Modern Intellectual History, 9, 1 (2012), pp. 77–88
doi:10.1017/S1479244311000485

KUHN AND PHILOSOPHY*

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Initially trained as a physicist, Kuhn became a leading and extraordinarily influential figure in the history of science. He saw his work in the history of science as contributing to a novel philosophical conception of the nature of science. At the outset of *Structure*, for example, Kuhn announces his intention to replace the "development-by-accumulation" model he associates with the philosophical tradition before him—including, in particular, what he calls "early logical positivism"—with a new model of radical conceptual discontinuity or *incommensurability*.[1] *Structure* was written during Kuhn's tenure teaching

* In the years 1969–73 I was a graduate student at Princeton while Kuhn was a professor of philosophy and history of science there. At the time, however, I worked exclusively in philosophy of science and philosophy of physics, and had not yet become seriously interested in history and philosophy of science. Although I thus did not get to know Kuhn well at the time, I was thrilled (along with everyone else) when Kuhn, following Princeton tradition, served as a teaching assistant for my teacher C. G. Hempel when the latter taught his final course in the Philosophy Department. But I eventually did become seriously interested in both the history of science and the history of philosophy, and I talked with Kuhn about these matters while he was at MIT. I became increasingly interested, in particular, in pursuing my own philosophical approach to the history of science, and I presented some of my initial ideas on the subject at the conference in celebration of Kuhn's retirement at MIT in 1991. I have since published a short book on the topic, *Dynamics of Reason* (2001), where I begin to develop my own neo-Kantian approach to the problem of incommensurability that Kuhn first emphasized in *Structure*. I am presently engaged in pursuing this project considerably further, and I hope that, despite the divergences between my approach and Kuhn's, the result will nonetheless honor his memory.

1 Thomas Kuhn, *The Structure of Scientific Revolutions* (Chicago, 1970) begins by rejecting this model in chapter 1, although Kuhn does not there explicitly associate it with logical positivism. In chapter 9 of *Structure*, 98, however, he rejects the view, "closely associated with early logical positivism," that "would restrict the range and meaning of an accepted theory so that it could not possibly conflict with any later theory that made predictions about some of the same natural phenomena." Kuhn there opposes this view, and argues for incommensurability, using the example of Einsteinian relativity theory.

philosophy and history of science at Berkeley, and, shortly after its publication, he took up a new post as professor of philosophy and history of science at Princeton. From 1983 until his death in 1996 Kuhn was professor of philosophy at MIT, where he attempted further to articulate his conception of incommensurability, taking account of developments in linguistics and philosophy of language.

We can distinguish several stages in Kuhn's relationship with philosophy as a discipline after the publication of *Structure*. At first his work was severely criticized and rejected within Anglo-American philosophy of science, which had been greatly influenced by logical positivism and empiricism after the war.[2] In the 1970s and 1980s, however, there was a turn away from this influence throughout the Anglo-American world, and Kuhn's work (among others) was widely credited with being an important factor in this turn.[3] Beginning in the 1990s, in the context of renewed interest in the history of logical positivism and empiricism, a number of scholars (including myself) then called attention to striking similarities between Kuhn's views and those of the "early logical positivists"—in so far as they, many years before Kuhn, had already emphasized the deeply revolutionary character, from a conceptual point of view, of Einstein's theory of relativity (compare note 1 above).[4] This historical work highlighted Kantian and neo-Kantian aspects of the philosophy of logical positivism, and Kuhn, very late in his career, also underscored such influences on his own view, characterizing it, appropriately, as a version of "Kantianism with moveable categories."[5] After reconsidering the relationship between Kuhn and logical positivism, together with the neo-Kantian aspects of this philosophy, I shall devote the rest of my discussion to the roots of both Kuhn's philosophy and his historiography in the neo-Kantian tradition.

George Reisch first called attention to the striking parallels between Kuhn and logical positivism in a paper provocatively entitled "Did Kuhn Kill Logical Empiricism?".[6] Beginning with the fact that *Structure* first appeared as a volume

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2 See e.g. Dudley John Schapere, "The Structure of Scientific Revolutions", *Philosophical Review* 73 (1964), 383–94; Israel Scheffler, *Science and Subjectivity* (Indianapolis, 1967).

3 See e.g. Ronald N. Giere, *Explaining Science* (Chicago, 1988), 32: "Kuhn's *Structure of Scientific Revolutions* . . . was a major contributor to the decline of logical empiricism beginning in the 1960s." A similar view is found in the Introduction to Frederick Suppe, *The Structure of Scientific Theories* (Urbana, IL, 1977), where logical empiricism is characterized as the "Received View" to which more recent views—including Kuhn's—are opposed. See also Richard Rorty, *Philosophy and the Mirror of Nature* (Princeton, NJ, 1979), 59, 332–3.

4 See e.g. Michael Friedman, *Reconsidering Logical Positivism* (Cambridge, 1999), together with the secondary literature cited there.

5 Thomas Kuhn, *The Road since Structure* (Chicago, 2000), 264.

6 George Reisch, "Did Kuhn Kill Logical Empiricism?", *Philosophy of Science*, 58 (1991), 264–77.

of the *International Encyclopedia of Unified Science* (the official monograph series of the logical empiricist movement in exile), Reisch presents two previously unpublished letters written to Kuhn by Rudolf Carnap in the latter's capacity as editor. There Carnap expresses enthusiastic approval of Kuhn's ideas and states that he especially "liked your emphasis on the new conceptual frameworks which are proposed in revolutions in science, and, on their basis, the posing of new questions, not only answers to old problems."[7] This is by no means surprising, as Reisch also explains, because of the deep affinities between Carnap's underlying philosophical perspective and Kuhn's ideas. Natural science, for Carnap, is to be conceived as represented within a particular formal language or linguistic framework. And perhaps Carnap's most fundamental thought is that there are a plurality of essentially different and non-intertranslatable such frameworks. For Carnap, moreover, there is no sense in which one such framework can be correct while another is incorrect. Rather, all standards of logical correctness are relative or *internal* to a particular choice of linguistic framework. *External* questions concerning which linguistic framework to adopt are not similarly adjudicable by already established logical rules but rather require a conventional or pragmatic choice based on suitability or adaptedness for one or another given purpose.[8] Such an external question, involving a change from one linguistic framework to a different one, is precisely what is at issue, for Carnap, in a scientific revolution.[9]

It is especially noteworthy, therefore, that Kuhn, towards the end of his career, explicitly acknowledges these affinities between his views and Carnap's. Kuhn expresses embarrassment, to begin with, that "[w]hen I received the kind letter in which Carnap told me of his pleasure in the manuscript [one of the letters concerning the initial publication of *Structure* cited by Reisch], I interpreted it as mere politeness, not as an indication that we might usefully talk."[10] But Kuhn then goes on to explain the "correspondingly deep difference" between Carnap and

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7 Ibid., 266–7.

8 This philosophy of linguistic frameworks, including the sharp distinction between internal and external questions, is formulated most explicitly in Rudolf Carnap, "Empiricism, Semantics, and Ontology", *Revue internationale de philosophie* 11 (1950), 20–40. The basic ideas go back to *idem*, *The Logical Syntax of Language* (London, 1937; original published in 1934).

9 For discussion and references see Reisch, "Kuhn", 270–74. These affinities between Carnap and Kuhn are discussed by several authors in addition to Reisch, including John Earman, "Carnap, Kuhn, and the Philosophy of Scientific Methodology", in. Paul Horwich, ed., *World Changes: Thomas Kuhn and the Nature of Science* (Cambridge, MA, 1993), and Michael Friedman, "Remarks on the History of Science and the History of Philosophy", in Horwich, *World Changes*.

10 Thomas Kuhn, "Afterwords", in Horwich, *World Changes*, 313. Kuhn is responding to the last two papers cited in the previous footnote.

himself—which, he thinks, survives the acknowledged parallels. This does not consist, as one might first expect, in the circumstance that Carnap's linguistic rules must always be explicitly formulated whereas the rules and standards governing a Kuhnian paradigm are largely tacit. Kuhn rather emphasizes that he, unlike Carnap, is concerned from the start with *historical development*, so that, in particular, language change "is *cognitively* significant for me as it was not for Carnap."[11] Kuhn's point, as I understand it, is that a change of language, for Carnap, is not cognitive or epistemic in the only sense of "epistemology" Carnap recognizes. For, although Carnap, as Reisch emphasizes, does connect his notion of change of language with scientific revolutions, he never discusses such revolutions in any serious way. Such a historical investigation could never be a part of what Carnap himself preserves of epistemology, namely the logic of science (*Wissenschaftslogik*)—the formulation and examination of a variety of possible linguistic frameworks within which the results of the special sciences may be represented. What is crucial, for Carnap, is that the only remaining properly philosophical problems are purely formal and belong to the application of logic to the language of the special sciences.[12] For Kuhn, by contrast, as the very first chapter of *Structure* makes clear, the point is precisely that historical examination of scientific change can, above all, be genuinely philosophical.

We can deepen our appreciation of the affinities between Carnap and Kuhn—and also their important differences—by looking more closely into the backgrounds and intellectual contexts of both views. I suggested above that early logical positivism took its starting point from an explicit recognition of the profoundly revolutionary character of Einstein's theory of relativity. Carnap attempted philosophically to come to terms with this theory in his doctoral dissertation, written under the direction of the neo-Kantian philosopher Bruno Bauch at Jena.[13] One cannot, Carnap argues, still maintain Kant's original conception of the fixed synthetic a priori status of specifically Euclidean geometry. So Carnap instead defends a generalization of Kant's conception of spatial intuition according to which only the *infinitesimally* Euclidean character of physical space is thereby determined a priori.

This conception has significant points in common with that developed by the neo-Kantian philosopher Ernst Cassirer slightly earlier.[14] And Carnap's colleague Hans Reichenbach developed a related neo-Kantian approach around the same

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11 Kuhn, "Afterwords", 314, original emphasis.

12 See Carnap, *Logical Syntax*, §72: "*Wissenschaftslogik takes the place of the inextricable tangle of problems that is known as philosophy*." Original emphasis.

13 Rudolf Carnap, *Der Raum* (Berlin, 1922).

14 Ernst Cassirer, *Zur Einsteinschen Relativitätstheorie* (Berlin, 1921).

time.[15] Reichenbach draws a distinction between two meanings of the Kantian a priori: necessary and unrevisable, fixed for all time, on the one hand, and "constitutive of the concept of the object of [scientific] knowledge," on the other.[16] Reichenbach argues, on this basis, that the lesson of the theory of relativity is that the former meaning must be dropped while the latter should be retained. Relativity theory involves a priori constitutive principles as necessary presuppositions of its properly empirical claims just as much as did Newtonian physics, but these principles have changed in the transition from the latter theory to the former. Whereas Euclidean geometry is indeed constitutively a priori in the context of Newtonian physics, for example, only infinitesimally Euclidean geometry is constitutively a priori in the context of general relativity. The result is thus a *relativized* conception of a priori constitutive principles that change and develop along with the development of the sciences themselves.

The influence of neo-Kantian philosophy—and Cassirer in particular—is seen most clearly, however, in Carnap's first major work, the *Aufbau*.[17] Carnap focuses especially on the "genetic" (*erzeugende*) conception of knowledge characteristic of the Marburg School of neo-Kantianism founded by Cassirer's teacher Hermann Cohen. Empirical science, on this conception, proceeds by progressively embedding natural phenomena in an ordered sequence of abstract relational structures as we successively articulate and refine mathematical representations of these phenomena in the actual historical development of our theories. This procedure results in an infinite, never-ending sequence of relational structures, but one which is nonetheless converging on a limit-structure or limit-theory representing the ideal completion of scientific progress. The object of scientific knowledge is never completely given: it is only successively approximated in the limit as the ideal *X* towards which our mathematical representations of nature are converging.[18]

When Carnap, in the *Aufbau*, first introduces the question of the basic or fundamental relations on which his "constitutional system of reality" is to be erected, he cites Cassirer's *Substance and Function* as showing the necessity of formally defined relational concepts for ordering the "undigested experiential

15 Hans Reichenbach, *Relativitätstheorie und Erkenntnis Apriori* (Berlin, 1920) refers (in advance) to Cassirer, *Zur Einsteinschen Relativitätstheorie*, in a note. Similarly, Cassirer acknowledges Reichenbach's work in a note added in proof to his book. Further discussion of Carnap and Reichenbach in this connection can be found in Friedman, *Logical Positivism*.

16 Reichenbach, *Zur Einsteinschen Relativitätstheorie*, chap. 5.

17 Rudolf Carnap, *Der logische Aufbau der Welt* (Berlin, 1928).

18 For further discussion of Cassirer and the Marburg school see Michael Friedman, *A Parting of the Ways: Carnap, Cassirer, and Heidegger* (Chicago, 2000).

https://doi.org/10.1017/S1479244311000485 Published online by Cambridge University Press

given" favored by "positivism."[19] Carnap thus hopes to achieve a synthesis of empiricism and Kantianism—a synthesis that emphasizes, as does Cassirer, the indispensability of logico-mathematical formal structures for underwriting the clarity, precision, and intersubjective communicability of empirical scientific knowledge. Carnap also follows Cassirer in representing empirical knowledge by a serial or step-wise sequence of abstract formal structures, depicting, in an idealized fashion, how our scientific methods for acquiring knowledge actually play out in practice. For Carnap, however, this is not a temporal series of successor theories in the historical progress of mathematical natural science, but rather *a sequence of levels or ranks in the hierarchy of logical types* of Whitehead's and Russell's *Principia Mathematica*.[20]

The historically oriented epistemology of the Marburg tradition—which proceeds largely by the methods of intellectual history—is here transformed into a purely logical exercise: the project of formally presenting the logical definitions of all objects of (current) scientific knowledge subsisting at the various levels of Carnap's constitutional system. And, in the course of this formal exercise, Carnap is able, by means of the theory of types, to transcend the Marburg doctrine of the essentially incomplete character of the object of scientific knowledge—its character, that is, as a never-to-be-completed *X*. For Carnap, all objects whatsoever are defined or "constituted" at definite finite ranks within the hierarchy of logical types, and it is only the further empirical specification of these objects that remains essentially incomplete. As a result, Carnap is also able to reject the Kantian conception of synthetic a priori principles. Objects are defined or constituted by *stipulation* and then further investigated by *experience*: "According to the conception of constitutional theory there are no other components in cognition than these two—the conventional and the empirical—and thus no synthetic a priori [components]."[21]

In a direct engagement with neo-Kantian epistemology, Carnap thereby arrives at the same point that was reached in the context of the logical positivists' earlier engagement with Einsteinian relativity theory. Kant's synthetic a priori principles

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19 Carnap, *Aufbau*, §75. Carnap cites Ernst Cassirer, *Substance and Function* (Chicago, 1923; originally published in 1910).

20 Afred North Whitehead and Bertrand Russell, *Principia Mathematica* (Cambridge, 1910–13), 3 vols.

21 Carnap, *Aufbau*, §179. Carnap (ibid.) also explains the corresponding divergence with the Marburg school: "According to the conception of the *Marburg School* . . . the object is the eternal X, its determination is an incompletable task. In opposition to this it is to be noted that finitely many determinations suffice for the constitution of the object—and thus for its univocal description among the objects in general. Once such a description is set up the object is no longer an X, but rather something univocally determined—whose complete description then certainly still remains an incompletable task."

governing our empirical scientific knowledge are no longer necessarily fixed, but become subject to choice, and are relativized to a specific scientific context. Thus Carnap here stands on the brink of his mature philosophy of linguistic frameworks, which, as explained above, has striking affinities with the Kuhnian theory of scientific revolutions.[22] This philosophy can thus be viewed as a kind of generalization and "logicization" of the conception of relativized a priori principles developed by Reichenbach, resulting from Carnap's simultaneous engagement with both the details of neo-Kantian epistemology and the most recent developments in modern mathematical logic.

I began by noting that Kuhn, towards the end of his career, explicitly acknowledges the Kantian and neo-Kantian background to the development of logical empiricism and the resulting parallels with his own views. Commenting, in particular, on Reichenbach's distinction between two meanings of the a priori (fixed and unrevisable versus constitutive relative to a theory), Kuhn remarks that both meanings "make the world in some sense mind-dependent, but the first disarms the apparent threat to objectivity by insisting on the absolute fixity of the categories, while the second relativizes the categories (and the experienced world with them) to time, place, and culture."[23] Kuhn, like the early logical positivists, has thus adopted a relativized conception of Kantian a priori principles. Yet Kuhn's perspective, unlike theirs, is essentially historical: their a priori is relativized to a theory or linguistic framework, not to a "time, place, or culture." And this point, too, can be further illuminated against the background and context of Kuhn's historiography.

In the Preface to *Structure*, Kuhn portrays how he shifted his career plans from physics to the history of science, and, in explaining his initial intensive work in the subject, states that he "continued to study the writings of Alexandre Koyré and first encountered those of Emile Meyerson, Hélène Metzger, and Anneliese Maier[; more] clearly than most other recent scholars, this group has shown what it was like to think scientifically in a period when the canons of scientific thought were very different from those current today."[24] Then, in the introductory first chapter, Kuhn explains the background to his rejection of the development-by-accumulation model in a recent historiography that is "perhaps best exemplified

22 As I indicated above, Carnap's mature standpoint adopts *Wissenschaftslogik* as the substitute for all forms of traditional epistemology, including the epistemology of the *Aufbau*. For further discussion of this point see Alan W. Richardson, "From Epistemology to the Logic of Science", in Ronald N. Giere and Alan W. Richardson, eds., *Origins of Logical Empiricism* (Minneapolis, 1996).

23 Kuhn, "Afterwords," 331. Kuhn is responding to the last article cited in note 9 above.

24 Kuhn, *Structure*, v–vi.

in the writings of Alexandre Koyré."[25] In particular, Kuhn places himself squarely within the historiographical tradition initiated by Koyré in his work on Galileo—a tradition that played a leading role in establishing the history of science as an independent discipline in the immediate postwar period.[26]

In a later survey article on the development of the history of science, Kuhn again explains the initial break with the development-by-accumulation model, which began, according to Kuhn, with "the influence, beginning in the late nineteenth century, of the history of philosophy." We here learned an "attitude towards past thinkers which came to the history of science from philosophy[;] partly it was learned from men like Lange and Cassirer who dealt historically with people or ideas that were also important for scientific development . . . partly it was learned from a small group of neo-Kantian epistemologists, particularly Brunschvicg and Meyerson."[27] And finally, in a "Historiographic/Philosophical Addendum" to his book on Planck and black-body radiation, Kuhn states, "The concept of historical reconstruction that underlies [my book] has from the start been fundamental to both my historical and my philosophical work[; it] is by no means original: I owe it primarily to Alexandre Koyré; its ultimate sources lie in neo-Kantian philosophy."[28]

Virtually all the figures on Kuhn's list of influences are, in one way or another, taking inspiration from, and reacting to, Cassirer's seminal work on the history of modern science and philosophy, *Das Erkenntnisproblem*.[29] This is the first work, in particular, to develop a detailed reading of the seventeenth-century scientific revolution in terms of the "Platonic" idea that the thoroughgoing application of mathematics to nature (the so-called mathematization of nature) is the central and overarching achievement of this revolution.[30] Cassirer simultaneously

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25 Kuhn, *Structure*, 3. The passage concludes, "By implication, at least, these historical studies suggest the possibility of a new image of science. This essay aims to delineate that image by making explicit some of the new historiography's implications" (ibid.).

26 Alexandre Koyré, *Galileo Studies* (Atlantic Highlands, NJ, 1978; originally published in 1939). Kuhn, *Structure*, vi, also cites (among others) Emile Meyerson, *Identity and Reality* (London, 1930; originally published in 1908), to which I shall return below.

27 Thomas Kuhn, *The Essential Tension* (Chicago, 1977), 107–8. In the same pages Kuhn cites the work of E. A. Burtt and A. Lovejoy and refers to "the modern historiography of science" founded by "E. J. Dijksterhuis, Anneliese Maier, and especially Alexandre Koyré."

28 Thomas Kuhn, *Black Body Theory and the Quantum Discontinuity*, 1894–1912 (Chicago, 1987), 361.

29 Ernst Cassirer, *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit*, 2 vols. (Berlin, 1906–7).

30 Although he does acknowledge Cassirer's influence, H. Floris Cohen, *The Scientific Revolution* (Chicago, 1994), 543, nonetheless contends that "only Burtt, Dijksterhuis, and Koyré were to elaborate such views [on the mathematization of nature] into detailed examinations of the birth of early modern science." This contention is gainsaid by the text

https://doi.org/10.1017/S1479244311000485 Published online by Cambridge University Press

articulates an interpretation of the history of modern philosophy as the development and eventual triumph of what he calls philosophical idealism. This tradition takes its inspiration from the ideal formal structures paradigmatically studied in mathematics, and it is distinctively modern in recognizing the fundamental importance of the systematic application of such structures to empirically given nature in modern mathematical physics—a progressive and synthetic process wherein mathematical models of nature are successively refined and corrected without limit. Cassirer thereby interprets the development of modern thought as a whole from the point of view of the philosophical perspective of Marburg neo-Kantianism. And he here anticipates his own later systematic work by interpreting the characteristically modern conception of nature as the triumph of the mathematical-relational concept of *function*—as expressed in the universal laws of mathematical physics—over the traditional Aristotelian concept of *substance*.

Yet Meyerson, who is clearly the next-most-seminal figure on Kuhn's list of influences, takes a quite different view. He agrees with Kant and the neo-Kantians concerning the necessity for a priori requirements of the mind to give meaning and structure to the results of empirical science. But he is vehemently opposed to the attempt to assimilate scientific understanding to the formulation of universal laws governing phenomena. Indeed, the central thought of his *Identity and Reality* (note 26 above) is that genuine scientific knowledge and understanding can never be the result of mere lawfulness (*légalité*) but must instead answer to the mind's a priori logical demand for identity (*identité*). And the primary requirement resulting from this demand is precisely that some underlying *substance* be conserved as absolutely unchanging and self-identical in all sensible alterations of nature. Thus the triumph of the scientific revolution, for Meyerson, is represented by the rise of mechanistic atomism, wherein elementary corpuscles preserve their sizes, shapes, and masses while merely changing their mutual positions through motion in uniform and homogeneous space. And this same demand for trans-temporal identity is also represented, in more recent times, by Lavoisier's use of the principle of the conservation of matter in his new chemistry and by the discovery of the conservation of energy. However, in the even more recent discovery of what we now know as the second law of thermodynamics, which governs the *temporally irreversible* process of degradation or dissipation of energy, we encounter nature's complementary and unavoidable resistance to our a priori logical demands. In the end, therefore, Meyerson views the development of natural science as progressing via a perpetual dialectical opposition between the

of *Das Erkenntnisproblem* itself, however, which treats Kepler, Galileo, Descartes, Bacon, and Newton (along with Copernicus, Bruno, Leonardo, Gilbert, Gassendi, Hobbes, Boyle, and Huygens) in quite considerable detail.

mind's a priori demand for substantiality, and thus absolute identity through time, and nature's own irrational a posteriori resistance to this demand.

In the work of Cassirer and Meyerson, then, we find two sharply diverging visions of the history of modern science. For Cassirer, this history is seen as a process of evolving rational purification of our view of nature, as we progress from naively realistic substantialistic conceptions, focusing on underlying substances, causes, and mechanisms subsisting behind the observable phenomena, to increasingly abstract purely functional conceptions, in which we abandon the search for underlying ontology in favor of ever more precise mathematical representations of phenomena in terms of exactly formulated universal laws. For Meyerson, by contrast, this same history is seen as a necessarily dialectical progression, in something like the Hegelian sense, where reason perpetually seeks to enforce precisely the substantialistic impulse, and nature continually offers her resistance via the ultimate irrationality of temporal succession. It is by no means surprising, therefore, that Meyerson, in the course of considering, and rejecting, "anti-substantialistic conceptions of science," explicitly takes issue with Cassirer's characteristic claim that mathematical physics "turns aside from the essence of things and their inner substantiality in order to turn towards their numerical order and connection, their functional and mathematical structure."[31] And it is also no wonder, similarly, that Cassirer, in the course of his own discussion of "identity and diversity, constancy and change," explicitly takes issue with Meyerson's views by asserting that the "identity towards which thought progressively strives is not the identity of ultimate substantial things but the identity of functional orders and coordinations."[32]

It is especially striking, therefore, that Koyré—who is clearly the most direct and important influence for Kuhn—places himself squarely on the side of Meyerson. Indeed, Koyré's *Galileo Studies* is dedicated to Meyerson, and his allegiance to Meyerson's position in the dispute with Cassirer clearly emerges, if only implicitly, in Koyré's criticism of what he views as Cassirer's excessively

31 Meyerson, *Identity and Reality*, 388–9 (the quotation is from vol. 2 of *Das Erkenntnisproblem*).

32 Cassirer, *Substance*, 323–5. The passage continues, "But these [functional orders and coordinations (*Ordnungen und Zuordungen*)] do not exclude the moments of difference and change but only achieve determination in and with them. It is not manifoldness as such that is annulled [*aufgehoben*] but [we attain] only a manifold of another dimension: the mathematical manifold takes the place of the sensible manifold in scientific explanation. What thought requires is thus not the dissolution of diversity and change as such, but rather their mastery in virtue of the mathematical *continuity* of serial laws and serial forms" (ibid., original emphasis).

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Kantian reading of Galileo's "Platonism."[33] That this criticism does not merely concern the interpretation of Galileo, however, is clearly expressed in an earlier paper explaining and defending Meyerson's philosophy to a German audience. Koyré explicitly defends Meyerson's conception against the "anti-substantialistic" pretensions of neo-Kantianism, according to which "science has nothing to do with substantial causes, but is occupied only with constructing functional dependencies, functional interconnections of the phenomena and clothing them in mathematical formulas."[34] While science does aim at mathematical laws, of course, this is not the ultimate goal of the rational comprehension of phenomena required by thought. Here Meyerson, following the ancient tradition initiated by Parmenides and Plato, is perfectly correct: the demand for rational comprehension can only be satisfied by absolute unity and self-identity. Yet, as Plato—and, following him, Hegel—clearly saw, the reality with which thought is confronted is essentially irrational. In particular, temporal succession is ultimate and irreducible, and reality itself is a necessary mixture of (rational) sameness and (irrational) otherness. In the end, therefore, despite his well-known emphasis on rationalism and the mathematization of nature, Koyré is a Meyersonian. His "Platonism"—in explicit opposition to the more Kantian version articulated by Cassirer—is clearly and firmly based on a recognition of the *limits* of mathematical thought.

The historiographical tradition Kuhn attempts to assimilate in his theory of scientific revolutions is thus by no means unitary and uncontentious. On the contrary, it is characterized by a deep philosophical opposition between a mathematical idealist tendency taking its inspiration from Kant and a more realistic and substantialistic tendency taking its inspiration—via the thought of Meyerson—from a mixture of Platonic, Cartesian, and Hegelian ideas. The former tendency, following Kant, renounces the ambition of describing an ontological realm of substantial things subsisting behind the empirical phenomena in favor of a rigorous mathematical description of the lawlike relations among the phenomena themselves. It differs from Kant, however, in recognizing that no particular mathematical structures (such as those of Euclidean geometry and Newtonian physics) are necessarily instantiated in the phenomena. And, accordingly, it portrays the objectivity and universality of

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33 Koyré, *Galileo*, 223: "E. Cassirer, in his *Erkenntnisproblem*, vol. I, expresses the opinion that Galileo resurrected the Platonist ideal of scientific knowledge; from which follows, for Galileo (and Kepler), the necessity for mathematising nature . . . Unfortunately (at least in our opinion) Cassirer turns Plato into Kant. Thus, for him, Galileo's 'Platonism' is expressed by his giving priority to function and law over being and substance."

34 Alexandre Koyré, "Die Philosophie Emile Meyersons", *Deutsch–Französische Rundschau* 4 (1931), 207–8.

https://doi.org/10.1017/S1479244311000485 Published online by Cambridge University Press

scientific progress as a historical evolution marked by a continuous unfolding and generalization of the powers of mathematical thought itself, entirely independently of any concern for the correspondence of such thought to a mind-independent ultimate reality. The latter tendency, by contrast, maintains precisely an ontology of substantial things, and, accordingly, it emphatically rejects the attempt to reduce the task of science to the formulation of precise mathematical laws. It thus ends up with a more pessimistic reading of the history of modern science in which our demand for fundamentally ontological rational intelligibility is met by an inevitable resistance to this demand arising from the irrational essentially temporal character of nature itself.

If I am not mistaken, this deep philosophical tension is clearly echoed in Kuhn's theory of scientific revolutions when he considers the question of theoretical continuity over time. Here Kuhn shows himself, in this respect, to be a follower of the Meyersonian tendency, for he consistently gives the question an ontological rather than a mathematical interpretation. Thus, for example, when Kuhn considers the relationship between relativistic and Newtonian mechanics, in explicit opposition to what he calls "early logical positivism," he rejects the notion of a fundamental continuity between the two theories on the grounds that the "physical reference" of their terms is essentially different.[35] And Kuhn nowhere considers the contrasting idea, characteristic of the Marburg School, that continuity of the relevant mathematical structures might be sufficient. Moreover, Kuhn consistently gives an ontological rather than a mathematical interpretation to the question of theoretical convergence over time. The question is always whether our theories can be said to converge on an independently existing truth about reality, on a theory-independent external world.[36] By contrast, the Marburg school rejects this realistic reading at the outset. Our theories do not ontologically converge on a mind-independent realm of substantial things. Instead, they mathematically converge *within* their historical evolution, as they continually approximate, but never actually reach, an ideally complete mathematical representation of the phenomena.

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35 Kuhn, *Structure*, 101–2.

36 See ibid., 206–7, which rejects all talk of convergence over time on the grounds that there is, "I think, no theory-independent way to reconstruct phrases like 'really there'; the notion of a match between the ontology of a theory and its 'real' counterpart in nature now seems to me illusive in principle." Kuhn continues (now speaking "as a historian"), "I do not doubt, for example, that Newton's mechanics improves on Aristotle's and that Einstein's improves on Newton's as instruments for puzzle-solving. But I can see in their succession no coherent direction of ontological development."

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