



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Philosophy and the sciences after Kant

Citation for published version:

Massimi, M 2009, 'Philosophy and the sciences after Kant' *Royal Institute of Philosophy Supplements*, vol. 65, pp. 415-452. <https://doi.org/10.1017/S1358246109990142>

Digital Object Identifier (DOI):

<http://dx.doi.org/10.1017/S1358246109990142>

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Publisher's PDF, also known as Version of record

Published In:

Royal Institute of Philosophy Supplements

Publisher Rights Statement:

© Cambridge University Press. Massimi, M. (2009). Philosophy and the sciences after Kant. *Royal Institute of Philosophy Supplement* 65 (pp. 415-452).doi: <http://dx.doi.org/10.1017/S1358246109990142>

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



Royal Institute of Philosophy Supplement

<http://journals.cambridge.org/PHS>

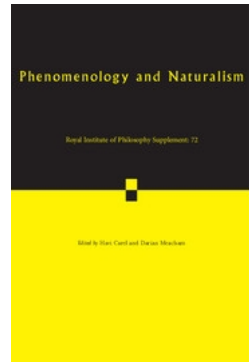
Additional services for *Royal Institute of
Philosophy Supplement*:

Email alerts: [Click here](#)

Subscriptions: [Click here](#)

Commercial reprints: [Click here](#)

Terms of use : [Click here](#)



Philosophy and the Sciences After Kant

Michela Massimi

Royal Institute of Philosophy Supplement / Volume 65 / October 2009, pp 275 - 311
DOI: 10.1017/S1358246109990142, Published online: 14 December 2009

Link to this article: http://journals.cambridge.org/abstract_S1358246109990142

How to cite this article:

Michela Massimi (2009). Philosophy and the Sciences After Kant. Royal Institute of Philosophy Supplement, 65, pp 275-311 doi:10.1017/S1358246109990142

Request Permissions : [Click here](#)

Philosophy and the Sciences After Kant

MICHELA MASSIMI

1. Preamble: HPS and the troubled marriage between philosophy and the sciences

On 11th October 2007, at the first international conference on Integrated History and Philosophy of Science (&HPS1) hosted by the Center for Philosophy of Science in Pittsburgh, Ernan McMullin (University of Notre Dame) portrayed a rather gloomy scenario concerning the current relationship between history and philosophy of science (HPS), on the one hand, and mainstream philosophy, on the other hand, as testified by a significant drop in the presence of HPS papers at various meetings of the American Philosophical Association (APA).

Since my research activity falls primarily into the category of history and philosophy of science, I am delighted to be able to contribute to this volume on *Conceptions of Philosophy*, by discussing what I see as the very important role that history and philosophy of science plays, or ought to play within philosophy. And the aforementioned gloomy depiction of the current relationship between HPS and philosophy invites some preliminary reflections. There is no doubt, I think, that recent years have witnessed an increasing gap between the sort of topics and themes pursued by HPS scholars, and those pursued by their colleagues in mainstream philosophy. HPS scholars are interested in practicing philosophy by looking at science and history of science in the first place, and by exploring the specific ways in which new scientific ideas and concepts historically originated and evolved. They think that good philosophy has to be historically and scientifically informed. Analytic philosophers pursue philosophy as a perfectly independent discipline, which not only does not need to resort to the sciences or to history of science, but it *ought not* to, if philosophy has to remain a logically rigorous and methodologically autonomous discipline (independent of any historical and scientific contingency). This gap concerns methodologies, systems of values, and intellectual priorities: there could hardly be a more profound gulf. Speciation within a

population is *per se* a positive, healthy sign of adaptation to the environment. But I think that the type of speciation that we are witnessing in history and philosophy of science within philosophy should not be regarded as a happy parting of the ways. I want to begin this paper by briefly reminding what is at stake in this parting of the ways and what both parties risk losing, or, sadly, have already lost sight of.

Without denying the methodological autonomy of philosophy as a discipline, we should not forget at the same time that philosophy began – in the words of Aristotle – with the sense of wonder that men experience in front of nature. Philosophy flourished for centuries as the highest expression of men's strive to understand nature and the world they lived in. For centuries, philosophy has gone hand in hand with the sciences. Nor can the sciences dispense with philosophy. In Newton's time, the name for physics was *natural philosophy*, and scientific discussions on the nature of space, time and gravitation were entangled with metaphysical debates on nature. Still in twentieth-century physics, the reception of relativity theory and quantum mechanics in the works of Einstein, Bohr, Reichenbach, Weyl and others was entangled with epistemological debates about *a priori* knowledge and the nature of physical reality, whereas some of the most beautiful pages in history of science were written in the first half of the last century by people such as Alexander Koyré, who came from Edmund Husserl's phenomenology, or Émile Meyerson, who studied Descartes and Kant as well as being a historian of chemistry.

These are just a few scattered examples of how fruitful the interaction among philosophy, the sciences and, I would add, the history of science (which seems to me an important 'third man' in this binary relation between philosophy and the sciences), has been for long time. Speciation is a recent phenomenon of our time.

In this paper I want to go back to what I take to be an important turning point in the relationship between philosophy and the sciences, namely to Immanuel Kant. Kant's critical philosophy marks probably the highest point in the happy long marriage between philosophy and the sciences. At the same time, it marks also a watershed: after Kant, the marriage became increasingly rocky. The aim of this paper is to offer a historical reconstruction and a possible (tentative and surely not exhaustive) diagnosis of why such a happy long marriage between philosophy and the sciences went eventually wrong after Kant.

In section 2, I focus on Kant's view on philosophy and the sciences, from his early scientific writings to the development of critical

Philosophy and the sciences after Kant

philosophy and the pressing epistemological problems he felt the need to address in response to the sciences of his time. In section 3, I take a look at the relationship between philosophy and the sciences after Kant in the early nineteenth century: despite the fruitful Kantian legacy in some of the greatest achievements of nineteenth century physical sciences, post-Kantian German philosophy began to signal an increasing divide between philosophy and the sciences. In section 4, I turn to the relationship between philosophy and the sciences in the twentieth century. In particular, I pay attention to three main episodes in twentieth-century philosophy. The first episode is the revival of neo-Kantianism with the Marburg school of Hermann Cohen and Ernst Cassirer (section 4.1); the second is the emergence of logical positivism, especially of Rudolf Carnap's philosophy of science with its debt and, at the same time, departure from the neo-Kantian tradition (section 4.2). The third significant episode is Thomas Kuhn's establishment of HPS as a new field or sub-field of philosophy, and the consequences that it still has for HPS as is practised today. I conclude the paper (section 5) by foreshadowing what I hope to be a better future for the philosophy and the sciences of the twenty-first century (and for HPS itself as a subject area that investigates the relationship between philosophy and the sciences) by recovering what I take to be the most important Kantian insight in this respect. Namely, that epistemology should be informed by the scientific preoccupations of our time, as much as philosophy of science should rediscover the Kantian epistemological soul that it has long lost.

2. Kant on philosophy and the sciences

For centuries, philosophy and natural sciences went hand in hand. Newton called his masterpiece *Philosophiae naturalis principia mathematica* to indicate that his aim was to investigate the mathematical principles of what at the time was still called natural philosophy. It is within this Galilean–Newtonian tradition that we can find some paradigmatic examples of the fruitful two-way relationship between philosophy and the sciences. Immanuel Kant is one of those paradigmatic examples. Kant was educated within this Galilean–Newtonian tradition, and in all his writings there is a constant reference to Newton's natural philosophy as the highest example of the secure foundations achieved by the physical sciences of his time. Kant's intense and life-long engagement with the sciences of his time which I am going to briefly summarise in what follows – from his

pre-critical writings to his critical period up to his last and incomplete work published in the *Opus postumum* – testifies to what is probably one of the highest points in the troubled marriage between philosophy and the sciences.

In the pre-critical period,¹ Kant composed twenty-five works, of which several on physics and astronomy. Most of these pre-critical works focussed on the then ongoing lively debates concerning physical sciences. For instance, Kant's very first work back in 1747 entitled *Thoughts on the true estimation of Living Forces* (1747) addressed one of the most debated topics at the time: namely, the physical concept of *vis viva* (the ancestor of the current concept of kinetic energy), which Leibniz defined as the product of mass times squared velocity, by correcting Descartes's definition in terms of mass times velocity. Eight years later, in 1755, Kant wrote another scientific essay entitled *Universal Natural History and Theory of the Heavens*, which was bound to have a long-lasting impact in the history of astronomy because of the introduction of the so-called 'nebular hypothesis'.² The key idea, later expanded by Laplace in 1796 and now known as the Kant–Laplace hypothesis, was that the universe and the galaxies in it originated from a nebula (a rotating cloud of gases that expanded and gradually cooled down) according to the fundamental laws of physics, in particular Newton's laws as the expression of God's divine providence, Although Kant legged to differ from Newton on the exact role of God in the constitution of the universe.

Even more interesting for the relationship between philosophy and the sciences of his time was the theme of *Physical Monadology* (1756).³ With this work Kant intervened in the then heated debate – triggered by the Berlin Academy of Sciences Prize Question for 1745–7-between the Leibnizians–Wolffians, on the one hand, and the Newtonian Pierre Maupertuis, on the other hand, on the specific theme as to whether Leibniz's monadology was compatible with the Newtonian idea of infinite divisibility of space and time. Kant's original proposal was to try to reconcile the Newtonian idea of the infinite divisibility of space with a physical monadology that regarded monads as physical point-like centers of attractive and repulsive forces filling a space, rather than as Leibnizian metaphysical

¹ By 'pre-critical period', it is usually intended the period preceding Kant's Inaugural Dissertation in 1770, when he was appointed Professor of Logic and Metaphysics at the University of Königsberg.

² Kant (1755a).

³ Kant (1756).

Philosophy and the sciences after Kant

substances occupying a finitely divisible space.⁴ If the theme of this early writing is *per se* already symptomatic of Kant's engagement both with mainstream (Leibnizian–Wolffian) metaphysics *and* with the physics of his time, on the other hand, the far-reaching consequences of Kant's original attempt to reconcile the two are even more extraordinary. Indeed, Kant's take on physical monads anticipated the dynamical theory of matter that he developed later in 1786 in the *Metaphysical Foundations of Natural Science*, and that was bound to have a huge impact in the development of the physical sciences of nineteenth century from Oersted to Faraday, as we shall see in the next section.

With the *Inaugural Dissertation* of 1770, entitled *Concerning the Form and Principles of the Sensible and the Intelligible World*, which marks a watershed in Kant's philosophy, Leibnizian metaphysics and Newtonian science are finally disentangled. Against both the Newtonian and the Leibnizian tradition and their respective attempts to reconcile physics with a metaphysics of space, time, and physical substances, Kant's critical philosophy for the very first time introduced a distinction between the faculty of sensible cognition and the faculty of intellectual cognition, and relegated the monadic realm to the second, and space and time as autonomous forms of sensible intuition to the former.

With the beginning of Kant's critical period, the relationship between philosophy and the sciences was completely reconsidered. The task for Kant was no longer to reconcile physical discoveries with metaphysical debates on the nature of space, time, and physical

⁴ To this purpose, Kant resorted to a slightly modified proof already present in the *Introduction to Natural Philosophy* by the Newtonian John Keill (1726). The idea of physical monads was at odds with Leibnizian–Wolffian metaphysics, according to which monads are indeed constituted by primitive active and passive forces which are however distinct from derivative active and passive forces at work in the dynamics of moving bodies (Leibniz's *Specimen dynamicum*, and Wolff *Cosmologia generalis* §§183–4. I thank Silvia De Bianchi for helpful research collaboration on this issue). As Watkins (2005), 70 notes, the main problem for Leibniz was to try to harmonize 'the realm of final causality' (monads) with the 'realm of efficient causality' (bodies), i.e. the 'freedom of monads with the determinism of bodies'. Watkins goes on to claim that the idea of monads as physical points, and not just metaphysical substances, was defended on the other hand by Martin Knutzen, who was Kant's teacher although the relationship between the two was not very rosy and polemic references to Knutzen can be found in Kant (1747). On the Kant–Knutzen relationship, see Beiser (1992), Schönfeld (2006), and Kuehn (2001).

substances. Instead, the main task for Kant's critical philosophy became that of explaining and justifying how the very successful mathematical-physical sciences of his time were possible, by looking at the conditions of possibility of our scientific knowledge of nature. The answer that Kant gave to this question is well-known: our scientific knowledge of nature is the serendipitous result of applying pure concepts of the faculty of understanding to 'appearances', intended as the conceptually still undetermined spatio-temporal objects as given to the mind in empirical intuition. If the task of critical philosophy was to explain why we have achieved such secure foundations in the mathematics and natural sciences of the time, the answer that critical philosophy gave to this epistemological question relied on the way in which our mind contributes to our scientific knowledge, by projecting onto nature *a priori* forms of sensibility such as space and time as well as *a priori* principles of the understanding, such as for instance causality.

It is not my aim in this paper to enter into the details of Kant's critical philosophy. Instead, since the topic of this paper is to analyse the relationship between philosophy and the sciences after Kant, I simply want to highlight some points which I deem relevant to this topic. First, as the above short remarks about Kant's pre-critical writings show, we can legitimately regard Kant's critical philosophy as the final outcome of Kant's life-long commitment to both the philosophy and the sciences of his time (namely, to Leibniz–Wolff metaphysics on the one hand, and Newtonian physics, on the other hand). Second, the original solution that Kant gave to the problem of how to reconcile the two, consisted in relegating traditional metaphysical debates to the noumenal realm and redefining the role of philosophy as mainly centred around the epistemological questions of 'how is pure mathematics possible?' and 'how is pure natural science possible?'. Kant's transcendental method starts from the fact of science and traces it back to the conditions of possibility of our scientific knowledge. Indeed, the exact sciences continued to play a key role in Kant's critical philosophy as the very source of inspiration and motivation for his entire epistemological project.

No wonder Kant opened the Preface to the second edition of the *Critique of Pure Reason* (1787) by programmatically linking his Copernican turn to the work of scientists such as Galileo, Torricelli and Stahl:

When Galileo rolled balls of a weight chosen by himself down an inclined plane, (. . .) a light dawned on all those who study nature. They comprehended that reason has insight only into what it itself produces according to its own design; that it must take the lead

Philosophy and the sciences after Kant

with principles for its judgements according to constant laws and compel nature to answer its questions, rather than letting nature guide its movements by keeping reason, as it were, in leading-strings; for otherwise accidental observations (...) can never connect up into a necessary law, which is yet what reason seeks and requires. Reason, in order to be taught by nature, must approach nature with its **principles** in one hand, (...) and, in the other hand, the **experiments** thought out in accordance with these principles – yet in order to be instructed by nature not like a pupil, who has recited to him whatever the teacher wants to say, but like an appointed judge who compels witnesses to answer the questions he puts to them. (...) This is how natural science was first brought to the secure course of a science after groping about for so many centuries.⁵

Galileo is here portrayed as the scientist who paradigmatically accomplished the revolutionary shift that Kant was urging for in epistemology: namely, the shift from the view that our scientific knowledge proceeds from nature itself (i.e. that what we *believe* there is proceeds from what there *is*, which is the very source of the problem of knowledge) to the opposite Kantian view, according to which ‘we can cognize of things *a priori* only what we ourselves have put into them’.⁶ The certainty and secure foundation achieved by natural science from the time of Galileo onwards is – to Kant’s eyes – the paradigmatic expression of this shift. Reason must approach nature with its *principles* on the one hand, and with *experiments* thought out in accordance with these principles, on the other hand.⁷ And the task of transcendental philosophy is to clarify what are the principles that make our scientific knowledge of nature possible.

Thus, by asking how pure natural science is possible, Kant was trying to justify why we *do* in fact have a science of nature from the time of Galileo onwards. It is from this particular perspective – I want to suggest – that we can read Kant’s entire philosophical enterprise from the *Metaphysical Foundations of Natural Science* (1786) until his last incomplete work ‘Transition from the Metaphysical Foundations of Natural Science to Physics’ published in the *Opus postumum*.

⁵ Kant (1781, 1787); Eng. transl. (1997) *Critique of Pure Reason*, Preface to the second edition, B xiii–xiv. Emphasis added.

⁶ *Ibid.* Bxviii.

⁷ I have explored this point in Massimi (2008b) in relation to what I think is Kant’s new conception of phenomena and its relevance to current debates in philosophy of science.

In the *Metaphysical Foundations of Natural Science* (1786) Kant expressly tried to latch the transcendental apparatus developed in the *Critique of Pure Reason* onto the physical sciences of his time, namely Galilean–Newtonian physics, so as to provide a justification for its secure foundations.⁸ The task of this fundamental work is to show how the empirical concept of matter can be schematised according to the table of categories developed in the Transcendental Analytic of the *Critique of Pure Reason*, i.e. namely according to the four categories of quantity, quality, relation and modality. Hence, four corresponding chapters entitled respectively *Metaphysical Foundations of Phoronomy*, *Dynamics*, *Mechanics* and *Phenomenology*. And while the chapter on *Phoronomy* investigates matter as a mathematical point-like movable in space endowed exclusively with a certain ‘quantity of motion’ (namely, speed and direction), in the following chapter ‘*Metaphysical Foundations of Dynamics*’, Kant defined the empirical concept of matter according to the category of quality as the *movable* that fills a space through a *particular moving force*. More precisely, he introduced a priori *attractive and repulsive forces* (which featured already in the 1756 *Physical Monadology*) as two fundamental moving forces, through which matter can fill a space by either causing other bodies to approach it or to be removed from it. Kant derived these two fundamental moving forces a priori from two basic properties of matter, namely its impenetrability and its ability to strive to enlarge the space that it fills so as to counteract the opposite tendency expressed by the repulsive force.

The *a priori* introduction of these two fundamental moving forces paves the way to the chapter on *Mechanics*, where Kant reformulated Newton’s three laws of motion, including Newton’s second law, which is regarded as instantiating the category of causality (whereby the impressed force is the *cause* of change in the inertial state of the system). Finally, in the fourth chapter on *Phenomenology*, the empirical concept of matter as the movable in space is defined according to the category of modality. Kant’s aim was to show how to transform *appearance* (*Erscheinung*) into *experience* (*Erfahrung*); more precisely, how to

⁸ Michael Friedman has discussed in detail Kant’s project in the *Metaphysical Foundations* as strictly related to, and almost an instantiation of Kant’s epistemological stance in the *Critique of Pure Reason* (see Friedman 1992a, 1992b). For an alternative reading of Kant’s project in the *Metaphysical Foundations* that disentangles the enduring significance of Kant’s philosophy from the fortunes of Newtonian mechanics, see Buchdahl (1969a), (1969b), (1974); for a similar line of argument, see also Allison (1994).

Philosophy and the sciences after Kant

transform *apparent motions* into *true motions*. According to Friedman,⁹ since Kant rejected Newton's view on absolute space and time, he needed to find a way of explaining true or absolute motions without resorting to absolute space as a privileged reference frame. Kant's strategy consisted in identifying the centre of mass of our solar system as a privileged reference frame. To this purpose, he needed to derive Newton's law of gravitation, responsible for the planetary motions in the solar system, as a necessary and universal feature of matter as the movable in space.

Without going any further into this discussion, the point I want to stress is that following Friedman's reading, in the *Metaphysical Foundations of Natural Science* Kant was trying to give an answer to the epistemological question 'how is pure natural science possible?' by looking at the specific way in which Newton's three laws of motion and the law of gravitation could be justified within the conceptual apparatus of Kant's transcendental philosophy.

In this respect, the *Metaphysical Foundations of Natural Science* occupies a central role in the history of epistemological naturalism, namely in the view according to which answers to the **problem of knowledge** can be found by drawing on **natural sciences** (especially, the physical sciences as historically developed from the time of Galileo and Newton onwards). Kant's **epistemological naturalism**¹⁰ starts with the questions 'what is knowledge?', 'how

⁹ Friedman (1992a), ch. 4, on which I draw here.

¹⁰ A terminological clarification is in order here. I shall henceforth refer to Kant's 'epistemological naturalism' in the specific sense clarified above: namely, that answers to the problem of knowledge should be found by drawing on the natural sciences and on their history. If we want to understand how knowledge is possible, we should investigate how the very successful sciences of the time (Galilean–Newtonian mechanics) were possible, in the first place. Kant's epistemological project was patterned upon the sciences of his time. This is what I mean here – in a somehow liberal sense – by 'epistemological naturalism'. The term should not be confused with a more common usage of the expression in contemporary (post-Quinean) epistemology to indicate that epistemology should be naturalised, and become a chapter of cognitive psychology (see Quine's seminal work (1969), and Laudan (1990), Kitcher (1992) for more recent discussions of the topic). Kant never endorsed what we now call 'naturalised epistemology': for him, human thought has a fundamentally normative role that cannot be clarified in terms of any naturalistic description. As Hatfield (1990), 17 has pointed out, for Kant 'empirical or natural-scientific description of the mind [is] irrelevant to the discovery and application of standards of epistemic valuation'. On the other hand, this was precisely the path

is scientific knowledge of nature possible?'. The pursuit of these epistemological questions led him naturally to the **sciences** and to **philosophy of science** in the attempt to understand the growth of scientific knowledge from the time of Galileo onwards.

If physical sciences, in particular the Galilean–Newtonian tradition, is Kant's main concern in the *Metaphysical Foundations of Natural Science*, on the other hand in the final period of his career and life Kant somehow went back to a series of problems that occupied him already in his early (mid-1750s) works, in particular new discovery in experimental physics and chemistry about combustion, cohesion of solids, and changes of physical state. And if back in 1786, he had dismissed chemistry as a 'systematic art' rather than a proper science, now Kant's awareness of Lavoisier's chemical revolution at the turn of the century, and of the then fashionable theories of caloric and ether as the substances for heat and light, features clearly in his last and never completed work entitled 'Transition from the Metaphysical Foundations of Natural Science to Physics', published as part of the *Opus postumum*.¹¹

In this last work, which in Kant's intention was meant to fill a gap he felt was still open in his transcendental philosophy after the *Critique of Judgment*, Kant claimed that in order to complete the transition from the metaphysical foundations of natural science to

followed after Kant by Hermann von Helmholtz's empirical research on the physiology of spatial perception.

¹¹ Friedman (1992a), ch. 5, has illuminatingly pointed out how Lavoisier's chemical revolution, and the recent discoveries of pneumatic chemistry underlie and prompted the 'Transition', whose specific aim was to bridge the gap between the *Metaphysical Foundations* on the one hand, and the vast realm of empirical forces recently discovered, on the other hand. In addition to Friedman's analysis, it must be noted that although the characterization of ether as Wärmestoffe, i.e. as a medium for the transmission of heat, betrays Kant's attempt to reconcile Lavoisier's caloric with ether theories, Kant's use of the ether as a medium for the transmission of attractive and repulsive forces is to be found already in Kant (1755a) and (1755b), with some clear echoes of Newton's analogous use of the ether in the second edition of *Principia* (1713) and most importantly in the 2nd English edition of *Optics* (1717). I have investigated the influence of the Newtonian experimentalism of Oprechts, and of the ensuing British and Dutch Natural Philosophy of Stephen Hales and Herman Boerhaave, for Kant (1755a) and (1755b) in a paper currently under preparation. It is as if the last Kant of the *Opus postumum* felt the need to go back to some physical problems that originally prompted his philosophical investigation back in the 1750s.

physics, it was not enough to establish *a priori* attraction and repulsion as two fundamental moving forces in nature. It was not enough because there remains a gap between postulating these two fundamental moving forces in nature from a metaphysical point of view, on the one hand, and accounting for the wide range of specific empirical properties of matter discovered by the chemical revolution by the end of eighteenth century, on the other hand. Hence the necessity to bridge the gap between the all-encompassing metaphysical framework canvassed in the *Metaphysical Foundations* on the one hand, and the multifarious range of more specific empirical properties of matter that natural scientists were discovering, on the other hand.

This is the specific task that Kant aimed to accomplish with the ‘Transition to Physics’, where by physics Kant meant ‘the systematic investigation of nature as to empirically given forces of matter, insofar as they are combined among one another in one system’ (22: 298). The main concern of the ‘Transition’ was then to justify and ground bottom-up a *system of empirically given forces* in nature. The problem is that in nature we may observe objects moving in space and time, changing physical state (from solid to liquid to gaseous) or displaying some properties (e.g. being elastic). But these are only appearances [*Erscheinungen*]. Only when we introduce moving forces as the underlying *causes* that make the objects move in space, or change their physical state or displaying some physical or chemical properties, do we have a conceptually determined appearance or *phenomenon* as the proper object of scientific knowledge. Once again, the category of causality was regarded as crucial in our scientific understanding of a variety of physical phenomena involving moving forces (e.g. forces responsible for the solidification, liquefaction, elasticity, and cohesion of objects).¹² Thus, still in this last and incomplete work, Kant was striving to implement and extend his transcendental apparatus well beyond Newtonian physics to include pneumatic chemistry, theories of heat and light, and even biological theories of his time.¹³

¹² I have investigated the relevance of the ‘Transition’ in relation to a Kantian conception of phenomena and current debates in philosophy of science, in Massimi (2008b).

¹³ For an alternative analysis of Kant’s project in the ‘Transition’, and his proof of the existence of the ether as part of his search for a replacement of his earlier dynamic theory of matter – exposed in the *Metaphysical Foundations* – see Förster (2000).

To sum up, with Immanuel Kant epistemology, or better what became later known as *Erkenntnistheorie*¹⁴ acquired a central role in philosophy: analyses of the transcendental conditions for human knowledge replaced time-honoured metaphysical discussions about the nature of time and space triggered by Newtonian science and the Leibniz–Clarke debate. But the normative role of epistemology in tackling the problem of knowledge is – in Kant’s view–intrinsically related to the role of the sciences as exemplars of human knowledge. Kant’s **epistemological naturalism** is entangled with and ultimately leads into **philosophy of science**: the latter is necessary to accomplish the normative task of the former.

I take this as the greatest Kantian insight that unfortunately both current epistemologists *and* philosophers of science in the Anglo-American world seem to have lost sight of. From the 1930s onwards, in the Anglo-American world, knowledge was identified with justified true belief, and the task of epistemology was no longer to investigate the ‘fact of science’ so as to find the transcendental conditions for human knowledge, but rather to investigate the logical structure and syntax of language so as to find the sufficient conditions for beliefs to count as knowledge. In the rest of this paper, I attempt a diagnosis of how we got to this stage of detaching epistemology from philosophy of science and hence from science itself. I believe that despite the revival of naturalized epistemology in the second half of twentieth-century, there remains a gap between the philosophy and the sciences that has never been bridged since the time of Kant. And the first signs of this increasing gap became soon evident in the Kant aftermath, at the beginning of the nineteenth century.

3. Philosophy and the sciences after Kant. The nineteenth century

In this section, I take a brief look at some salient aspects of the relationship between philosophy and the sciences after Kant, with a focus on two main aspects of the Kantian legacy for the nineteenth century. The first concerns the impact that Kant’s philosophy of

¹⁴ As Caygill (1995), 176 points out ‘the German term *Erkenntnistheorie* (theory of knowledge) often translated as epistemology is (...) post-Kantian and was coined by K.L. Reinhold as part of his attempt to transform the critical philosophy into a theory of representation in *Letters on the Kantian Philosophy* (1790–2).’

Philosophy and the sciences after Kant

science had for the developments of the nineteenth-century physical sciences. The second is more directly related to the end of Kant's epistemological naturalism, i.e. his project of tackling the problem of knowledge by taking the sciences as exemplars of human knowledge, in the post-Kantian German tradition. Let us take a look at the first of these two aspects.

Historians and philosophers of science have recently begun to pay more attention to the impact of Kant's philosophy of science for nineteenth-century physical sciences.¹⁵ One of the most significant implications was the role that Kant's dynamic theory of matter played for the movement known as *Naturphilosophie* that developed mainly around Friedrich von Schelling's two main works *Ideas towards a philosophy of nature* (1797) and *First Outline of a System of Philosophy of Nature* (1799). As mentioned in the previous section, following Friedmann's analysis, in the *Metaphysical Foundations of Natural Science* Kant identified two fundamental moving forces in nature: a repulsive force responsible for matter's impenetrability and an attractive force counterbalancing the repulsive force. Kant's aim was to start with these two *a priori* established moving forces to provide a top-down justification for his three laws of mechanics. Kant saw the three laws of motion as ultimately grounded on the transcendental principles of substance, causality and reciprocity and on the *constitutive* role these principles play for experience. This top-down procedure finds its natural counterpart in a bottom-up procedure that Kant developed from the *Critique of Judgment* (1790) to the 'Transition from the Metaphysical Foundations of Natural Science to Physics' in the *Opus postumum*. According to this alternative bottom-up procedure, we should start instead from empirically given forces of matter and empirical laws, such as those that the chemical revolution was discovering at the end of eighteenth century, and try to subsume them under higher level yet still empirical laws so as to seek after a *system* of forces in nature. *Systematicity* or *systematic unity* in the investigation of nature was presented as an open-ended, *regulative* (as opposed to *constitutive*) principle of scientific inquiry. It is precisely this distinction between constitutive versus regulative principles, which in Kant runs parallel to the distinction between the faculty of understanding

¹⁵ For the multifarious aspects of the Kantian legacy for nineteenth-century physical sciences, see the excellent anthology by Michael Friedman and Alfred Nordmann (2006), on which I draw here (for a review of this volume, see Massimi 2008a).

and the faculty of reason or reflective judgment¹⁶ that the *Naturphilosophen* dismantled.

The *Naturphilosophen* rejected the dualism between constitutive and regulative principles, and gave a constitutive twist to the regulative principle of systematicity. While Kant stressed systematicity as a regulative principle that the mind projects upon nature, Schelling saw nature itself as systematic and ordered. The speculative physics championed by *Naturphilosophen* regarded nature as productivity, i.e. as *natura naturans* (as opposed to *natura naturata*). This idea of nature as productivity prompted an investigation of forces in nature as the causes of variety of phenomena.

The *Naturphilosophen* extended Kant's dynamic theory of matter well beyond what Kant had envisaged: for them, nature as a whole *dialectically* evolved from the inert/lifeless matter described by Kant into the variety of forms described by contemporary chemistry and biology. Under the influence of the Romantics (from Goethe to Novalis) and influenced by the new electrochemistry, Schelling extended Kant's theory of matter beyond attraction and repulsion and regarded magnetic, electrical and galvanic forces as a *dialectical* development of these two fundamental forces of matter.¹⁷ The search for interconversion processes in the name of the unity and productivity of nature was open, and became a dominant theme of nineteenth-century physical sciences. The interconversion of electrical and magnetic phenomena is one example.

Indeed, Schelling's reinterpretation of Kant in his *System of Transcendental Idealism* (1800) had important implications for the history of electromagnetism in the early nineteenth century. Hans Christian Oersted's pioneering discovery in 1820 that the passage of electric current in a wire could twist sideways a magnetic needle marks the beginning of electromagnetic theory. Oersted was deeply influenced by Schelling, who he came to know via Johann W. Ritter, and even more so by Kant's own dynamic theory of matter that was

¹⁶ In the *Critique of Pure Reason*, in the Appendix to the Transcendental Dialectic, Kant defended systematicity as a regulative principle of the faculty of reason; but in the Introduction of the *Critique of Judgment* the very same regulative principle was re-assigned to the faculty of reflective judgment as the faculty responsible for subsuming the particular under the universal.

¹⁷ For an excellent analysis of how *Naturphilosophie* expanded some Kantian themes and at the same time influenced some physical discoveries see Gower (1973); and Friedman (2006).

Philosophy and the sciences after Kant

the subject of his doctoral dissertation.¹⁸ Moreover, he attended Fichte's lectures in Berlin and Friederich Schlegel's lecture at Jena.

Some historians of science have even stressed the influence that the German *Naturphilosophie* had in the English-speaking world through Samuel Taylor Coleridge, who was a disciple of Kant in his stay in Germany at the end of eighteenth century, and back in England, allegedly inspired his friend Humphry Davy and via Davy, Michael Faraday, who worked for Davy at the Royal Institution in London.¹⁹ It is no surprise then that Faraday's discovery of electromagnetic induction in 1831 was welcomed by Schelling as vindicating the *Naturphilosophie* manifesto of nature as productivity.

Electromagnetism is not the only example of how Kant's philosophy of science, via Schelling's reformulation, had an impact on the physical sciences of the nineteenth century. The interconversion of heat and mechanical work expressed by the first law of thermodynamics – jointly discovered by Julius Robert Mayer, Hermann von Helmholtz and James Prescott Joule in the 1840s – is another eloquent example. While the link between Mayer and *Naturphilosophie* has become a debated issue in history of science after Thomas Kuhn's seminal article 'Energy conservation as an example of simultaneous discovery' in the late 1950s,²⁰ a more robust historical link between *Naturphilosophie* and Hermann von Helmholtz, whose father was a close friend of Fichte, has generally been recognised.²¹

But the Kantian legacy for nineteenth-century science is not confined to the interconversion processes at work in electromagnetism and thermodynamics. It extends also to more theoretical aspects of mathematical physics in the works of Jakob F. Fries' *The Mathematical Philosophy of Nature* (1822).²² In the same

¹⁸ On Schelling's influence on Oersted's discovery of electromagnetism see Friedman (2006). Shanahan (1989) argues that Oersted owed more to Kant than to *Naturphilosophie*. He had to study Kant as part of the curriculum in natural philosophy at the University of Copenhagen and indeed wrote his doctoral dissertation on Kant's *Metaphysical Foundations of Natural Science*.

¹⁹ The Kant-Coleridge-Davy-Faraday connection is advocated by the historian Williams (1965), (1973), and questioned by the historian Caneva (1997).

²⁰ Reprinted in Kuhn (1977), 66–104. Against Kuhn's claim that *Naturphilosophie* was an important factor in Mayer's discovery of energy conservation, see Caneva (1993), ch. 7.

²¹ For the influence of *Naturphilosophie* on von Helmholtz see Cahan (1993), ch. 7 and 12.

²² See Pulte (2006).

aforementioned spirit of rejecting the constitutive/regulative distinction and affirming the priority of the regulative over the constitutive, Fries saw Euler and Lagrange's principles of analytical mechanics as the result of a bottom-up approach for systematizing mechanical experience before any constitutive principle could be found and any forces of matter identified. Even more striking is the impact of Kant's *Transcendental Aesthetic* for the discovery of non-Euclidean geometries. For Kant, the universal and necessary status of Euclidean geometry could be traced back to the fact that objects are given to the mind in empirical intuition according to space and time as *a priori* forms of sensibility. Hermann von Helmholtz challenged Kant on the allegedly necessary status of Euclidean geometry by showing that what makes space seem Euclidean is a series of sense-impressions about the free mobility of rigid bodies and paths of light rays, and the very same empirical evidence can acquaint us with the structure of a non-Euclidean space; hence the non-necessary status of Euclid's fifth postulate. In this way, Helmholtz's empiricism paved the way to Poincaré's conventionalism about geometry, and to non-Euclidean geometries in relativity theory in the twentieth century.²³

While the *Naturphilosophen* rejection of the regulative versus constitutive distinction and emphasis on the unity of nature opened undreamt-of avenues for the physical sciences, on the other hand, it also engendered a swirl of new philosophical problems. One of the central tenets of post-Kantian German idealism, from Schelling to Fichte to Hegel, was the rejection of Kant's distinction between the faculty of sensibility and the faculty of understanding. For Kant, the distinction between these two faculties was central to understand how nature as given to us in sensible receptivity could become an object of scientific knowledge. And, for Kant, the answer to the problem of knowledge was to be found in the way in which concepts of the faculty of understanding are 'schematised' and applied to spatiotemporal objects of the faculty of sensibility (namely, to 'appearances' as given to the mind in empirical intuition according to *a priori* forms of space and time).

In the hands of post-Kantian German idealists, Kant's interplay of the faculty of sensibility and the faculty of understanding received a new twist, and the contribution of the faculty of sensibility was significantly downplayed. Nature was increasingly regarded as embedded in the conceptual realm, and eventually as the historicized

²³ For the link between Kant, Helmholtz's empiricism and Poincaré's conventionalism, see DiSalle (2006a) 55–72, (2006b).

Philosophy and the sciences after Kant

manifestation of the dialectical development of the spirit, according to Hegel. But it is not just the faculty of sensibility that was downplayed to emphasise the conceptual aspect of human knowledge over and above the contribution of sensibility. The same faculty of understanding was in turn downplayed with respect to the faculty of reason. For Kant, there was an important difference between understanding and reason: the former is the realm of *constitutive* principles that enter in the way we constitute experience by ‘schematizing’ concepts (i.e. by applying them to spatio-temporal appearances); reason, on the other hand, is the realm of *regulative* principles that provide open-ended and never achievable ideals, towards which we should strive in our scientific knowledge of nature. We have already mentioned that a distinctive feature of *Naturphilosophie* was the pre-eminence assigned to regulative principles over constitutive ones. A consequence of this shift was precisely the aforementioned development of a new dynamic theory of matter that – in the name of the regulative principle of systematicity – took nature as *natura naturans* developing *dialectically* from polar forces. This very same shift, however, had also the effect of opening a gulf between philosophy and the sciences. The historicized, dialectical development of human reason, in conjunction with the downplay of the Kantian faculty of sensibility, meant that knowledge of nature was no longer secured by the Kantian interplay of intuitions and concepts; but rather by the spontaneous activity and dialectical unfolding of human reason itself.

The problem of bridging the gap between what we believe there is and what there is was no longer tackled through Kant’s Copernican turn of making appearances conform to *our* way of representing. Instead, *our* way of representing became all there is. The very same dichotomy between us as epistemic agents and the external world as an object of knowledge disappeared in post-Kantian German idealism. And with it, the problem of knowledge that had haunted epistemological naturalism from Hume to Kant also disappeared. Or better, in its place now there was a new problem: that of the unbounded autonomy of human reason in its historicised unfolding. The immediate effect of this idealistic twist was of course that the scientific preoccupations that had triggered Kant’s Copernican turn were put to rest for some time. The aim of philosophy – for post-Kantian German idealism – was no longer to explain how we can have scientific knowledge of nature. Nor is the aim of science to provide an exemplar of human knowledge: the post-Kantian idealistic tradition rediscovered the importance of the arts and humanities (from music to art) as exemplars of human knowledge alternative to

the sciences. Hence the ensuing debate between *Naturwissenschaften* and *Geisteswissenschaften* that became so typical of German philosophy.

But it is from within this idealistic tradition that at the end of nineteenth century and beginning of the twentieth century a new movement developed, whose primary aim was to rediscover the problem of knowledge and to return to Kant's epistemological project and to the scientific preoccupations behind it. This movement was the Marburg School of neo-Kantianism with Hermann Cohen, Paul Natorp, and Ernst Cassirer.

4. Philosophy and the sciences after Kant. The twentieth century

4.1. Marburg neo-Kantianism

It was the impressive progress of the physical sciences at the end of nineteenth century and beginning of twentieth century (from Maxwell's electromagnetic theory to Boltzmann's statistical mechanics, from quantum theory to relativity theory) that brought philosophers' attention back to the problem of knowledge in the distinctive way in which Kant originally posed it. The return to Kant coincided with and was prompted by the advances of positive sciences. And the primary aim of philosophy became that of providing a theory of knowledge – *Erkenntnistheorie* – that could encompass the fundamental principles of knowledge at work not just in the positive sciences but also in other domains of human knowledge (from morality to aesthetics). *Erkenntnistheorie* became the main focus of the Marburg School of neo-Kantianism. Starting from what – in typically Marburgers' style – they called the 'fact of science' (but also of human culture, more in general), the aim of critical philosophy was to identify the transcendental principles that make it possible.

At the same time, the Marburg return to critical philosophy was inevitably filtered through the post-Kantian idealistic tradition. By contrast with Kant, there is an important residue of idealism in the Marburg *Erkenntnistheorie*. The transcendental principles that make the 'fact of science', of art, of human culture possible are primarily 'ideas' (or, to use Kant's terminology, *regulative ideas*) providing an open-ended normative goal to philosophical inquiry, and analysed in their historical unfolding across the history of science, history of art and of human culture, more in general. By contrast with Kant, who saw in the interplay of the faculty of sensibility and

Philosophy and the sciences after Kant

the faculty of understanding (of spatio-temporal intuitions and concepts of the understanding) the key to answer how scientific knowledge is possible, the neo-Kantians Marburgers rejected what to their eyes appeared as Kant's semi-psychologistic approach. In their hands the Marburgers, Kant's system came out completely transformed, with the faculty of sensibility gone and the faculty of understanding being played down in favour of the faculty of reason.

Despite these important differences with respect to the Kantian system, we owe to Marburg neo-Kantianism the rediscovery of the Kantian insight about philosophy and the sciences. As Alan Richardson has nicely put it, for them 'science serves both as a resource in the fight against metaphysics and its sceptical antithesis and as a problem for transcendental philosophy. More precisely, (...) the fact of science explodes scepticism and humbles metaphysics, while the philosophical account of scientific objectivity becomes the highest speculative burden of transcendental philosophy'.²⁴ Transcendental philosophy is considered the best safeguard against the risks of both metaphysics and scepticism, and, at the same time, as laying down the 'idealistic' principles that should account for scientific objectivity. The real novelty compared to Kant has to be found both in the quasi-*Naturphilosophisch* insistence on the *regulative* (as opposed to *constitutive*) *principles*, and on the quasi-Hegelian emphasis on the historical unfolding of these principles. In Hermann Cohen's pioneering work on the history of analytical mechanics from Euler to Lagrange,²⁵ as in Ernst Cassirer's monumental four-volume *Erkenntnistheorie* from Galileo to Hegel and modern times,²⁶ critical philosophy – or better, **epistemology intended as *Erkenntnistheorie*** – was intertwined with both history of philosophy and history of science. And history of science, intended as intellectual history, became an indispensable element to understand the historical unfolding of the transcendental principles of human knowledge. As we shall see below, this rediscovery of intellectual history is a distinctive Marburg feature that many decades later Thomas Kuhn himself acknowledged as having played a role in his own conception of the relationship between philosophy of science and history of science.

The emphasis on regulative over constitutive principles, and on the historicised unfolding of human thought through an open-ended series of logico-mathematical structures as a regulative idea of

²⁴ Richardson (2006), p. 216.

²⁵ Cohen (1883).

²⁶ Cassirer (1906–1957).

reason, is particularly evident in Ernst Cassirer's so-called 'genetic' conception of knowledge.²⁷ Cassirer reinterpreted the Kantian '*a priori*' in *regulative* terms. This reinterpretation of the *a priori* as a regulative idea finds its natural expression in what Cassirer called the 'invariants of experience'.²⁸ The *a priori* no longer denotes that which is *prior* to experience in the sense of being the condition of possibility of experience; but rather that which is the ultimate 'invariant' of experience, unattainable at any stage and yet a regulative goal of scientific inquiry. This seminal investigation – carried out in *Substance and Function* (1910) – was further articulated and explored in Cassirer's later books, namely in the one dedicated to the philosophy of the Enlightenment, and in *Determinism and Indeterminism in Modern Physics*.

In *The philosophy of the Enlightenment* (1932), Cassirer offered a long overdue reappraisal of the Enlightenment conception of scientific progress and rationality. Against the dogmatic tendency to build up philosophical systems, the Enlightenment rediscovered the importance of starting from phenomena. Newton's method of deduction from phenomena (paradigmatically deployed in the *Principia*) became the gold standard of the Enlightenment 'systematic spirit' (*esprit systématique*). Newton's method does not proceed from concepts and axioms to phenomena, but the other way around: reason becomes the form of the immanent connection of phenomena. This is evidently a neo-Kantian reading of the philosophy of the Enlightenment, a way of linking the philosophical roots of the Kantian regulative demand to the *philosophes'* conception of 'reason' and their admiration for Newton's method. From this perspective, Newton's method of deduction from phenomena comes to fulfil a regulative task: it reveals lawlikeness as immanent in phenomena.

²⁷ In an interesting study, on which I drew here, dedicated to a comparison of Carnap, Cassirer, and Heidegger, Michael Friedman (2000), ch. 6, has noticed that it is typical of the teleologically oriented 'genetic' conception of knowledge of Cassirer (and of the Marburg School, more in general) to replace Kant's conception of the constitutive *a priori* with a purely regulative idea.

²⁸ 'From this point of view, the strictly limited meaning of the '*a priori*' is clearly evident. Only those ultimate logical invariants can be called a priori, which lie at the basis of any determination of a connection according to natural law. A cognition is called a priori not in any sense as if it were *prior* to experience, but because and insofar as it is contained as a necessary premise in every valid judgment concerning facts' Cassirer (1910), English transl. (1953), 269.

Philosophy and the sciences after Kant

These ideas were further spelled out in Cassirer's later book *Determinism and Indeterminism in Modern Physics* (1936). According to Cassirer, modern physics has not given up the salient features of Kant's philosophical enterprise. On the contrary, quantum mechanics has only made evident the fact that Kant's philosophical apparatus is to be thought of not as rigid but as dynamic. Hence, 'the *a priori* that can still be sought and that alone can be adhered to must do justice to this flexibility. It must be understood in a purely methodological sense. *It is not based on the content of any particular system of axioms, but refers to the process whereby in progressive theoretical research one system develops from another.*'²⁹

I cannot go any further here in an analysis of Cassirer's neo-Kantianism. For the purpose of the present paper, it suffices to note that the relationship between philosophy and the sciences in the twentieth century changed dramatically with the Marburg school. It changed in two main ways. First, philosophy of science was rediscovered once again as a branch of epistemology as *Erkenntnistheorie*, along Kant's original lines. Cassirer's works on Galileo, Newton, and quantum mechanics testifies to the new important role that philosophy of science – intended in the Marburg sense, and surely not in the current sense – played within general epistemology. Second, philosophy of science as a branch of epistemology came to be practiced in strict conjunction with both history of philosophy and history of science. The 'genetic' conception of knowledge prompted the Marburgers to look for the conditions of possibility of human knowledge as historically realised in modern science. However, the serendipitous combination of epistemology, philosophy of science and history of science achieved by the Marburgers was not bound to last. The Vienna Circle of Rudolf Carnap, Moritz Schlick, Hans Hahn, Otto Neurath and Waissman soon gave a new twist to the relationship between philosophy and the sciences, which had far-reaching consequences for the way philosophy of science has been practised in the Anglo-American world since.

4.2. Rudolf Carnap

Among the Vienna Circle, Rudolf Carnap is surely one of the figures that owed most to Marburg neo-Kantianism. As Friedman has

²⁹ Cassirer (1936), Eng. trans. (1956), 74, emphasis added.

illuminatingly reconstructed,³⁰ Carnap studied with the neo-Kantian Bruno Bauch in Jena. He read Kant and neo-Kantians, and many references to Cassirer's *Substance and Function* can be found both in his early works, including his dissertation *Der Raum* (1922), and in *Der logische Aufbau der Welt* (1928). In this latter work, Carnap tried to synthesize the Marburg 'genetic' conception of knowledge with the positivistic faith in a rock bottom level of empirically given sense data (without yet falling back to Kant's faculty of sensibility, or to any phenomenalist foundationalism *à la* Ernst Mach). But the neo-Kantianism that reached Carnap had been filtered through the logicism of Frege and Russell, and through the idea that what Kant thought was pure mathematics is in fact only a branch of logic (and hence analytic a priori, rather than synthetic a priori).

Following up on Frege's logicism that showed that mathematics is not synthetic a priori, Carnap rejected the Kantian idea that Euclidean geometry is the result of pure intuition. Instead, for Carnap what geometry we choose is an entirely conventional matter (following the path originally opened by Helmholtz and later explored by Poincaré). While for Kant, space, time and causality are *a priori* given and hence constitutive of the object of experience, for Carnap what type of spatio-temporal-causal structure (what in a pre-*Aufbau* terminology he referred to as 'secondary world') we pick out is entirely conventional. What is necessary and not conventional is what Carnap called the positivistic 'primary world' of immediately given sense experience.³¹

This fundamental level of immediately given sense experience provides the foundations for Carnap's project of a 'constitutional system' in the *Aufbau*, namely for what – with Kantian terminology – Carnap calls the 'constitution of reality'. The key idea is to replace Cassirer's 'genetic' conception of knowledge, and hence Cassirer's idea of a sequence of *historically given* mathematical-physical structures as a *regulative* idea, with an alternative sequence of increasingly more abstract logical-mathematical structures, as given to each cognitive subject starting from his/her own sense experience. The idea is to ultimately ground the objectivity of knowledge by embedding subjective sense data into an overarching and intersubjectively valid hierarchy of logical structures. It is in this specific sense that the *Aufbau* was meant to reconcile the positivistic faith in the empirically given with the logical idealism of the Marburg School. The final result, in

³⁰ Friedman (1999), ch. 6, and (2000), ch. 5, on which I draw here.

³¹ Carnap (1924). See on this point Friedman (2000), 69.

Philosophy and the sciences after Kant

Friedman's words, was the transformation of 'neo-Kantian tradition into something essentially new: 'logical-analytic' philosophy.'³²

The most important consequence of this 'logicization' of the Marburg School is, in Friedman's words, that 'epistemology (...) is transformed into a logical-mathematical constructive project... This formal exercise is to serve as a *replacement* for traditional epistemology.'³³ Carnap's project dissolved traditional epistemological debates, such as the debate between idealism and realism, into the *Aufbau* 'constitutional system'. Thanks to a neutral common basis of formal logic underlying the construction of reality, and thanks to physicalism (i.e. the belief in a physical basis to which ultimately all scientific concepts are logically reducible) all epistemological and metaphysical disputes could be dissolved.

Yet the problem with Carnap's 'constitutional system' is that by pushing Kant's Copernican turn to its extreme limits, and by showing that our scientific knowledge is *objective* thanks to its being reducible to a series of logical-mathematical structures, Carnap was in fact not only dissolving traditional epistemological and metaphysical disputes. He was also dissolving epistemology as *Erkenntnistheorie* and replacing it with philosophy of science intended – in a positivist way – as a logical-mathematical exercise (along the lines of Frege's *Begriffsschrift*, Russell's *Principles of Mathematics*, and Wittgenstein's *Tractatus*).

This is the point where, in the history of twentieth-century philosophy, epistemology – intended as *Erkenntnistheorie* – and philosophy of science parted their ways, after the short-lived re-union operated by the Marburg School. And this is where we come from, almost eighty years after the *Aufbau*. As I see it, a rather large portion of current philosophy of science seems in some relevant respect still under the logical positivist spell of practicing their subject as detached from epistemology, intended in the original Kantian and neo-Kantian sense as a theory of knowledge. Be it Bayesian networks or decision theory; be it Everettian philosophy of physics or natural kinds in philosophy of biology, most of the current debates in philosophy of science have, on the one hand, revived the epistemological and metaphysical disputes that Carnap's 'constitutional system' was meant to dissolve; on the other hand, they have also engendered a speciation of subfields in philosophy of science, which seem to have lost sight of their origins. Not only have they lost sight of the problem of knowledge that triggered Kant's epistemological naturalism, but they

³² Friedman (1999), 141. See also Richardson (1998).

³³ Friedman (2000), 82.

have also lost sight of the historical dimension that Marburg neo-Kantianism brought to this problem. Two main episodes in the history of twentieth-century philosophy are primarily responsible for this speciation, in my opinion.

The first episode is of course the failure of Carnap's project by its own means, as pointed out by Quine's compelling criticism. Quine's criticism of logical positivism, and in particular his critique of Carnap's notion of analyticity³⁴ constituted ultimately an attack to the Kantian notion of *a priori* as the blueprint of Carnap's 'constitutional' project. In 'Carnap and Logical Truth',³⁵ Quine attacked Carnap's reformulation of *a priori* knowledge in terms of stipulations or conventions: being 'constitutive' of the meanings of some terms of a linguistic framework (in Carnap's conventionalist sense) does not *per se* imply being immune from revision, according to Quine's holism. At the same time, Quine is responsible for a revival of naturalism in epistemology in the 1960s.³⁶ Epistemology is no longer regarded as a transcendental enterprise, as it was for Kant and the neo-Kantians, for whom the primary aim of epistemology is to answer how scientific knowledge is possible. Under Quine, naturalised epistemology becomes a branch of psychology.

But even more interesting for the purpose of my paper and of my analysis of the relationship between science and philosophy, is the second episode in the history of twentieth-century philosophy. An attempt to recover the neo-Kantian sensitivity to history of science, without however recovering also the underlying epistemological motivation, took place in the 1960s, when Thomas Kuhn launched his anti-positivistic trend in philosophy of science, to which I now turn.

4.3. Thomas Kuhn

If the early signs of the divorce of philosophy of science from epistemology (intended as *Erkenntnistheorie*) were already evident with the Vienna Circle, the real divorce was complete in the 1960s. With the works of Thomas Kuhn, a new era began for philosophy of science. While philosophy of science rediscovered the importance of history of science, it also expressly rejected normative epistemology as an inquiry into the conditions of possibility of scientific

³⁴ Quine (1951). For the Carnap–Quine debate see Creath (1990).

³⁵ Quine (1963).

³⁶ Quine (1969).

Philosophy and the sciences after Kant

knowledge. Whereas Carnap's 'constitutional system' in the *Aufbau* still retained some link with the Kantian and neo-Kantian epistemological tradition, although it ended up replacing epistemological disputes with a logical analysis of language; by contrast, Kuhn's philosophy of science dissolved any normative analysis of how scientists acquire knowledge and replaced it with a historical-sociological analysis of what scientists did and believed. Kuhn broke once and for all the link between philosophy of science and epistemology, by rejecting the idea that epistemology has any normative function in an attempt to understand the growth of scientific knowledge. In so doing, Kuhn broke once and for all with the Kantian and neo-Kantian tradition of epistemological naturalism that we have examined so far. With Kuhn's philosophy of science, naturalism is brought to its extreme consequences: philosophy of science should not investigate the problem of knowledge as it may manifest itself in the sciences. Instead, philosophy of science becomes a chapter of history of science, and (even more so after Kuhn) a chapter of sociology of science. What Kitcher portrays as Kuhn's 'radical naturalism'³⁷ originates from his firm opposition to logical positivism.

In the 1960s, Thomas Kuhn was one of the very first to voice a concern about the neglect of history of science, which he ascribed primarily to the logical positivist tradition, and one of the first to advocate an integration of philosophy of science with history of science. Interestingly enough, he appealed to the neo-Kantian tradition for this integration and for the rediscovery of the historical dimension in philosophy of science: 'There have been philosophers of science, usually those with a vaguely neo-Kantian cast, from whom historians can still learn a great deal. I do urge my students to read Emile Meyerson and sometimes Leon Brunschvicg. But I recommend these authors for what they saw in historical materials not for their philosophies, which I join most of my contemporaries in rejecting'.³⁸ Kuhn acknowledges here his debt to the historicised philosophy of science typical of neo-Kantianism, stripped of any underlying epistemological claim. To his eyes, the main contribution of neo-Kantianism has to be found in the important role ascribed to the history of science, not in the underlying epistemological program or in the way in which that program engendered a new wave of philosophy of science. Kuhn rejected Cassirer's philosophy of science as much as he rejected Carnap's philosophy of science,

³⁷ Kitcher (1992).

³⁸ T. Kuhn 'The relations between the history and the philosophy of science', in Kuhn (1977), 11.

albeit for different reasons. He rejected the former because of its link with *Erkenntnistheorie* and its normative role. He rejected positivist philosophy of science, on the other hand, because of its lack of historical dimension.

And to positivist philosophy of science, Kuhn opposed a new 'philosophy of science' that he himself forged and for which history of science may be all the more relevant: this is the philosophical area that Kuhn himself developed with his view on scientific revolutions, paradigm-shift, and incommensurability in *The Structure of Scientific Revolutions* (1962). The only philosophy of science that can be happily wedded with history of science is a *new* philosophy of science that has little in common with positivist philosophy of science. Kuhn the historian *had to create* a brand new philosophy of science to reconcile it with history of science.

In sum, Kuhn could achieve a reconciliation between history and philosophy of science at the cost of 1) rediscovering the historical sensitivity typical of neo-Kantianism, suitably stripped of any underlying epistemological motivations; 2) creating a brand new, anti-positivist philosophy of science for which history could be of some relevance. Is this a cheap price to pay? I think the answer is no, and indeed within the philosophy of science community, many have never accepted the Kuhnian revolution. The divide remains between those that have embraced Kuhn's lesson and try to do a historically informed philosophy of science, and those that following the positivist tradition are still mainly concerned with logical analyses.

We have identified then two main episodes in the twentieth century that mark respectively the divorce of philosophy of science from epistemology (namely, Carnap's logical positivism), and the subsequent divorce of HPS from philosophy of science (with Thomas Kuhn). What these two episodes have in common is the rejection of the Kantian and neo-Kantian program of tackling the problem of knowledge by taking the sciences as exemplars of human knowledge. Namely, what both positivist philosophy of science and Kuhnian HPS share is the view that the sciences cannot really help us answer the problem of knowledge in the sense of identifying the conditions of possibility of human knowledge. On the other hand, sciences can be all the more important in tackling metaphysical problems about space-time, or reductionism in philosophy of biology, or supervenience in philosophy of mind. The detachment of the sciences from the normative role of epistemology as Kant and the neo-Kantians saw it is the distinctive feature of our era, in my view.

I have now finally reached the end of my historical survey of the troubled marriage between philosophy and the sciences after

Kant. I believe that the current situation in history and philosophy of science is just the last episode of this rather long and troubled marriage between philosophy and the sciences that began after Kant. I would like to conclude this paper by foreshadowing possible future directions of research for the field of history and philosophy of science that somehow take their inspiration precisely from Kant.

5. Conclusion. What future for history and philosophy of science after Kuhn? The Kantian legacy

I want to conclude by urging philosophers of science to go beyond Kuhn. In order to reconcile history and philosophy of science, Kuhn created in fact a new sub-discipline within philosophy of science itself, known as HPS. He set his own philosophical agenda, with his manifesto of scientific revolutions, incommensurability, and theory-choice. He clearly and expressly took his distance from positivistic philosophy of science, and identified new problems and new challenges for philosophers of science to address. By contrast with Kuhn, I think that we do not need to set a separate agenda for a historically informed philosophy of science: we do already have a philosophical agenda with a series of compelling and still open questions (from confirmation to scientific explanation; from underdetermination to laws of nature; from causality to foundational issues in physics and biology, among many others). Those questions have traditionally been regarded as falling in the province of logical analyses dear to positivist philosophy of science. They have been regarded as questions that can be addressed in purely analytical, logical terms without any need to engage with history of science. I think that the future of HPS as an integrated discipline consists in showing that those questions do not belong exclusively to the positivist province and can more profitably be addressed by paying due attention to history of science.

But I urge to go beyond Kuhn also in another sense. I think we are still under the Carnapian and Kuhnian spell in thinking that philosophy of science should not only be detached from epistemology, but should in fact replace it. My vision of HPS is different. I see history and philosophy of science as integral part of the overarching normative function of epistemology. The practice of history and philosophy of science, as I see it, is inherent the meliorative project of epistemology. That is why I believe that the current risk that HPS runs of being increasingly isolated from philosophy is not just to be

blamed on post-Fregean epistemology, but is to be blamed also on Kuhn's radical naturalism that has broken the link between philosophy of science and epistemology intended in the Kantian way. My hope is that HPS will eventually rediscover Kantian epistemological naturalism as the family to which it naturally belongs: we do history and philosophy of science because we are ultimately interested in addressing the problem of how we can and indeed *do* have scientific knowledge, and why we do have developed such a surprisingly successful science across centuries. In a truly Kantian spirit, I believe that current history and philosophy of science should rediscover its Kantian epistemological soul (to echo a recent paper by Alan Richardson).

Only in this way, can we hope to bridge the gap between philosophy and the sciences that opened wide after Kant. I am not suggesting that like Kant, we should provide a justification for currently accepted scientific theories. Nor am I, of course, suggesting that we have to dust the Kantian apparatus of *a priori* forms of sensibility and categories of the understanding. I am suggesting instead that any inquiry into the foundations of space-time, or the nature of causation, or living organisms in philosophy of biology, should be addressed and pursued in such a way as to make the question 'how is scientific knowledge possible?' at least meaningful (if not answerable). This particular way of reconciling the practice of history and philosophy of science with the Kantian epistemological tradition has been revived in recent times, thanks to the contributions of Gerd Buchdahl, among the first in the 1960s, and more recently Michael Friedman, Robert DiSalle, Thomas Ryckman, Roberto Torretti, Margaret Morrison, among many others.

Gerd Buchdahl was one of the first in the 1960s to voice the necessity of a return to Kant in the treatment of philosophy of science with his marvellous book *Metaphysics and the Philosophy of Science* (1969a). In more recent years, Michael Friedman has been one of the main advocates of the necessity to rediscover not only Kant's own philosophy of science, but most importantly, Kant's epistemological project and its relevance to twenty-first century history and philosophy of science, despite the widespread prejudice that modern science has proved Kant wrong. In the Kant lectures delivered at Stanford University and published as *The dynamics of reason* (2001), Friedman addresses the very delicate and controversial issue of showing how Kant's epistemology can still be fruitfully applied to twentieth-century science. In particular, he set the ambitious task of reconciling Kuhn's view of scientific revolutions with Kant's idea that there are some *constitutive a priori* elements defining

Philosophy and the sciences after Kant

the conditions of possibility of experience as displayed by any scientific theory. By *relativising* those constitutive *a priori* elements to different theoretical frameworks, Friedman argues that it is possible to accept the Kuhnian picture of science as a sequence of scientific revolutions and paradigm shifts, while at the same time maintaining the Kantian insight that what makes our scientific knowledge of nature possible is precisely the presence of some constitutively *a priori* elements within each theory.

The key idea of Friedman's *dynamic* Kantianism consists then in relativising Kant's notion of *a priori*. Friedman refers back to Hans Reichenbach's *Theory of Relativity and A Priori Knowledge* (1920), suggesting that we should distinguish between two possible meanings of the term 'a priori' in Kant: namely 1) fixed and unrevisable, and 2) constitutive of the object of experience. According to Reichenbach, modern physics has only proved the first meaning wrong, while the second can be maintained and applied to modern scientific theories such as relativity theory. As such, we can keep on using Kant's notion of *a priori* even for twentieth-century physics. The *a priori* becomes relativised: it maintains its constitutive function, while at the same time it is allowed to change with time and to become relative so as to make room for scientific revolutions. This is what Friedman calls the 'relativised *a priori*': it is a significant change compared to Kant, but in a way it allows to reconcile Kant's epistemological project with some modern visions of science.

Accordingly, Friedman claims that we should regard mature theories in science such as Newtonian mechanics or special relativity or general relativity as consisting of two distinct parts: (1) a properly empirical part, containing empirical laws such as Newton's law of gravitation, or Maxwell's equations of electromagnetism in special relativity (SR), or Einstein's equations for the gravitational field in general relativity (GR); and (2) a *constitutively a priori* part containing both the relevant mathematical principles used in formulating the theory (Euclidean geometry; Minkowski space-time in SR; Riemannian theory of manifolds in GR) and certain fundamental physical principles (Newton's laws of motion in Newtonian mechanics, the light principle of SR, the equivalence principle of GR). The claim is that even if the elements of part (2) (i.e. both mathematical and physical principles) can and typically do change in the history of science through scientific revolutions, nonetheless they still retain their Kantian constitutive *a priori* character in making possible the empirical part (1) of the theory.

Friedman points out that the scientific revolutions of twentieth century have made even more clear the constitutive function of *a*

priori principles in Kantian terms, and have even more emphasised the distinction between those constitutively *a priori* elements, on the one hand, and the properly empirical part of the theory, on the other hand. The scientific revolution that Einstein brought about with general relativity, for example, has made even more evident the need of finding constitutive principles as coordinating between an increasingly more abstract mathematical framework, on the one hand, and empirical phenomena, on the other hand. Instead of Euclidean three-dimensional space, we now have a four-dimensional Riemannian manifold of variable curvature. In place of inertial trajectories of Newtonian mechanics, we now have the four-dimensional geodesics of the Riemannian metric. In place of Newton's law of gravitation, we now have Einstein's field equations which relate the four dimensional space-time metric with the stress-energy tensor. Hence, there is an increasing need for principles of coordination mediating between the abstract mathematical structures and concrete physical phenomena. In the case of general relativity for instance, the equivalence principle coordinates the four-dimensional Riemannian geodesic paths with the concrete phenomena of free falling particles in a gravitational field. Friedman claims that the equivalence principle in GR and the light principle in SR have exactly the same coordinating function that Newton's laws of motion have in the context of Newtonian mechanics. And like Newton's laws of motion, they too are fundamental mathematical-physical presuppositions without which the properly empirical laws of the new theory (namely, Maxwell's equations for the electromagnetic field in special relativity; and Einstein's equations for the gravitational field in general relativity) have no empirical meaning or application at all.

Against Quine's holism, Friedman then goes on to claim that it is a big mistake to confuse the mathematical-physical part of a theory with the properly empirical part. While we can subject to experiment the latter, we cannot subject to experiment the former. For instance, despite the fact that Riemannian manifolds can be used to formulate both general relativity and a version of classical mechanics, we cannot say that we can test Riemannian manifolds in either of these two different theories, because Riemannian manifolds provide instead the conditions of possibility of either of the two theories and as such cannot be tested in either of them. Riemannian manifolds together with some fundamental principles such as the equivalence principle in general relativity cannot be subject to experiment or modified because they play a fundamental constitutive function within relativity theory.

In my book *Pauli's Exclusion Principle* (2005), I have latched onto Friedman's dynamic Kantianism by providing an analysis of a

Philosophy and the sciences after Kant

scientific principle, namely Pauli's exclusion principle. Discovered in 1924 by the Austrian Nobel laureate Wolfgang Pauli, the principle excludes the possibility in nature of two electrons, two protons and in general two fermions being in the same dynamic state, and as such it explains a wide array of phenomena such as the stability of matter at the level of galaxies as well as the dynamics of coloured quarks at the subatomic level, among others. I wanted to understand how a scientific principle, such as this one, originates and whether or not it could play a constitutive *a priori* role like the one that Friedman ascribes it to other scientific principles. I then reconstructed in some historical and physical detail the origins of Pauli's principle in the history of early quantum theory and its evolution with the development of quantum statistics in 1926 and later quantum field theory and quantum chromodynamics in the 1960s. The history of Pauli's principle was in my intention functional to addressing the philosophical question of what a scientific principle is, and more in general the epistemological question of how our scientific knowledge of nature – as displayed by QM (and Pauli's principle in it) – is possible.

In my monograph, I drew attention to a different perspective about scientific principles, one that is still *dynamically* Kantian in considering them as relative and revisable, and yet is not distinctively Reichenbachian in identifying them with constitutive *a priori* principles 'coordinating' the mathematical with the proper empirical part of a scientific theory. The history of Pauli's exclusion principle lent itself naturally to this alternative perspective, which latches onto Friedman's by highlighting the complementary, *regulative* Kantian aspect. The upshot of my monograph was to show that an empirical and contingent rule such as Pauli's 1924 exclusion rule attained lawlikeness and necessity because of the *systematizing* role it played in the quantum mechanics framework, whereby systematicity is not just a desirable feature of scientific knowledge. Rather, in a truly Kantian spirit, systematicity as a regulative principle underpins the possibility itself of identifying empirical regularities as lawlike. It is only the systematizing role that an empirical regularity plays within a body of knowledge that transforms it into a fundamental law of nature. This approach has the advantage of doing justice to the revisable and experimentally testable nature of Pauli's principle as much as it grounds its nomological validity on the degree of empirical support it receives within quantum mechanics.

I have lingered on Friedman's dynamic Kantianism and my own more recent work simply because they represent a possible way (albeit not the only one) of developing history and philosophy of science along the epistemological lines that Kant originally traced.

Michela Massimi

Or better, they represent a possible way of practising history and philosophy of science in such a way that the underlying epistemological question ‘how is scientific knowledge possible?’ remains at least meaningful. But many other ways are possible and need to be explored in future research.

To sum up and conclude, I think we should resist two opposite and similarly dangerous temptations. The first is the temptation to make philosophy of science a branch of science itself, where philosophy risks becoming a footnote at the end of a theorem, be it in decision theory or philosophy of physics. Let us leave the sciences to the scientists and content ourselves as philosophers with the perennial problem of understanding how we could reach scientific knowledge in the first place. The second is the opposite temptation of leaving those epistemological questions to the epistemologists, as if an answer to the problem of knowledge should necessarily pertain to the exclusive domain of epistemology as is practised nowadays in analytic philosophy. If philosophy of science has lost its Kantian epistemological soul, similarly current epistemology seems to have in part lost its scientific soul in trying to pursue those important questions beside and beyond any scientific preoccupation.

Kant opened the path by producing an epistemology that was informed by the scientific preoccupations of his time. The burden now is on us to explore the path further and to venture uncharted territories, even if the path may well be rocky and ultimately open-ended. Or better, it is precisely because the path is probably open-ended that the inquiry into the relationship between philosophy and the sciences can and must go on, after Kant, and despite all the limits of Kant’s project.

Acknowledgements

I am very grateful to Anthony O’Hear, Hasok Chang, and the audience of the Royal Institute of Philosophy Annual Series for stimulating comments on a shorter version of this paper. In more recent times, I have much benefited from research collaboration with Silvia De Bianchi on Kant’s early writings on natural science.

Bibliography

Allison, H. E. (1994) ‘Causality and Causal Laws in Kant: a Critique of Michael Friedman’ in Paolo Parrini (ed.) *Kant and Contemporary Epistemology* (Dordrecht: Kluwer Academic Publishers), 291–307.

Philosophy and the sciences after Kant

- Beiser, F. C. (1992) 'Kant's Intellectual Development: 1746–1781' in P. Guyer (ed.) *The Cambridge Companion to Kant* (Cambridge: Cambridge University Press), 26–61.
- Buchdahl, G. (1969a) *Metaphysics and the Philosophy of Science* (Cambridge, Mass.: MIT Press).
- (1969b) 'The Kantian "Dynamic of Reason", with special reference to the place of causality in Kant's system' in L. W. Beck (ed.) *Kant Studies Today* (La Salle, Ill.: Open Court), 341–74.
- (1974) 'The Conception of Lawlikeness in Kant's Philosophy of Science' in L. W. Beck (ed.) *Kant's theory of knowledge* (Dordrecht: Reidel), 128–50.
- Cahan D. (ed.) (1993) *Hermann von Helmholtz and the Foundations of Nineteenth-Century Science* (University of California Press).
- Caneva, K. L. (1993) *Robert Mayer and the Conservation of Energy* (Princeton University Press).
- (1997) 'Physics and *Naturphilosophie*: a Reconnaissance' *History of Science* **35**, 35–106.
- Carnap, R. (1922) *Der Raum. Ein Beitrag zur Wissenschaftslehre* (Berlin: Reuther and Reichard).
- (1924) 'Dreidimensionalität des Raumes und Kausalität', *Annalen der Philosophie und philosophischen Kritik* **4**, 105–130.
- (1928) *Der logische Aufbau der Welt* (Berlin: Weltkreis). English translation (1967) by R. George, *The Logical Structure of the World* (Los Angeles: University of California Press).
- Cassirer, E. (1906) *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit*. (Berlin: Bruno Cassirer).
- (1907) *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit. Zweiter Band* (Berlin: Bruno Cassirer).
- (1920) *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit. Dritter Band: die nachkantische Systeme* (Berlin: Bruno Cassirer).
- (1957) *Das Erkenntnisproblem in der Philosophie und Wissenschaft der neueren Zeit. Vierter Band: von Hegels Tod bis zur Gegenwart* (Stuttgart: Kohlhammer).
- (1910) *Substanzbegriff und Funktionsbegriff. Untersuchungen zu den Grundfragen der Erkenntniskritik* (Berlin: Bruno Cassirer). Engl. transl. (1953) *Substance and Function and Einstein's Theory of Relativity*, by W. C. Swabey (New York: Dover Publications).
- (1932) *Die Philosophie der Aufklärung* (Tübingen: J. C. B. Mohr). English translation, 5th edn *The Philosophy of the*

Michela Massimi

- Enlightenment*, by F. Koelln and J. Pettegrove (Boston: Beacon Press).
- (1936) *Determinismus und Indeterminismus in der modernen Physik* (Göteborg: Höskolas Arsskrift 42). Engl. translation (1956) *Determinism and Indeterminism in Modern Physics*, by O. T. Benfey (New Haven: Yale University Press).
- Caygill, H. (1995) *A Kant Dictionary* (Oxford: Blackwell).
- Cohen, H. (1883) *Das Princip der Infinitesimal-Method und seine Geschichte* (Berlin: Dümmler).
- Creath R. (1990) (ed.) *Dear Carnap, Dear Van. The Quine–Carnap correspondence and related work* (Berkeley: University of California Press).
- DiSalle, R. (2006a) *Understanding Space-Time. The Philosophical Development of Physics from Newton to Einstein* (Cambridge: Cambridge University Press).
- (2006b) ‘Kant, Helmholtz, and the Meaning of Empiricism’ in M. Friedman and A. Nordmann (eds.) *The Kantian Legacy in Nineteenth-Century Sciences* (Harvard: MIT Press), 123–140.
- Förster, E. (2000) *Kant’s Final Synthesis. An Essay on the Opus postumum* (Cambridge, Mass.: Harvard University Press).
- Friedman, M. (1992a) *Kant and the Exact Sciences* (Cambridge, Mass.: Harvard University Press).
- (1992b) ‘Causal Laws and the Foundations of Natural Science’, in Paul Guyer (ed.) *The Cambridge Companion to Kant* (Cambridge: Cambridge University Press), 161–99.
- (1999) *Reconsidering Logical Positivism* (Cambridge: Cambridge University Press).
- (2000) *A Parting of the Ways. Carnap, Cassirer, and Heidegger* (Chicago: Open Court).
- (2001) *The Dynamics of Reason. Stanford Kant Lectures* (Stanford: CSLI Publications).
- (2006) ‘Kant – Naturphilosophie – electromagnetism’ in Friedman, M. and Nordmann, A. (eds.) *The Kantian Legacy in Nineteenth-Century Science* (Cambridge, Mass.: MIT Press), 51–80.
- Friedman, M. and Nordmann, A. (eds.) (2006) *The Kantian Legacy in Nineteenth-Century Science* (Cambridge, Mass.: MIT Press).
- Gower, B. (1973) ‘Speculation in Physics: The History and Practice of *Naturphilosophie*’ *Studies in History and Philosophy of Science* **3**, 301–356.
- Hatfield, G. (1990) *The Natural and the Normative: Theories of Spatial Perception from Kant to Helmholtz*, (Cambridge, Mass.: MIT Press).

Philosophy and the sciences after Kant

- Kant, I. (1747) *Gedanken von der wahren Schätzung der lebendigen Kräfte und Beurtheilung der Beweise, deren sich Herr von Leibniz und andere Mechaniker in dieser Streitsache bedient haben, nebst einigen vorhergehenden Betrachtungen, welche die Kraft der Körper überhaupt betreffen* (AK 1:1-181); English translation (in press) *Thoughts on the true estimation of living forces*, in E. Watkins (ed.) *Natural Science, The Cambridge edition of the works of Immanuel Kant* (Cambridge: Cambridge University Press).
- (1755a) *Allgemeine Naturgeschichte und Theorie des Himmels oder Versuch von der Verfassung und dem mechanischen Ursprunge des ganzen Weltgebäudes, nach Newtonischen Grundsätzen abgehandelt* (AK 1:215-368). Engl. translation (1968) *Universal Natural History and Theory of the Heavens*, in W. Ley (ed.) *Kant's Cosmogony* (New York: Greenwood Publishing).
- (1755b) *Meditationum quarundam de igne succincta delineatio* (AK 1:369-84). Engl. translation *Succinct exposition of some meditations on fire*, in L. W. Beck et al. (1986) *Kant's Latin Writings* (New York: Peter Lang).
- (1756) *Metaphysicae cum geometria iunctae usus in philosophia naturali, cuius specimen I. continet monadologiam physicam* (AK 1:473-87). Engl. translation *Physical Monadology*, in D. Walford and R. Meerbote (eds.) (1992) *Theoretical Philosophy 1755–1770. The Cambridge edition of the works of Immanuel Kant* (Cambridge: Cambridge University Press).
- (1781, 1787) *Critik der reinen Vernunft* (Riga: Johann Hartknoch). Engl. translation (1997) by P. Guyer and A. W. Wood *Critique of pure reason, The Cambridge edition of the works of Immanuel Kant* (Cambridge: Cambridge University Press).
- (1786) *Metaphysische Anfangsgründe der Naturwissenschaft* (Riga: Johann Hartknoch). Engl. translation (2004) by M. Friedman, *Metaphysical Foundations of Natural Science* (Cambridge: Cambridge University Press).
- (1790) *Kritik der Urteilskraft* (Berlin: Lagarde). Engl. translation (2000) by P. Guyer and E. Matthews, *Critique of the Power of Judgement, The Cambridge edition of the works of Immanuel Kant* (Cambridge: Cambridge University Press).
- (1796–1803) *Opus postumum*, Engl. translation (1995) by Eckart Förster and Michael Rosen, *The Cambridge edition of the works of Immanuel Kant* (Cambridge: Cambridge University Press).
- Keill, J. (1726) *An Introduction to Natural Philosophy*, 2nd edn (London: J. Senex et al.).
- Kitcher, P. (1992) 'The Naturalist's Return' *Philosophical Review* 101, 53–114.

Michela Massimi

- Kuehn, M. (2001) 'Kant and his Teachers in the Exact Sciences' in Watkins E. (ed.) *Kant and the Sciences* (New York: Oxford University Press), 11–30.
- Kuhn, T. S. (1962) *The Structure of Scientific Revolutions*, International encyclopaedia of unified science: Foundations of the unity of science, vol. 2, no. 2 (Chicago: University of Chicago Press).
- Kuhn, T. S. (1977) *The Essential Tension* (Chicago: University of Chicago Press).
- Laudan, L. (1990) 'Normative naturalism', *Philosophy of Science* **57**, 44–59.
- Massimi, M. (2005) *Pauli's Exclusion Principle. The Origin and Validation of a Scientific Principle* (Cambridge: Cambridge University Press).
- (2008a) 'The Relevance of Kant's Philosophy for the Physical Sciences of Nineteenth Century', *Metascience* **17**, 79–83. Review of M. Friedman and A. Nordmann (eds.) *The Kantian legacy in Nineteenth Century Science* (MIT Press).
- (2008b) 'Why There are no Ready-Made Phenomena: What Philosophers of Science Should Learn from Kant' in Massimi, M. (ed.) (in press), *Kant and Philosophy of Science Today*, (Cambridge: Cambridge University Press), Royal Institute of Philosophy Supplement 63.
- Pulte, H. (2006) 'Kant, Fries and the Expanding Universe of Science' in M. Friedman and A. Nordmann (eds.) (2006) *The Kantian Legacy in Nineteenth-Century Sciences* (Harvard: MIT Press), 101–122.
- Quine, W.V.O. (1951) 'Two Dogmas of Empiricism' *Philosophical Review* **60**, 20–43. Reprinted in (1963) *From a Logical Point of View* (New York: Harper), 20–46.
- (1963) 'Carnap and Logical Truth' in Schilpp P. A. (ed.) (1963) *The Philosophy of Rudolf Carnap*, (La Salle: Open Court), 385–406.
- (1969) 'Epistemology Naturalised' in *Ontological Relativity and Other Essays* (New York: Columbia University Press), 69–90.
- Reichenbach, H. (1920) *Relativitätstheorie und Erkenntnis Apriori* (Berlin: Springer). Engl. translation (1965) *The Theory of Relativity and A Priori Knowledge* (Los Angeles: University of California Press).
- Richardson, A. (1998) *Carnap's Construction of the World: the Aufbau and the Emergence of Logical Empiricism* (Cambridge: Cambridge University Press).

Philosophy and the sciences after Kant

- (2006) “‘The Fact of Science’ and Critique of Knowledge: Exact Science as Problem and Resource in Marburg Neo-Kantianism’ in M. Friedman and A. Nordmann (eds.) *The Kantian Legacy in Nineteenth-Century Sciences* (Harvard: MIT Press), 211–226.
- Schelling, F. (1797) *Ideen zu einer Philosophie der Natur*, 1st ed. Vol. 1 of *Schellings Werke* (Munich: C. H. Beck, 1927).
- (1799) *Erster Entwurf eines Systems der Naturphilosophie*, in 1st ed. Vol. 2 of *Schellings Werke* (Munich: C. H. Beck, 1927).
- (1800) *System des transcendentalen Idealismus*, in 1st ed. Vol. 2 of *Schellings Werke* (Munich: C. H. Beck, 1927).
- Shanahan, T. (1989) ‘Kant, *Naturphilosophie*, and Oersted’s Discovery of Electromagnetism: A Reassessment’, *Studies in History and Philosophy of Science* **20**, 287–305.
- Schönfeld, M. (2006) ‘Kant’s Early Dynamics’ in Graham Bird (ed.) *A Companion to Kant* (Blackwell), 33–46.
- Watkins, E. (2005) *Kant and the Metaphysics of Causality* (Cambridge: Cambridge University Press).
- Williams, L. P. (1965) *Michael Faraday: a Biography*, Basic Books).
- (1973) ‘Kant, *Naturphilosophie*, and Scientific Method’ in R. Giere and R. Westfall (eds.) *Foundations of Scientific Method in the Nineteenth Century* (Indiana University Press), 3–22.