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INTRODUCTION

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The Canonical Imperative: Rethinking the Scientific Revolution

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The Scientific Revolution is probably the single most important unifying concept in the history of science. Usually referring to the period from Copernicus to Newton (roughly 1500 to 1700), it is considered to be the central episode in the history of science, the historical moment at which that unique way of looking at the world that we call "modern science" and its attendant institutions emerged. It has been taken as the terminus ad quem of classical and medieval science and the terminus a quo of all that followed. Not itself an explanatory concept, the Scientific Revolution has become the reference point for questions that guide historians of science, questions about what it was, what exactly happened, why it happened, and why it happened when and where it did.[1]

Traditional histories of the Scientific Revolution have customarily focused on a list of canonical individuals who explored a canonical set of subjects. The individuals usually include Copernicus, Tycho, Kepler, Galileo, Vesalius, Harvey, Descartes, Boyle, and Newton. The subjects are astronomy, physics, mathematics, anatomy, physiology, and chemistry.[2] This book reflects the problematization of the canon in recent scholarship. The traditional canonical figures often devoted

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1 Floris Cohen organizes his book around this set of questions. See H. Floris Cohen, *The Scientific Revolution: A Historiographical Inquiry* (Chicago: University of Chicago Press, 1994). See also Toby E. Huff, *The Rise of Early Modern Science: Islam, China, and the West* (Cambridge: Cambridge University Press, 1993).

2 Consider, for example, the following old standards: Herbert Butterfield, *The Origins of Modern Science, 1300–1800*, rev. ed. 1949: reprint, (New York: Free Press, 1957); A. Rupert Hall, *The Revolution in Science, 1500–1750* (New York: Longman, 1983; first published 1954); and Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (New York: John Wiley, 1971).

themselves to noncanonical subjects and frequently resembled many of their contemporaries who have not found a place in the Scientific Revolution's hall of fame. Moreover, the subjects that engaged their attention do not readily map onto the canonical list of modern sciences. Questioning the canon leads us to inquire why and how it was formed. And this inquiry, in turn, causes us to interrogate our own presuppositions as historians and how those presuppositions affect what we see in the past.

The chapters in this volume engage in a critical dialogue with the traditional understanding of the Scientific Revolution. The late Betty Jo Teeter Dobbs opens the discussion by stating her intention "to undermine one of our most hallowed explanatory frameworks, that of the Scientific Revolution." Starting from I. B. Cohen's definition of "revolution" as "a change that is sudden, radical, and complete,"[3] she argues that the Scientific Revolution had none of these characteristics. She observes that the reception of Copernicanism was slow, that traditional histories extend the process to one that took anywhere from 150 to 500 years, that the break with Aristotelianism was not complete, and that even the heroes of the traditional accounts – most notably Newton – did not think in the same way as modern scientists. Indeed, Newton's intellectual preoccupations had more to do with theology and alchemy than with the physics and mathematics on which his modern reputation rests.

In a resounding defense of the historiography for which he was one of the most distinguished spokesmen, the late Richard S. Westfall responds with an eloquent reassertion of "our central organizing idea . . . [because] without it our discipline will lose its coherence, and what is more, the cause of historical understanding take a significant step backward." Arguing for the undeniable impact of science on the modern world and for the central role of the Scientific Revolution as the one idea that has brought coherence to the entire history of science, Westfall reaffirms the importance of the traditional historiography that he helped to create. He argues that the break with Aristotelianism was a major discontinuity in the history of ideas and that the new science that developed was qualitatively different from traditional natural philosophy. As for the canon, Westfall states that Newton is remembered today for his contributions to physics, optics, and mathematics – not for his studies of alchemy and theology.

This debate between Dobbs and Westfall signals a deep rupture in

3 I. Bernard Cohen, *The Revolution in Science* (Cambridge, Mass.: Harvard University Press, 1985), pp. 51–90.

the present understanding of the historical development of science. Westfall's analysis is fundamentally forward-looking, based on the assumption that what is interesting in the past are those developments that led to our present understanding of the world. In contrast to Westfall, Dobbs seeks to understand the presuppositions and assumptions of her historical actors rather than searching for anticipations of modern ideas in their thought.

In considering intellectual developments in the period between 1500 and 1700 and in considering the figure of Isaac Newton, Dobbs and Westfall start from different assumptions, which inevitably lead them to different conclusions. Dobbs challenges a traditional assumption about the heroes of the Scientific Revolution, namely, "that their thought patterns were fundamentally just like ours." It is only because they make this assumption that historians have found it difficult to explain Kepler's Pythagoreanism or Newton's devotion to alchemy. By making a different assumption, namely that people have not always viewed the world in the same way that we do, Dobbs is able to argue that we can make sense of their diverse interests and preoccupations. This is the crux of Westfall's disagreement with Dobbs. He assumes that thinkers in the past are similar to us and that what is important for the historian is that aspect of a thinker's work that has survived until the present or that has led to our present way of looking at things.

Despite the polar differences between Westfall and Dobbs about the existence of the Scientific Revolution and its utility as a historiographical concept, they are talking about the same revolution, the one that either did or did not occur during the period bounded by 1500 and 1700. As Margaret Jacob argues in the concluding chapter, however, their disagreement is badly posed: it rests on the heroic assumption of who and what made the revolution. The reconsideration of the canonical heroes of the revolution in this volume leaves the question – Was there or was there not a scientific revolution? – dangling. One possible answer, suggested in Jacob's chapter, is that there was a scientific revolution, but not the one that both Dobbs and Westfall tacitly assume to be at stake. Rather, the revolution was constructed in the eighteenth century when natural philosophers selectively took up Newton's physics and mathematics while ignoring his alchemical and theological views. In addition to understanding the intellectual developments of this period, then, future research must address the interests and concerns of subsequent generations, which created the perception that a scientific revolution occurred in the sixteenth and seventeenth centuries and then bequeathed it to us. If Jacob's interpretation is valid, its power derives from the kinds of questions, reassessments, and challenges posed by the scholarship represented in this volume.

These differences bring the question of the nature of intellectual change into bold relief. Because contemporary science makes claims about the world that scientists and historians take to be true, historians of science have sometimes succumbed to the Whiggish tendency to understand the history of science as the unfolding of ideas by the force of their own, internal logic. This tendency explains why they have left certain critical developments incompletely explained. Examples include the acceptance of Copernican astronomy, the rise of the mechanical philosophy, the decline of astrology and transmutational alchemy, and the acceptance of Newtonian physics.[4] Such developments seem not to require explanation, since they are presumed to be *right*. Less anachronistic historians understand that all historical developments demand explanation, since there is no preordained or *right* way for ideas to develop. Interrogating the developments that seem to require no explanation yields insight into the assumptions guiding our historical actors. Peter Barker asks how we can account for the fact that some people were more receptive to heliocentric astronomy than others. He argues that Lutheran theology with its emphasis on order and design predisposed certain astronomers to be especially receptive to Copernicanism.

Ideas do not influence subsequent ideas; nor do they develop by their own intrinsic power. Rather they are deployed or developed by particular individuals in real historical contexts to solve problems of their own. Taking questions of agency seriously means using actors' categories to account for the development of ideas.[5] What, then, do actors do in the context of intellectual history? Borrowing a metaphor that Peter Barker appropriated from A. I. Sabra, I maintain that thinkers appropriate ideas from the traditions within which they work and use them in their own contexts to solve the particular problems that concern them.[6] The metaphor of appropriation gives agency to the historical actors who work within their own particular social, ideolog-

4 Westfall, *Construction of Modern Science*, pp. 30–1, 159. On the decline of transmutational alchemy, see William R. Newman and Lawrence M. Principe, "Alchemy vs. Chemistry: The Etymological Origins of a Historiographical Mistake," *Early Science and Medicine* 3 (1998): 32–65.

5 My analysis here is indebted to Quentin Skinner, "Meaning and Understanding in the History of Ideas," *History and Theory* 8 (1969): 3–53.

6 Peter Barker develops this point in detail in "Understanding Change and Continuity: Transmission and Appropriation in Sixteenth Century Natural Philosophy," in *Tradition, Transmission, Transformation*, ed. F. J. Ragep and S. Ragep, with Steven Livesey (Leiden: Brill, 1996), pp. 527–50.

ical, and intellectual contexts. "By speaking of 'appropriation,' we acknowledge the change in a previously established idea, theory, technique, or practice as it enters a new historical (and perhaps geographical) location. If the practice, idea, or whatever takes root, it is because it serves the continuing needs of the appropriators."[7] The act of borrowing may be more or less deliberate; nonetheless, natural philosophers draw on earlier thought to address problems in their own context.

Thinking in terms of appropriation leads us to consider different questions from those asked by traditional historiography. The contexts in which ideas are used become of paramount importance, as do detailed histories of particular concepts within those contexts. Why were particular figures attracted to one tradition or another? How does the way they ask their questions affect the use they make of the ideas they borrow? Why do they ask questions in the particular way that they do? The new historiography is characterized by an increasing awareness of the importance of the intellectual and social context within which ideas have developed, along with a renewed respect for the presuppositions and concepts of the historical actors rather than those of historians.[8] It takes the history of science to places where it has not usually been seen before: into the courts, into the streets, into the countryside, and into local societies.[9] Accordingly, Pamela Smith

7 Ibid., p. 21.

8 Westman has shown how this problem affects Thomas S. Kuhn's analysis in *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought* (Cambridge, Mass.: Harvard University Press, 1957). He comments that "the narrative is historical, but not historicist." See Robert S. Westman, "Two Cultures or One? A Second Look at Kuhn's *The Copernican Revolution,*" *Isis* 85 (1994): 88.

9 For science in court culture, see Robert S. Westman, "Proof, Poetics, and Patronage: Copernicus' Preface to *De revolutionibus,*" in *Reappraisals of the Scientific Revolution*, ed. David C. Lindberg and Robert S. Westman (Cambridge: Cambridge University Press, 1990), pp. 167–206; Mario Biagioli, *Galileo Courtier: The Practice of Science in the Culture of Absolutism* (Chicago: University of Chicago Press, 1993); Bruce T. Moran, *The Alchemical World of the German Court: Occult Philosophy and Chemical Medicine in the Circle of Moritz of Hessen (1572–1632)* (Stuttgart: Franz Steiner Verlag, 1991); David S. Lux, *Patronage and Science in Seventeenth-Century France* (Ithaca, N.Y.: Cornell University Press, 1989); and Pamela H. Smith, *The Business of Alchemy: Science and Culture in the Holy Roman Empire* (Princeton: Princeton University Press, 1994). For science in the streets, see William Eamon, *Science and the Secrets of Nature: Books of Secrets in Medieval and Early Modern Culture* (Princeton: Princeton University Press, 1993); and Patrick Curry, *Prophecy and Power: Astrology in Early Modern England* (Ithaca, N.Y.: Cornell University Press, 1989). For science in the countryside, see Keith Thomas, *Man and the Natural World: Changing Attitudes in England, 1500–1800* (London: Allen Lane, 1983); Andrew Cunningham, "The Culture of Gardens" and Paula Findlen, "Courting Nature," in *Cultures of Natural History*, ed. N. Jardine, J. A. Secord, and E. C. Spary (Cambridge: Cambridge University Press, 1996), pp. 38–56, 57–74. For science in mu-

takes us to the artisan's workshop and to various German courts; William Burns, to the streets of London during the Interregnum; and Margaret Jacob, to the schools and local philosophical societies of the eighteenth century in which Newtonianism was taught to diverse and often nonprofessional audiences.

Once we think in terms of appropriation, the traditional canons of historical figures and disciplines become problematized because we must ask why and how the canon was constructed. By elucidating the similarities between Athanasius Kircher and Isaac Newton, Paula Findlen raises the question of why Newton was incorporated into the canon and Kircher was not. It is only the judgment of later generations that forged our distinction between genius and crackpot. In the new historiography, questions of when and why certain figures become canonical replace the practice of reading history backward from the present. Thus, it becomes evident that the concerns of the appropriators determine which past figures are useful, seminal, or important rather than the intrinsic or timeless merit of their ideas. Returning to the example of Newton, it was the interests of eighteenth-century natural philosophers that put his mathematical physics in the foreground, as Margaret Jacob argues, and it was the concerns of twentieth-century historians of science who valued mathematical sciences above all others that gave him his ruling position in the canon. Moreover, different commentators may find different aspects of a single thinker's ideas significant. Twentieth-century scientists and historians may value Newton's contributions to mathematics and physics, but, as Richard Popkin demonstrates, religious fundamentalists are more impressed by his approach to biblical scholarship.

Nevertheless, to contextualize the canon is not to deny the reality of historical change. Despite historical continuities and the appropriation of ideas from ancient, medieval, and Renaissance sources, the period from 1500 through 1700 witnessed major changes in natural philosophy. These changes become evident if we examine ideas separated by a sufficiently long temporal gap. As Westfall wisely notes, "Scientists of today can read and recognize works done after 1687. It takes a historian to comprehend those written before 1543." Unlike Steven Shapin who opens his book by proclaiming, "There is no such thing as the Scientific Revolution," I think it is crucial to acknowledge that there were major changes in thinking about the natural world during the early modern period, changes in cosmology, metaphysics, episte-

seums, see Paula Findlen, *Possessing Nature: Museums, Collecting, and Scientific Culture in Early Modern Italy* (Berkeley: University of California Press, 1994). For an attempt to incorporate some of these approaches into a new synthesis, see Steven Shapin, *The Scientific Revolution* (Chicago: University of Chicago Press, 1996).

mology, matter theory, physics, and optics.[10] Likewise, the practices and social locations in which these subjects were supported and pursued underwent considerable change. However all these changes cannot be embraced in a single formulation as implied by a phrase like "*The* Scientific Revolution."[11] The trick is to recognize that intellectual change occurred while at the same time recognizing that change is not necessarily linear or self-evident progress toward our modern way of thinking.

Avoiding presentism or Whiggish historiography, uncontroversial though such a strategy may appear, raises a further conundrum. If we assert that historiographical sophistication is increasing as we learn to take actors' categories into account, are we unwittingly giving a Whiggish history of our own historiographical practice?[12] Such an infinite regress of Whiggism can be avoided as long as we do not claim progress for historical method itself. Historians need to recognize the role that their own assumptions play in their constructions of the past. There is no escaping them, but consciously acknowledging them staves off the temptation of claiming objectivity and progress.

10 On cosmology, see Alexandre Koyré, *From the Closed World to the Infinite Universe* (Baltimore: Johns Hopkins Press, 1957). On metaphysics and epistemology, see E. A. Burtt, *The Metaphysical Foundations of Modern Science* (reprint, Garden City, N.Y.: Doubleday Anchor, 1954; first published 1924); Richard H. Popkin, *The History of Scepticism from Erasmus to Spinoza*, rev. and exp. ed. (Berkeley: University of California Press, 1979; first published 1960); Margaret J. Osler, *Divine Will and the Mechanical Philosophy: Gassendi and Descartes on Contingency and Necessity in the Created World* (Cambridge: Cambridge University Press, 1994); Barbara Shapiro, *Probability and Certainty in Seventeenth-Century England: A Study of the Relationships between Natural Science, Religion, History, Law, and Literature* (Princeton: Princeton University Press, 1983); and Jan W. Wojcik, *Robert Boyle and the Limits of Reason* (Cambridge: Cambridge University Press, 1997). On matter theory, see Dennis Des Chene, *Physiologia: Natural Philosophy in Late Aristotelian and Cartesian Thought* (Ithaca, N.Y.. Cornell University Press, 1996); *The Fate of Hylomorphism: "Matter" and "Form" in Early Modern Science*, ed. C. H. Lüthy and William R. Newman, *Early Science and Medicine* 2 (1997): 216–352; and Norma E. Emerton, *The Scientific Reinterpretation of Form* (Ithaca, N.Y.: Cornell University Press, 1984). On physics, see Daniel Garber, *Descartes' Metaphysical Physics* (Chicago: University of Chicago Press, 1992), and Richard S. Westfall, *Force in Newton's Physics: The Science of Dynamics in the Seventeenth Century* (London: MacDonald and American Elsevier, 1971). On optics, see A. I. Sabra, *Theories of Light from Descartes to Newton* (London: Oldbourne, 1967), and Alan E. Shapiro, *Fits, Passions, and Paroxysms: Physics, Method, and Chemistry and Newton's Theories of Colored Bodies and Fits of Easy Reflection* (Cambridge: Cambridge University Press, 1993).

11 This kind of essentialism marks Cohen's attempt to formulate a general account of the Scientific Revolution. See *The Scientific Revolution*, part 3.

12 See Thomas Nickles, "Philosophy of Science and the History of Science," in *Constructing Knowledge in the History of Science*, ed. Arnold Thackray, *Osiris* 2 ser., 10 (1995): 139–63.

This historical approach is at odds with traditional accounts of the Scientific Revolution. In the scholarly tradition stemming from nineteenth-century positivist Ernst Mach, historians have told a story that stresses the radical discontinuity of the Scientific Revolution from what came before and locates the point of rupture in the mind of Galileo.[13] Subsequent historians of science – whatever their historiographical predilection[14] – all tended to accept Mach's identification of the revolutionary moment as Galileo's transition from the theory of impetus in the early *De motu* to his mature science of inertial motion published in the *Discorsi*.[15] Their differences have revolved around the causes of that revolution, but they generally have accepted the same basic story.[16] The received narrative begins with the Copernican challenge to Aristotelian cosmology and Ptolemaic astronomy, continues with the discovery of Kepler's Laws in astronomy, Galileo's development of a new physics and the emergence of the mechanical view of

13 Ernst Mach, *The Science of Mechanics: A Critical and Historical Account of its Development*, trans. Thomas J. McCormack, 6th ed. with revisions through the 9th German ed. (Lasalle, Illinois: Open Court, 1960; originally published in German, 1883), pp. 39–45.

14 John McEvoy sees historians as having gone through three stages of analysis: "during the last fifty years, the discipline of the history of science has passed through three distinct historiographical stages, each characterized by a dominant, but not exclusive, interpretative style. The first stage was shaped by the positivist-Whig view of science as a teleologically structured corpus of experimental knowledge. This perspective was challenged, in the early 1960s, by the postpositivist identification of the history of science with the articulation and application of theoretical doctrines and research programs. The postpostivist hegemony was itself displaced, in the 1970s and '80s, by the postmodernist view of science as a sociological entity shaped by the contingent constraints of specific agents and local practices." John G. McEvoy, "Positivism, Whiggism, and the Chemical Revolution: A Study in the Historiography of Chemistry," *History of Science* 35 (1997): 1.

15 See, for example, Burtt, *The Metaphysical Foundations of Modern Science*; Edward W. Strong, *Procedures and Metaphysics* (Berkeley: University of California Press, 1936); Alexandre Koyré, *Études galiléennes* (Paris: Hermann, 1939); E. J. Dijksterhuis, *The Mechanization of the World Picture*, trans. C. Dikshoorn (Oxford: Clarendon Press, 1961; originally published in Amsterdam, 1950); and Westfall, *The Construction of Modern Science*.

16 Mach's influence explains the immense amount of detailed scholarship on Galileo's intellectual development. See for example Koyré, *Études galiléennes*; Stillman Drake, *Galileo at Work: His Scientific Biography* (Chicago: University of Chicago Press, 1978); Ernan McMullin, ed., *Galileo: Man of Science* (New York: Basic Books, 1967); Maurice Clavelin, *The Natural Philosophy of Galileo: Essay on the Origins and Formation of Classical Mechanics*, trans. A. J. Pomerans (Cambridge, Mass.: MIT Press, 1974); William R. Shea, *Galileo's Intellectual Revolution: Middle Period, 1610–1632* (New York: Neale Watson, 1974); Winifred Lovell Wisan, "Galileo's Scientific Method: A Reexamination," in *New Perspectives on Galileo*, ed. R. E. Butts and J. C. Pitt (Dordrecht: Reidel, 1978); and William A. Wallace, *Galileo and His Sources: The Heritage of the Collegio Romano in Galileo's Science* (Princeton: Princeton University Press, 1984).

nature that replaced Scholastic Aristotelianism, and reaches a triumphant climax with the Newtonian synthesis that bound these strands together into one coherent whole, thus heralding the triumph of modern science.[17] This story presumes that by 1700 there was a definitive rupture between the worn-out Scholasticism of pre-Copernican thought and the new science that emerged in the seventeenth century. The revolution in cosmology and metaphysics included the following radical transformations: the finite Aristotelian cosmos was replaced with an infinite Newtonian universe; nature was mathematized and mechanized; and experiment came to play an important role in the justification of scientific theories.[18] This is the story Westfall reiterates.

Without denying the reality of these changes in some areas of thought, historians have found it necessary to reexamine several assumptions that guided the traditional historiography.[19] One of these assumptions, drawn from nineteenth-century positivist classifications of the sciences, is that physics is the most fundamental science. Consequently, historians have highlighted the mathematization of physics in the seventeenth century, thereby marginalizing developments in other areas of natural philosophy.[20] They have concluded that the other sciences underwent their revolutions only when they became similarly mathematized. These assumptions lie at the root of the oxymoronic extension of the Scientific Revolution into a process that took many centuries to complete, since the revolutions in chemistry and biology did not occur until the eighteenth and nineteenth centuries, respectively.[21] A further assumption is that disciplinary boundaries

17 See, for example, Koyré, *Études galiléennes*; Alexandre Koyré "The Significance of the Newtonian Synthesis," in *Newtonian Studies*, ed. Alexandre Koyré (Cambridge, Mass.: Harvard University Press, 1965), pp. 3–24; Burtt, *The Metaphysical Foundations of Modern Science*. Similar ideas can be found in Hall, *The Revolution in Science, 1500–1750*; Dijksterhuis, *The Mechanization of the World Picture*; and Westfall, *The Construction of Modern Science*.

18 On the persistence of this account, see Westman, "Two Cultures or One?"

19 See Andrew Cunningham and Perry Williams, "De-centering the 'Big Picture': *The Origins of Modern Science* and the Modern Origins of Science," *British Journal for the History of Science* 26 (1993): 407–32. Cunningham and Williams delineate a number of the difficulties with the traditional understanding of the Scientific Revolution.

20 Comte's classification of the sciences, which embodies a reductionist and universalist criterion, is consonant with and perhaps historically connected to twentieth-century historians' of science privileging the mathematization of nature and the development of mathematical physics in their accounts of the Scientific Revolution. See Auguste Comte, *Cours de philosophie positive* (Paris, 1830), 1:47–95. Mach did not share Comte's reductionism. See *The Science of Mechanics*, p. 596.

21 Consider, for example, Butterfield's now notorious characterization of "The Postponed Scientific Revolution in Chemistry," not to mention his extension of the Scientific Revolution to a process that took five hundred years to complete. See Butterfield, *The Origins of Modern Science*, chap. 11.