agree in the domain of constitutional theory: for example, there is no issue from the point of view of constitutional theory between realism and subjective idealism. Indeed, each of the traditional schools has a perfectly legitimate part of the truth, and they disagree, as Carnap puts it, only by transgressing their proper boundaries—by going beyond the properly epistemological question of how cognition in fact proceeds to irresoluble metaphysical questions about which objects of cognition are "really real." Constitutional theory, as Carnap puts it, represents the "neutral foundation [*neutrale Fundament*]" which all of the traditional schools share in common. We therefore see, finally, that Carnap's antimetaphysical stance is not fueled primarily by a commitment to verificationism or radical empiricism—although what is correct in positivism or radical empiricism is in fact represented in the constitutional system. It is fueled, rather, by an overarching commitment to place the discipline of philosophy itself on a scientific or metaphysically neutral path, on which, at the same time, the traditional problems of philosophy are not so much militantly rejected as radically reconceived in a true scientific spirit.

And the model for this new spirit is precisely the distinctively logically structural conception of the objectivity of scientific knowledge that gradually evolved, throughout the 19th and early 20th centuries, against the background of Kant's original conception.[13]

Appendix: The Development of Modern Philosophy of Science

This course traces the historical development of the philosophy of science from approximately 1800 to the early 20th century, beginning with the philosophy of Newtonian science developed by Immanuel Kant and ending with Rudolf Carnap's *Der logische Aufbau der Welt* (1928). It is in these years that the philosophy of science begins to take shape as a specialized discipline within philosophy more generally; and the problems, in the first place, are stimulated and framed by revolutionary developments in 19th-century science: the discovery of non-Euclidean geometries, the wave theory of light and electrodynamics, thermodynamics and the conservation of energy, and molecular-atomic theory. Accordingly, the initial work in what we now call philosophy of science is undertaken by professional scientists attempting to come to terms with these new developments—in particular, by Hermann von Helmholtz, Ernst Mach, and Henri Poincaré. Then, about the turn of the century, philosophy of science is stimulated once again by revolutionary developments: Einsteinian relativity theory, on one hand, and new work in logic and the foundations of mathematics by Gottlob Frege, Bertrand Russell, and David Hilbert on the other. Now philosophy of science is pursued more by professional philosophers—and, in particular, by the so-called Vienna Circle of logical positivists represented especially by Moritz Schlick and Rudolf Carnap. The work of these philosophers then sets the stage for most of 20th-century philosophy of science.

Required Reading

(Volume numbers refer to photocopied course readers.)

Boltzmann, "The Recent Development of Method in Theoretical Physics," 1900, vol. 2, 63–78.

Boltzmann, "On the Necessity of Atomic Theories in Physics," 1901, vol. 2, 79–86.

Carnap, *The Logical Structure of the World* [*Aufbau*], 1928, vol. 4.

Einstein, "Geometry and Experience," 1921, vol. 2, 187–202.

Helmholtz, "The Aim and Progress of Physical Science," 1869, vol. 1, 87–98.

Helmholtz, "The Conservation of Force," 1847, vol. 1, 1–27.
Helmholtz, "The Facts in Perception," 1878, vol. 1, 51–86.
Helmholtz, "Introduction to the Lectures on Theoretical Physics," 1894, vol. 1, 99–107.
Helmholtz, "On the Origin and Significance of the Axioms of Geometry," 1870, vol. 1, 31–49.
Mach, *The Analysis of Sensations,* 1886, vol. 3.
Mach, "The Guiding Principles of My Scientific Theory of Knowledge", 1910, vol. 2, 128–35.
Mach, "Newton's Views of Time, Space, and Motion," 1883, vol. 2, 39–52.
Mach, "The Relations of Mechanics to Other Departments of Knowledge," 1883, vol. 2, 53–62.
Mach, *Space and Geometry,* 1906.
Planck, "On Mach's Theory of Physical Knowledge," 1911, vol. 2, 136–40.
Planck, "The Unity of the Physical World-Picture," 1909, vol. 2, 114–27.
Riemann, "On the Hypotheses which Lie at the Foundations of Geometry," 1854, vol. 2, 31–38.
Poincaré, *Science and Hypothesis,* 1902.
Poincaré, "Space and Time," 1912, vol. 2, 145–50.
Schlick, "Critical or Empiricist Interpretation of Modern Physics?" 921, vol. 2, 159–65.
Schlick, *General Theory of Knowledge,* 1918/25.

Recommended Reading

Bellone, *A World on Paper*
Bonola, *Non-Euclidean Geometry*
Brush, "Mach and Atomism," vol. 2, 87–98.
Buchdahl, *Metaphysics and the Philosophy of Science*
Carnap, "The Structure of Space," vol. 2, 21–30T.
Coffa, *The Semantic Tradition from Kant to Carnap: To the Vienna Station*
Friedman, *Kant and the Exact Sciences*
Friedman, "Logical Positivism, Philosophy of" (handout)
Friedman, "Poincaré's Conventionalism and the Logical Positivists," vol. 2, 151–57.

Greenberg, "The Poincaré Models," vol. 2, 141–44.
Hankins, *Science and the Enlightenment*
Harman, *Energy, Force, and Matter*
Kant, *Philosophy of Material Nature (Metaphysical Foundations, Prolegomena)*
Klein, "Planck, Entropy, and Quanta, 1901–1906," vol. 2, 99–113.
Kuhn, "Energy Conservation as an Example of Simultaneous Discovery," vol. 2, 1–20.
Miller, "Why did Poincaré not formulate Special Relativity in 1905?" vol. 2, 244–60.
Poincaré, "On the Foundations of Geometry," 1898, vol. 2, 203–24.
Schlick, "The Philosophical Significance of the Principle of Relativity," 1915, vol. 2, 167–85.
Torretti, "The 'Relativity Theory of Poincaré and Lorentz,'" vol. 2, 225–29.
Zahar, "Poincaré's Independent Discovery of the Relativity Principle," vol. 2, 230–43.

Unit I: Introduction

Kant and Newton
Kant; Friedman, *Kant*, Part One; Coffa, 1
Newtonianism and the Nineteenth Century
Hankins; Harman, I, II

Unit II: Helmholtz

Energy and Atomism "Conservation," "Aim and Progress," "Introduction"; Kuhn; Harman, III, IV
Geometry and Intuition
"Axioms," "Facts"; Carnap, "Space," 125–43, 177–83; Bonola; Riemann; Coffa, 2, 3

Unit III: Mach

Phenomenology and Phenomenalism
Analysis, I–V, XIV, XV, "Relations"; Boltzmann; Brush; Harman, V–VI; Bellone, 1–4, 7; Planck-Mach, 1909–11; Klein
Concept Formation
Analysis, VI–X, XIV, XV, *Geometry*, "Newton's Views"

Unit IV: Poincaré

Arithmetic and Geometry
Science, Parts I–III, "Foundations"; Greenberg; Coffa, 3, 4, 7
The Structure of Physical Theory (Electrodynamics and Relativity)
Science, Parts IV, V, "Space and Time"; Bellone, 5, 6; Miller; Torretti; Zahar

Unit V: Schlick

Geometry and Relativity
"Critical or Empiricist," "Principle of Relativity"; Einstein; Friedman, "Conventionalism"; Carnap, "Space," 144–76; Coffa, 9, 10; *Knowledge*, Part I
Concepts and Reality
Knowledge, Parts II, III

Unit VI: Carnap

Logic, Mathematics, and Sense-Experience
Aufbau, Parts I–III, §107; Coffa, 4–6
The Logical Construction of the World
Aufbau, Parts IV, V; Coffa, 11, 12

Notes

1. See M. Wilson, *Ideas and Mechanisms*, Princeton, N.J.: Princeton University Press, 1999; D. Garber, *Descartes' Metaphysical Physics*, Chicago: University of Chicago Press, 1992; and (for example) the essays collected in S. Voss, ed. *Essays on the Philosophy and Science of René Descartes*, Oxford, England: Oxford University Press, 1993.
2. See G. Buchdahl, *Metaphysics and the Philosophy of Science*, Oxford, England: Basil Blackwell,1969, and (for example) the essays collected in E. Watkins, ed. *Kant and the Sciences*. Oxford, England: Oxford University Press, 2001.
3. See M. Friedman, *Kant and the Exact Sciences*, Cambridge, Mass.: Harvard University Press, 1992.
4. See M. Friedman, *Reconsidering Logical Positivism*, Cambridge, England: Cambridge University Press, 1999.
5. For more on Helmholtz and Poincaré see M. Friedman, "Helmholtz's *Zeichentheorie* and Schlick's *Allgemeine Erkenntnislehre*," *Philosophical Topics* 5, 1997, 19–50, and "Geometry, Construction, and Intuition in Kant and His Successors," in G. Scher and R. Tieszen, ed. *Between Logic and Intuition,* Cambridge, England: Cambridge University Press, 2000. For Einstein and the logical empiricists, see my "Geometry as a Branch of Physics," in D. Malament, ed. *Reading Natural Philosophy,* Chicago: Open Court, 2002.
6. See my "Kant—*Naturphilosophie*—Electromagnetism," in M. Friedman and A. Nordmann, ed. *Kant's Scientific Legacy in the Nineteenth Century*, Cambridge, Mass.: MIT Press, forthcoming. To see the connection between these developments and the foundations of geometry, for example, note that Helmholtz's work in this subject was a part of his larger project in the psychophysiology of perception, which, for him, was intimately connected with his work in thermodynamics and electricity and magnetism—and his work in these latter sciences, in particular, was in part a reaction against Schelling, but it also built on Kant's original dynamical theory of matter to which Schelling had recently given scientific prominence.
7. A further example of this phenomenon, discussed in the reference cited in note 6, is H. C. Oersted's work in electrochemistry and electromagnetism, which is explicitly framed under the influence of both Kant's original theory of matter and Schelling's radical revision thereof.
8. For a first attempt to develop this point of view, see my *Dynamics of Reason,* Stanford, Calif.: CSLI, 2001. For a discussion of Kuhnian

historiography in this context, see my "Kuhn and Logical Empiricism," in T. Nickles, ed. *Thomas Kuhn*, Cambridge, England: Cambridge University Press, 2003.

9. For my translation of this work (together with an introduction and notes) see I. Kant, *Metaphysical Foundations of Natural Science*, Cambridge, England: Cambridge University Press, 2004.
10. See J. A. Coffa, *The Semantic Tradition from Kant to Carnap,* Cambridge, England: Cambridge University Press, 1991.
11. For Helmholtz and the dispute between nativism and empiricism, see G. Hatfield, *The Natural and the Normative*, Cambridge, Mass.: MIT Press, 1990. For the more general debate, including the position of Hering, in particular, see R. Turner, *In the Eye's Mind*, Princeton, N.J.: Princeton University Press, 1994.
12. Immediately before *General Theory of Knowledge* Schlick published an extremely influential semipopular philosophical explanation and defense of Einstein's new theory, *Space and Time in Contemporary Physics*, which went through four editions from 1917 to 1922, and which secured Schlick—most likely with help from Einstein himself—the chair in the philosophy of inductive sciences at the University of Vienna previously occupied by Ernst Mach and Ludwig Boltzmann.
13. Carnap's mature antimetaphysical position is articulated in "Empiricism, Semantics, and Ontology," *Revue Internationale de Philosophie* 11 1950: 20–40; reprinted in the second edition of *Meaning and Necessity,* Chicago: University of Chicago Press, 1956. Here, too, Carnap's position owes less to traditional empiricism and verificationism and more to the idea that the distinctive task of philosophy lies in the formulation and logical investigation of alternative "linguistic frameworks" in which the language of science may be formally represented.