Introduction

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It may be anachronistic to say that Isaac Newton and his *Principia* decisively changed physics and philosophy, because separate fields of physics and philosophy did not yet exist. But the notion of decisive change captures something significant about the continuing relevance of studying Newton. What has been aptly termed "Newton's new way of inquiry" (Harper and Smith 1995) was baffling for even his most sophisticated contemporaries, and it took Europe's brightest astronomers and mathematically inclined natural philosophers almost a century in order to evaluate and assimilate the *Principia*. But for reasons that need not detain us here, few of these figures (e.g., Clairaut, Euler, Laplace), who were fully immersed in Newton's work, really offered a definitive account of the methodology of the *Principia*. Of course, many scholars from Newton's day onward have offered interpretations of Newton's explicit methodological claims, but surprisingly few have combined this approach with detailed knowledge of Newton's technical practice. As is well known, by the time physics became enshrined as the leading part of the disciplinary structure of science, its attitude toward its own history did not encourage close scrutiny of past practices. In this volume, the three chapters on methodology by George Smith, William Harper, and Ori Belkind all capture important aspects of Newton's new way of inquiry.

Newton also changed philosophy in two important ways. First, the body of work eventually known as "Newtonian mechanics" became a privileged form of knowledge that had to be dealt with somehow within metaphysics and epistemology. Second, it initiated a slow process in which philosophy defined itself in terms that often contrasted with – or were modeled on – Newtonian success. But as a consequence, in philosophy's evolving self-conception Newton stopped being central to the history of philosophy. Somewhat surprisingly, philosophical interest in Newton revived at the beginning of the twentieth century, precisely when his physical theory was called into question by Einstein's revolutionary work. Most of the papers in this volume engage with Newton's place within the history of philosophy. Before we turn to a detailed description of the chapters collected here, we offer a brief introduction to the scholarship that in many ways forms the shared background of recent philosophically motivated work on Isaac Newton.

The philosophical study of Newton's thought has undergone a series of revolutionary developments during the past century.[1] During the first half of the twentieth century, in the context of Einstein's transformative science, much of the key work was accomplished by European historians of science such as Hélène Metzger and Alexandre Koyré, but E. A. Burtt's *The Metaphysical Foundations of Natural Science* (1924) also had a lasting influence.[2] Burtt's text is remarkable for its insistence on treating canonical modern philosophers – such as Descartes and Hobbes – in tandem with canonical natural philosophers – such as Boyle and Newton – in the same fashion, thereby expressing a more expansive conception of philosophy's history than one might have encountered elsewhere.[3] For her part, Metzger wrote insightfully about Newton's place within the history of chemistry and also about a number of substantive philosophical and theological issues that some of Newton's interpreters took to be raised by his work. At the time of her tragic death in Auschwitz, Metzger was writing another work that traced developments in chemistry and optics from Newton through to later figures.[4] Koyré's prodigious scholarship concerned a host of philosophical and historical issues, encompassing a range of figures from Galileo to Newton[5] – his influence was felt not merely in his own scholarship, but through the magisterial critical edition of the *Principia* that he undertook with I. B. Cohen (see below). Any historian or philosopher wishing

1 This introduction must be brief, and will therefore inevitably leave out discussions of important scholars who have grappled with Newton during the past hundred years. Even a volume-length introduction could not provide a comprehensive treatment of scholarly developments during that time frame, let alone a standard introduction. We deal here with those authors who seem, according to the editors of this volume, to have been the most significant twentieth-century figures from the perspective of the philosophical engagement with Newton. Discussions of mathematics, physics, alchemy, optics, politics, etc., would obviously focus on other scholarly figures, texts and traditions. Finally, in what follows, when we cite and discuss the scholarship of important figures who have worked on Newton, we focus solely or principally on their main works concerning Newton and his influence (many historians and philosophers have written on various topics over the years).

2 Pierre Duhem's remarks about Newton in (1906) – which was translated as *The Aim and Structure of Physical Theory* by Phillip Wiener in 1954 (reprinted 1982) – were also a significant aspect of the reception of Newton in the pre-war period. Duhem argues in particular that Newton's "deduction" of the principle of universal gravity from Kepler's Laws is fundamentally flawed (see Duhem 1982, pp. 190–195). For a critical engagement with Duhem's criticism, see Smith (2007b).

3 Serious philosophical engagement with Newton's work even in the 1970s would still involve a citation or discussion of Burtt's work – see, e.g., Westfall (1971).

4 Metzger was the author, *inter alia*, of (1930) and (1938); for an extensive discussion of her life and work, see Freudenthal (1990).

5 The scope of Koyré's scholarship in the history of science and in the history of philosophy, to the extent that they can be distinguished, was immense. By the time of the beginning of the Second World War in 1939, he had already published several monographs, a collection of essays entitled *Études Galiléennes*, and a translation and commentary on Copernicus's magnum opus. For details of Koyré's life and scholarship, see Herivel (1965b).

to engage with Newton in, say, the 1950s or 1960s would have felt it necessary to begin with – although not necessarily to end with – the work of these figures.[6] The sale of many key Newton manuscripts in 1936 – in which John Maynard Keynes played a crucial role[7] – enabled many scholars to edit and publish texts in the post-war period. These texts now form an essential component of our understanding of Newton's life and thought.[8]

During the immediate post-war period, Newton scholarship underwent another major revolution at the hands of two towering figures in Britain and the United States, I. B. Cohen and Sam Westfall.[9] Having received the first American Ph.D. in the history of science (1947), Cohen probably did more than any single figure in the past century to make Newton's texts available to scholars and to the general public. In 1972, Cohen published *Isaac Newton's Philosophiae Naturalis Principia Mathematica*, an edition co-edited with Koyré, whose untimely death prevented him from seeing it through to completion. In 1958, Cohen had already edited *Isaac Newton's Papers and Letters*, which expertly collected a number of key Newtonian texts, including his optical papers from the 1670s[10] and his correspondence with Bentley (first published in the mid-eighteenth century), and many years of work with Anne Whitman would eventually lead (in 1999) to the first fully new English translation of the *Principia* in two centuries.[11] Cohen's outstanding editorial work was matched

6 In the post-war period, the French tradition of Newton scholarship was continued by a number of important figures, including Michel Blay (1995), and Francois de Gandt (1995). The work of Léon Bloch (1908) was an early component of twentieth-century French scholarship.

7 John Maynard Keynes' 1946 lecture "Newton the Man," characterized Newton's interest in alchemy, "with one foot in the Middle Ages and one foot treading a path for modern science," see: www-groups.mcs.st-andrews.ac.uk/~history/Extras/Keynes_Newton.html

8 Perhaps the most significant post-war investigation of Newton's alchemical manuscripts was presented in Betty Jo Teeter Dobbs's (1975). There has been a tremendous amount of interest in Newton's alchemy in the past two decades – see, for instance, Figala's assessment in (2002) and, more recently, Newman (2006).

9 In addition to *Force in Newton's Physics* and *Never at Rest*, Westfall was also the author of (1958), (1971b) and numerous articles on Newton and the history of science. Cohen's works include (1956), (1971), and (1980). Before his untimely death in 1996, Westfall was slated to edit the *Cambridge Companion to Newton*, which ultimately became a significant institutional signal that Newton's work was of continuing importance for philosophers working in the English-speaking world. The volume, which eventually appeared in 2002, was published under the editorship of I. B. Cohen and of George Smith.

10 During the past twenty years, the most significant research into Newton's optics, and the most important work on the scholarly editions of Newton's work in optics, has been published by Alan Shapiro (Newton 1984).

11 Cohen's editorial and scholarly work on Newton's manuscripts and on the *Principia* has certainly been matched by the immense, decades-long project represented by D. T. Whiteside's *The Mathematical Papers of Isaac Newton*, and by H. W. Turnbull *et al.*'s crucial project, *The Correspondence of Isaac Newton*. These are indispensable scholarly editions.

by his immense range of publications on many aspects of Newton's life and thought.

After finishing a Ph.D. in 1958 at Yale on science and religion in seventeenth-century England, Westfall began to focus almost exclusively on Newton for the next few decades, culminating in his two great works: *Force in Newton's Physics* (1971) and his unsurpassed biography, *Never at Rest* (1980). Although Westfall held a Ph.D. in history, he taught in the History and Philosophy of Science Department at Indiana University (founded in 1960 by the philosopher Norwood Russell Hanson), and he showed a remarkable capacity for combining a subtle understanding of historical detail with an insightful analysis of philosophical issues and problems. Hence *Force in Newton's Physics* is a contribution not only to our understanding of Newton's physical theory, but also to our conception of how Descartes's and Leibniz's work in dynamics intersects with their broader concerns and preoccupations. Even today, every scholar must grapple with the enormously important work of Cohen and Westfall, which have reshaped our understanding of Newton in numerous ways. Indeed, their contributions may never be surpassed.

Beginning in the 1950s and 1960s, Marie Boas (later Marie Boas Hall) and A. Rupert Hall made available for the first time a series of Newton's manuscripts – most notably "De gravitatione et Aequipondio Fluidorum," a crucial unpublished anti-Cartesian tract that has garnered enormous attention in recent years – that have been central to the scholarly understanding of his life and work ever since.[12] In addition to their editorial and archival work, Hall and Hall published a number of articles and books that deal partly or centrally with Newton's thought, including Marie Boas's classic monograph, "The Establishment of the Mechanical Philosophy," and A. R. Hall's numerous books about Newton and his milieu.[13] During the 1960s and 1970s, key contributions to the philosophical understanding of Newton were made by Howard Stein, J. E. McGuire and Ernan McMullin.[14] Stein's most influential paper, "Newtonian Space-Time," was presented in 1967 and then published

12 Hall and Hall's collection is Newton (1962). An updated translation of "De Gravitatione" by Christian Johnson (with the assistance of Andrew Janiak) is available in Newton (2004).

13 See Marie Boas's monograph-length article on the mechanical philosophy, Boas (1952). Much of her subsequent work concerned Boyle and also the history of the scientific revolution, including: Hall (1958), (1962), and (1991). A. Rupert Hall wrote, inter alia, the following influential works: (1963), (1980), and (1992). Together, Hall and Hall also edited Henry Oldenburg's correspondence (Hall and Hall 1965), which is obviously crucial for understanding the history of the Royal Society of London, as Oldenburg was its secretary for many years. Many of Newton's published and unpublished writings, on a wide variety of topics, are now available via The Newton Project: www.newtonproject.sussex.ac.uk.

14 Although Max Jammer did not write specifically about Newton during this period, his famous trilogy in the history of science contained substantial engagement with Newton's ideas: Jammer (1954), (1957) and (1961). At least two of the concepts Jammer discussed, force and mass, are given their canonical modern formulation by Newton in 1687.

in 1970 – it served to introduce a generation of philosophers, many of whom worked not on Newton but on more general issues concerning philosophy of science, to Newton's thinking about space, time and motion.[15] The originality and power of Stein's contribution were felt for many decades. In the ensuing years, Stein has continued to influence many philosophers – including Michael Friedman and Robert DiSalle – seeking to understand Newton's place within the early modern tradition of natural philosophy and the modern tradition of philosophy of physics. J. E. McGuire's life-long engagement with Newton's philosophical work began in the 1960s with a remarkable series of papers concerning the then-neglected alchemical aspects of Newton's unpublished oeuvre. During the ensuing decades, McGuire also made seminal contributions to the study of key Newtonian concepts such as space, time, and force, connecting them to various philosophical and scientific traditions of the late Renaissance and early modernity.[16] For his part, McMullin's wide ranging scholarship on the history and philosophy of modern physics included a crucial early monograph entitled *Newton on Matter and Activity* (1978). McMullin's text was one of the only systematic treatments of Newton's philosophical views to have been written in the post-war period, and its influence is still evident in contemporary scholarship.

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The contributions to this volume build on the influential work in the twentieth century discussed above, and they often see Newton through the various lenses provided by that work. Indeed, contemporary philosophical engagement with Newton must not only react to the myriad published and unpublished works that form the known Newtonian corpus, they must also respond – both sympathetically and sometimes critically – to the vast field of twentieth-century scholarship on Newton and his influence. The editors have divided the fifteen contributed papers in this volume into three sections: (1) Newton and his contemporaries; (2) Philosophical themes in Newton; (3) the reception of Newton. Such a division is a bit arbitrary, of course, because there is considerable overlap among the papers in different sections. In this introduction we call attention to five broad themes that break new ground in Newton studies and that are shared by a number of contributions.

First, the study of Newton's methodology has long been the focus of George Smith's groundbreaking research.[17] This volume concludes with a new major

15 See Stein (1970a), (1970b), (1990b), and (2002), which presents and expands upon many classic themes from Stein's forty-year engagement with Newton.

16 Many of McGuire's papers are collected in his (1995). Together with Martin Tamny, McGuire edited Newton (1983), an edition of the notes Newton kept as an undergraduate at Trinity College, Cambridge in the 1660s. McGuire's influence is also felt through the many students he trained at Leeds and at Pittsburgh.

17 At present, Smith is probably the most influential English-speaking philosopher working on Newton. His now renowned course on Newton at Tufts University has introduced at

study of his that attempts to characterize Newton's conception of inquiry in the process of articulating nine different ways in which Newton changed physics. Smith details how physical research was predicated on the theory of gravity. Smith's study will be of interest not merely to historians and methodologists, but also to those exercised by the nature of scientific knowledge of gravity before and after Einstein's revolution. Smith's methodological researches have influenced many other contributions to this volume.

Smith's sometime co-author, William Harper, contributes a paper in which he contrasts Newton's methodology of successive approximations with the methodological views of Newton's greatest scientific contemporary, Christian Huygens, who articulates a view of methodology characteristic of the hypothetico-deductive approach. Harper focuses on Newton's richer ideal of empirical success. In particular, Harper calls attention to the importance within Newton's method of accurate theory-mediated measurement of the parameters of the model which explain the predicted phenomena. In line with Smith's approach to Newton, according to Harper's reconstruction a major feature of Newton's philosophy of science is the acceptance of theoretical propositions as guides to research in which empirical deviations from the model count as new theory-mediated phenomena to be exploited as carrying information to aid in developing a more accurate successor.

Ori Belkind shares in Smith's and Harper's rejection of attributing to Newton the hypothetico-deductive method. And like Harper, Belkind calls attention to the importance of Newton's strategy of contingently accepting certain (what Belkind calls) "structural assumptions." In his study of Newton's argument for universal gravity, Belkind calls attention to the importance in Newton's thought of the composition of the quantity of motion and the compositional nature of the gravitational force. By showing that such composition is legitimate, it becomes possible to treat measurement as a way of answering theoretically interesting questions.

A second major theme in which the volume breaks new ground is in its focus on Newton's matter theory, which is the subject of four papers. Zvi Biener and Chris Smeenk use the queries of Roger Cotes, the very able editor of the *Principia*'s second edition (1713), to highlight linked tensions in Newton's matter theory and empiricist methodology, and to stress their development in Newton's thought. Following Cotes, Biener and Smeenk identify two competing views on the nature of matter in Newton. On what they call the "dynamical conception of matter," quantity of matter is measured through a body's response to impressed force. They argue that this conception is dominant in the *Principia* and is justified by a quantitative empiricist method that

least an entire generation of students *and faculty* to Smith's powerful approach to Newton's work. In addition, see the following: Smith (1999), (2001b), (2002a), and (2002b). He also co-wrote an important article with Bill Harper (Harper and Smith 1995).

relies on theory-mediated measurement of parameters that play a role in the laws of motion, as articulated by Smith and Harper. On what they call the "geometrical conception of matter," quantity of matter is measured by the volume a body impenetrably fills. Biener and Smeenk argue that this Cartesian conception is dominant in *De Gravitatione* and is justified by an essentially qualitative empiricist method. They show that the tension between these two conceptions threatens to undermine the argument for Universal Gravitation. It is in response to this threat (as outlined by Cotes's queries) that Newton more decisively endorses a dynamical conception and casts off the vestiges of *De Gravitatione*'s Cartesianism.

Katherine Brading approaches Newton's account of bodies by way of a comparison between Descartes and Newton. She argues that Newton offers a law-constitutive solution to the problem of bodies, according to which the definition of bodies is incomplete prior to the specification of the laws of nature, and completed by those laws. She argues that according to Newton, it is a necessary condition for the individuation and identity of physical bodies that they satisfy the three laws of motion. She then spells out how Newton can be seen as generating a research program of identifying the laws that can account for the necessary and sufficient conditions for the individuation and identity of physical bodies.

Lynn Joy investigates Newton's treatment of body by comparing Boyle and Newton on dispositional properties. She claims that the very idea of a disposition itself underwent a major conceptual change between Boyle and Newton. She argues that Newton turned Boyle's philosophical theory of dispositions on its head by showing that mass could be conceived as an exclusively dispositional property of bodies without requiring that mass be causally grounded in the categorical properties of Boyle's matter. Joy also calls attention to the open-ended nature of Newton's science and philosophy; they were open to the revolutionary possibility that the disposition of mass, when conceived of as a natural force acting according to certain mathematical laws, constitutes an existence more fundamental than that of Boyle's matter.

Daniel Garber's paper compares Leibniz's and Newton's views on the nature of force. Garber spells out some of their most fundamental differences in terms of their different approaches toward thinking about the natural world. Garber sees Leibniz as inheriting a program in natural philosophy from Descartes that provides an account of bodies as such, one grounded in an understanding of their true causes. Garber sees Newton as inheriting a Galilean project that offers a quantitative account of the world, one that favors mathematical description over an account of ultimate first causes. Garber also argues that whereas Leibniz's interest in force is a means to illuminate the nature of body, Newton's account of force is allowed to remain explanatorily basic.

Strictly speaking, Nick Huggett's piece is not on Newton's matter theory, but on Newton's views on space and motion. Nevertheless, it reinforces and refines some of the other contributors' conclusions on how to think of Newton's "dynamics" and the status of the laws of motion. Huggett develops and then challenges Howard Stein's and Robert DiSalle's influential readings of Newton's Scholium on space. Huggett builds his case on the observation that Newton does not introduce "true motion" and "absolute motion" as synonyms; "absolute motion" connotes change of absolute place, while "true motion" connotes a special privileged sense of motion. More specifically, the latter concept gets meaning from the laws of mechanics – it is the concept of motion implicit in the laws. In other words, according to Huggett, in "true motion" Newton consciously held an extremely sophisticated conception of motion. The theoretical part of the concept is that of contemporary "dynamical" interpretations, which also hold motion to be that which the laws refer to as motion in the frames in which the laws hold. On Huggett's interpretation, Newton cannot be said to have advocated a purely dynamical view in the Scholium, but rather the view that motion with respect to absolute space satisfied the dynamical concept.

Two papers, one by Katherine Dunlop and the other by Marco Panza, focus on Newton's mathematics. They illuminate the relationship between mathematics and the science of motion in Newton, which is the third broad theme. Katherine Dunlop relates Newton's views to those of his teacher, Isaac Barrow, emphasizing continuities between teacher and pupil in order to call attention to Newton's departures. She explains the significance of Newton's Preface to the *Principia*, with its focus on postulates as the link between geometry and mechanics. By building on the methodological work of Smith and Harper, she explains the way in which geometry's first principles secure physical significance for the conclusions of theory-mediated measurement. The main point of Marco Panza's investigation of Newton's development of his theory of fluxions is to locate a crucial step in the origins of analysis, conceived as an autonomous mathematical theory. By closely analyzing Newton's *De Analysis* and *De Methodis* as well as Newton's reaction to Roberval's method of tangents, Panza argues that fluxions were conceived by Newton as abstract quantities related to other abstract quantities, called "fluents." By contrast, that which Newton called (in his notes of 1665–66) 'motion', 'determination of motion' or 'velocity,' was understood as (a scalar component of) punctual speeds of motions generating particular geometric magnitudes, typically segments. Panza's interpretation helps explain, in part, why in the *Principia* Newton did not rely on fluxions, but instead turned to geometry.

In the fourth broad theme, ever since the French Enlightenment, Locke and Newton have been considered intellectual fellow-travelers; in this picture Newton is seen as providing the physics and Locke the metaphysics for the new sciences. In much recent scholarship, what are often called the "empiricist" similarities between Locke and Newton have also been emphasized. Building on previous work by Howard Stein, three papers force a reconsideration of the relationship between Locke and Newton. Graciela De Pierris brings out some crucial differences between Locke and Newton, in part by comparing Hume's empiricism with Locke's. She argues that Locke remains wedded to the demonstrative ideal of the mechanical philosophy and lacks Newton's understanding of fruitful inductive generalization. She then reads Hume as simultaneously articulating many of the fruits of the Newtonian method while also offering a skeptical challenge to it.

Mary Domski reconsiders the famous "master-builders" and "under-Labourer" passage in the *Essay*. She argues that in the fourth edition of the *Essay*, Locke emphasizes Newton's success as a mathematician, but not as a mathematical natural philosopher. She also shows that in Locke's other writings from the 1690s, Newton is praised for his application of mathematics to a very specific domain of nature, namely, the motions of planetary bodies. According to Domski, then, Locke took Newton's work to be emblematic, not of a general physics, but of a sub-discipline of natural philosophy dealing only with the forces and motions of heavenly bodies.

Lisa Downing also re-evaluates the relationship between Locke and Newton; she does so by way of Maupertuis's analysis of the nature of attraction. Her paper helps explain both how Locke and Newton came to be seen as fellow travelers, and how philosophers drew on Lockean resources to defend Newtonian natural philosophy. In particular, she shows how Maupertuis transforms s'Gravesande's claim that laws as regularities are the ultimate aim of Newtonian knowledge into a claim in which experience is in principle capable of settling the existence of attraction as an inherent quality of body.

Finally, two papers investigate how the nature of philosophy was reconfigured through responses to Newton. Michael Friedman emphasizes the importance of metaphysical and theological issues – about God, his creation of the material world in space, and the consequences that different views of such creation have for the metaphysical foundations of physics. Friedman argues that Kant's differences with Newton over these issues constitute an essential part of Kant's radical transformation of the very meaning of metaphysics as practiced by his predecessors. Friedman shows that since Newtonian absolute space is viewed as a regulative idea of reason, there is also an associated reconfiguration, for the critical Kant, of the relationships among space, the interactions of matter, and the idea of God. For the idea of God, too, is a regulative idea of reason. Indeed, there is an important sense in which it is the ultimate such regulative idea. For the critical Kant the only possible meaning that the idea of divine omnipresence (and divine providence) can now have is a purely *practical* one, in so far as we unconditionally obey the command of morality to strive to realize the realm of ends here on Earth, and, accordingly, we take the whole of that material nature of which we are a part to be in principle *capable* of such a realization (or, more precisely, its successive approximation). On Friedman's account, Kant thereby brings the characteristic mode of metaphysical investigation into the relationships among space, God, and matter practiced by his predecessors to a close, and transforms it into transcendental philosophy.

Eric Schliesser explores how the most able eighteenth-century Scottish Newtonian, Colin MacLaurin, uses the authority of Newton to attack Spinoza on empirical and moral grounds. MacLaurin argues from the empirical success of Newtonian natural philosophy to the *rejection* of alternative positions, methodologies, and foundations within philosophy. At the same time, MacLaurin argues for a certain form of self-limitation: aiming for completeness is likely to get us into trouble. Schliesser argues that in MacLaurin's hands Newtonian science recommends a lowering of expectations – it favors piecemeal progress over the demands of systematicity. MacLaurin thereby subordinates application of Newton's science to his religious and moral outlook. Schliesser shows that MacLaurin constructed a tradition in which Descartes, Spinoza, and Leibniz are linked as a threesome not in opposition to empiricism, but in opposition to a tradition of mathematical-empirical research stretching back to Galileo. Thus Schliesser's analysis echoes Daniel Garber's.