This volume contains state-of-the-art essays, offering broad reflections on the Scientific Revolution, by a group of leading scholars actively engaged in the study of sixteenth- and seventeenth-century science. Although the volume's thirteen original essays display a wide variety of methods and approaches, all share the aim of reexamining fundamental assumptions and questioning established interpretations of the Scientific Revolution.

Some of the essays deal with questions of method, audience, and social context. Others examine the conceptions of science held by the major figures in sixteenth- and seventeenth-century science, reconsider the relationship of metaphysics to scientific inquiry, investigate the ideology of scientific openness and its origins, and revise traditional estimates of the place of science within the universities. Still others reconsider the map of scientific knowledge as viewed during these two centuries and the relationship of occult traditions to other features of the Scientific Revolution.

Several essays explore the significance of disciplines, such as medicine and natural history, that have been marginalized by the traditional historiography; and they question historians' preoccupation with Newton's celestial mechanics to the exclusion of other developments in mechanics. One of the essays examines changing canons of mathematical intelligibility. Others focus on rhetorical and political issues in chemical and astronomical discourse. And finally, the book contains an exploration of the historiography of sixteenth- and seventeenth-century science as it has developed over the past 350 years.

The overall theme of the volume is one of reappraising the prevailing metaphor of "revolution" for this period in the history of science. This book will provide impetus for the further reevaluation and reconceptualization of an important period of scientific development, often thought to be one of the cornerstones of the history of science.

Historians of science, philosophers of science, sociologists of science, and other scholars whose work is concerned with the nature of science will be interested in this book. It will also be of use as supplementary reading in courses on the history of science.

*Reappraisals of the Scientific Revolution*

# Reappraisals of the Scientific Revolution

Edited by

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and

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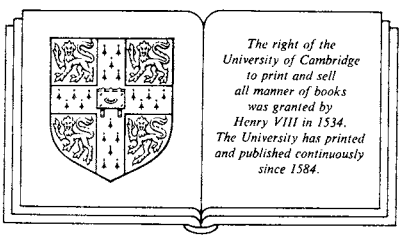


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*To A. Rupert Hall and Marie Boas Hall*

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This volume evolved out of a symposium, "Reappraisals of the Scientific Revolution," organized by the editors for the annual meeting of the History of Science Society in Los Angeles in December 1981. So lengthy and complex has been the evolutionary process that little remains in this volume from the original symposium, except the conviction that the Scientific Revolution, as it has been conceived over the past half-century, requires reappraisal. To those who contributed to the original symposium or to this book – and particularly to the contributors who have waited many years for the appearance of their work – we offer our sincerest thanks.

It is with gratitude and affection that the editors dedicate this volume to the teachers who first inspired their interest in the Scientific Revolution: A. Rupert Hall and Marie Boas Hall.

# INTRODUCTION

ROBERT S. WESTMAN AND DAVID C. LINDBERG

In 1948, Herbert Butterfield gave a series of lectures for the History of Science Committee at the University of Cambridge, in which he offered a "general historian's" view of a cultural change that he referred to as the Scientific Revolution. Conventional periodizations of Western civilization, Butterfield argued, had overlooked an episode of profound intellectual transformation – one that was comparable in magnitude to the rise of Christianity and that was deeply implicated in the very formation of "the modern mentality." Butterfield's Cambridge lectures, in published form, proved to be extraordinarily influential, deeply shaping the work of historians of science in the postwar years; forty years later, Butterfield's point of view continues to find expression in the writings of those, like Richard S. Westfall, who believe that "the Scientific Revolution was the most important 'event' in Western history."[1]

Seventeenth-century writers themselves deployed a rhetoric of "newness" in the titles of their works – Bacon's *New Atlantis* and *New Organon*, Kepler's *New Astronomy*, and Galileo's *Two New Sciences*, for example – and clearly set themselves up in opposition to the orthodoxy of "the schools." Thomas Hobbes expressed the sensibility of what he considered a new age, when he wrote that before Copernicus, Galileo, and William Harvey, "there was nothing certain in natural philosophy but every man's experiments to himself."[2] However, the notion of change employed by Hobbes and his contemporaries did not have the far-reaching meaning of the term Scientific Revolution, popularized by Butterfield and Westfall.[3] In a voice accessible to specialist and nonspecialist alike, Butterfield's *Origins of Modern Science* conveyed the conclusions of a tradition of twentieth-century epistemologists of science – scholars such as Pierre Duhem, Ernst Cassirer, Edwin Burtt, and Alexandre Koyré, who regarded history as a special resource for illuminating the evolution and progress of scientific knowledge.

Thomas Kuhn drew substantially upon this tradition when he proposed a general account of scientific change in *The Structure of Scientific Revolutions* (1962). But although he combined continuist ("normal") and discontinuist ("revolutionary") elements in his epistemological story, Kuhn provided quite a different sort of grounding for "revolution" in a theory of the everyday practices of scientific communities. And, unlike the historical epistemologists on whom he was drawing, Kuhn was phenomenally successful in disseminating his conception of science to disciplines far afield from that of the history and philosophy of science. Students in fields ranging from theology to art history and political science found in it, often to Kuhn's surprise, a kind of vade mecum of the philosophy of science. Whatever purchase the concept of Scientific Revolution had gained prior to Kuhn's *Structure*, that book's impressive reception among quite diverse groups helped significantly to make "revolution" the prevailing metaphor for scientific change.[4]

Although the books of Butterfield and Kuhn have become part of a canon of pedagogical texts that appear annually on history of science course lists,[5] forty years have passed since the publication of Butterfield's book and more than a quarter-century since the appearance of Kuhn's *Structure*. Other classic works in the same tradition – A. Rupert Hall's *Scientific Revolution, 1500–1800* (1954) and *From Galileo to Newton, 1630–1720* (1963), and Marie Boas's *Scientific Renaissance, 1450–1630* (1962) – have achieved a ripe middle age, and Richard S. Westfall's *Construction of Modern Science: Mechanisms and Mechanics* (1971) has been available for nearly two decades.[6] Meanwhile, a generation of scholars has been whittling away at all aspects of the historiographic corpus that Kuhn's *Structure* and its sources presupposed. For one thing, in the 1970s historians of science began to "discover" archives and lesser-known scientific characters, and to expose unknown sides of the familiar figures. They also began to produce specialized studies of the familiar figures celebrated by the classic conceptual histories. However, the new studies increasingly bore only a family resemblance to their older counterparts. History of science was beginning to be transformed into an encampment of specialists. Specialization brought with it an impatience with conceptual vignettes and broadly brushstroked stories; the new historians focused instead on "aspects" or "periods" of intellectual evolution, on "discovery," and especially on elements previously marginalized by too exclusive attention to the Greats. While academic presses continued to provide undergraduates with the older histories, the same learned presses joined the specialist journals in producing highly focused studies that took root and began subtly to undermine the wall on which Humpty-Dumpty sat.

Among many examples that could be offered, a few must suffice to hint at the range and depth of this shift in historiographic sensibility. First came the problem of integrating newly discovered personae with the old characters. If the Scientific Revolution was fundamentally a rethinking of metaphysical categories such as motion, space, and time, how could one square this view with archival evidence that seemed to reveal that Galileo had conducted actual experiments with inclined planes?[7] If Isaac Newton's genius lay first in finding a "mathematical way" to universal gravitation and then extending that to chemical reactions and phenomena of cohesion and capillarity, how could that achievement be situated within his voluminous alchemical writings, exegeses of the Book of Daniel, and sacred and secular chronologies? Did Newton regard the *Principia* as but a small part of a project to uncover all of nature's secrets, or was he a "skeptical alchemist," resigned to uncovering what he could from an ancient tradition?[8] Studies of Johannes Kepler, by contrast, more easily reconciled conflicting elements of his thought. The new scholarship showed, variously, that Kepler was not the deeply bifurcated thinker (empiricist and mystic) portrayed in the traditional literature but rather a man seeking natural harmonies throughout the creation. Yet it was still the old Kepler who provided the planetary laws essential to the classic Newton of the *Principia*, not the well-rounded Kepler constructed by the new history of science.[9]

Recently, an even more serious kind of challenge has arisen: a move away from intellectualist traditions and toward the contextualization of problems and solutions in specific intellectual polities. This view makes Boyle's famous air-pump experiments, for example, problematic by denying customary distinctions among text, instrumentation, and experimental facts and by viewing natural order not as something to be "discovered" but as a site of meanings produced by rival interest groups in struggles over political order.[10] Such a shift toward local frames of meaning calls into question the very possibility of assembling a definition of the Scientific Revolution as a decontextualized "list" of new concepts, instruments and natural objects, ideals and metaphors of knowledge.[11]

Indeed, it can now safely be said that the standard textbooks no longer present a picture fully consistent with recent developments.[12] This has created an acute dilemma for scholars interested in the early modern period – whether specialists in sixteenth- and seventeenth-century science, seeking coherent organizing principles by which to structure their research, or teachers in need of an overview of the "origins of modern science" suitable for classroom presentation.

The present volume, as the editors originally conceived it, was

intended to offer at least a partial remedy for this disturbing situation by furnishing an opportunity for broader reflections from a wide spectrum of scholars actively engaged in research on sixteenth- and seventeenth-century science. Since our aim was to solicit "reappraisals" of the Scientific Revolution, each of the original authors was free to interpret reappraisal in whatever way he or she understood the term. However, that task turned out to be more difficult than either the editors or the authors had imagined. Several of the original contributors dropped out of the enterprise, either in despair at the glacial pace at which the volume seemed to be taking shape or because the sheer difficulty of the problem defied new, overarching formulations. Everyone who wrote for the volume had to confront the uncertainties of a larger historiographic framework in flux – and with no Alexandre Koyré, Thomas Kuhn, or A. Rupert Hall on the scene to articulate a new synthesis or a paradigm of historical investigation around which consensus could form. Those of us who did not already know it discovered that historians of science are in greater disagreement today about how to conduct their craft than the ubiquitous metaphor of Scientific Revolution suggests. In the end, the reader will have to decide what the authors of this volume have done with their original charge. Does any unity emerge from their presentations? Has the very notion of a Scientific Revolution in the sixteenth and seventeenth centuries survived detailed studies and reformulations? Or has the rubric endured, while its original meanings have changed? Can historians sustain the long view of the Scientific Revolution, or has that image been so undermined that we can write only discrete, episodic histories: *petites histoires?*

The essays in this volume display clusters of concerns along a spectrum of methods and styles. One notable tendency is toward a new and more thoroughgoing historicism. Many of our authors hold that, in one way or another, a better appreciation of early modern science emerges from sensitivity to categories produced by the actors themselves. It is particularly interesting to observe how a new historicism in philosophy of science has begun to move away from an earlier notion of the past as a mere "epistemological laboratory." What is important, as Gary Hatfield argues in Chapter 3, are the metaphysical categories that Descartes and Galileo actually used, rather than, as E. A. Burtt urged in 1924, the unconscious presuppositions that we infer they held. What Ernan McMullin views as critical in Chapter 2, is not so much the quality of the knowledge that the early moderns attained, judged by later standards, as their own expectations of what that knowledge should look like, of what should count as knowledge and why, and of the gap between ideal and achievement. Michael

Mahoney in Chapter 12, provides support for this view when he asks us to examine canons of mathematical intelligibility as they existed – and as they changed – during the seventeenth century. And Alan Gabbey in Chapter 13, reformulates the notion of "revolution," using Larry Laudan's "problems-and-solutions" model of science. Amending Laudan, who developed a calculus of problem solving, Gabbey argues that progressive theories are also heuristic mechanisms that create, or point in the direction of, new problems.[13]

If the "historicist wing" of the philosophy of science and those historians in dialogue with it have begun to reconsider the older view that modern boundaries should guide the study of past science, another sort of historicism has been developing among historians who look to the sociology of knowledge and to the "linguistic turn" in cultural and intellectual history and literary theory.[14] An important perspective here is the view that language is not unitary, that it should be considered to be a set of languages, or even dialects, used for different ends at different times and places. The historical problem is to make sense of these forms of speech in specific social settings, to regard understanding not as the passive reception of information or the decoding of a reality underlying language but as a constant activity of defining, selecting, and remolding. On this view, the notion of "audience" is not an empty category. Jan V. Golinski, for example, examines in Chapter 9 the kind of discourse produced by seventeenth-century chemists in relation to the immediate circumstances of chemists' careers, available markets for texts, ties of interpersonal obligation, and rituals of information exchange. And Robert S. Westman, in Chapter 4, reads Copernicus's preface to *De revolutionibus* not as a representation of a Kuhnian "crisis" in astronomy but as a self-consciously styled rhetorical instrument, designed to persuade the pope that correcting the calendar and the order of the heavens should be part of a common agenda of church reform.

This study of context and audience is only one part of a developing tendency to study neglected areas of discourse and practice that have been overlooked because they did not fit into prevailing conceptions of science. Another question that has begun to receive serious consideration is that of the connection between science and the universities. Postwar internalist historiography tended to downgrade the importance of the universities in the development of science, viewing them as an insignificant and (at best) oppositional backdrop that paled in comparison with the drama of scientific revolutionaries slugging out the big issues of natural knowledge on their own. In some cases, historians simply adopted the loud, negative judgments about the sterility of the academies voiced by seventeenth-century contempo-

raries such as Francis Bacon, John Wallis, and Henry Power.[15] But recently historians, employing the methods of both social and intellectual history, have begun to recover the complexity of academic culture by studying the contents of diaries, catalogs of private libraries, wills, lecture notes, and textbooks. Some of these scholars have been specifically concerned with the question of the status of scientific knowledge in the universities.[16] At the very least, as John Gascoigne points out in Chapter 5, we need to account for what the revolutionaries learned in the schools, and indeed Gascoigne's own synthesis of recent secondary literature on this score reveals some interesting conclusions: that there was a flourishing, although still essentially conservative, mathematical culture in early modern universities; that some universities – Leyden and the Collegio Romano, for example – were unusually open to new sorts of learning; that academic faculties of medicine were genuine sites of rebellion against established authorities, as well as sources of new kinds of space for scientific work (anatomy theaters, botanical gardens, chemical laboratories); and that many of the figures judged in some sense to be "scientists" actually worked in the universities.

Such conclusions open another important challenge to the standard picture of the Scientific Revolution: What did the map of knowledge look like to contemporaries, and just which parts of it were undergoing changes that could deservedly be dubbed "revolutionary"? One way in which this problem has been cast is to distinguish between mathematical and nonmathematical or, as the latter are sometimes known, Baconian sciences. Taking up a formulation bequeathed by Butterfield and Koyré, Thomas Kuhn argued some years ago that the Scientific Revolution occurred not in chemistry or "experimental philosophy" but rather in the classical, "quasi-mathematical" fields of astronomy, optics, statics, mechanics, and harmonics.[17] Though provocative, as always, Kuhn's picture has not survived unscathed. John Heilbron has shown that an army of little-known academic Jesuits described and displayed an extensive corpus of electrical and magnetic effects during the seventeenth and eighteenth centuries. Instrument-based electrical theory, rather than cosmology, Heilbron argues, was "the bellwether of the flock of physical sciences created during the Scientific Revolution."[18] In our volume, Harold J. Cook contends, in Chapter 10, that medicine suffered a similar historiographic exclusion from the grand narrative of Scientific Revolution, because both the Koyré–Burtt–Butterfield tradition and the positivist medical histories, such as Charles Singer's, admitted only those few achievements in anatomy and physiology – the work of Vesalius and Harvey – that fit their story of rational progress. One consequence of historicizing

the classification grid, Cook shows, is to reveal agents' categories, such as "physic" and "empiric"; the use of these categories, in turn, permits us to see how the "new philosophy" endorsed an empirical medicine and thereby directly threatened those who professed a learned "physic" that purported to identify the causes of illness.

Still another area that has long interested students of the Scientific Revolution is the realm of the hidden, the invisible, or the unexpected. Anyone who studies early modern culture soon recognizes the preoccupation of that age with unseen spirits and forces, extraordinary beings, the alchemical transformation of metals and other substances, and the powerful and "magical" effects of words, images, and musical sounds.[19] Literatures that classified certain practices and objects as "occult," "secret," or "magical" promised some measure of control to the initiated. However, they sometimes carried with them the taint of illegitimacy, if not official disapproval. As William Eamon argues, in Chapter 8, the hiding of natural knowledge served a variety of ends. It protected arcane secrets from desecration by the unworthy, and, by keeping the powerful instrument of knowledge out of the wrong hands, it safeguarded the traditional sociopolitical and religious orders. Renaissance inventors and scholars practiced secrecy in order to reap the benefits of their own discoveries and protect their livelihood. Eamon associates the rise of the practical ideal of knowledge open to wider audiences with developments such as the invention of printing, an emerging sense that discoveries could be regarded as forms of property, new laws of patent and copyright, and the promotion of Christian unity in seventeenth-century England.

Yet, at the very time when the Baconian ideology of openness was gaining ground in Restoration England, charges of "atheism" and "scoffing" coexisted with it in a language that demarcated the legitimate from the illegitimate. Consider, for example, the following statement from Roger Cotes's preface to the second edition of Newton's *Principia:* "Newton's distinguished work will be the safest protection against the attacks of atheists, and nowhere more surely than from this quiver can one draw forth missiles against the band of godless men."[20] As Michael Hunter argues in Chapter 11, in the seventeenth century the term "atheism" was not restricted to its usual modern sense (the denial of God's existence); nor can accusations of atheism be understood narrowly as a specific response to fears of political subversion associated with the aftermath of the English Civil War. The anti-atheist literature, Hunter claims, was broad, and, if anything, the word "atheist" was a label for a supposed threat that was part of a wider, more diffuse, rhetoric of social anxiety: a discomfort with extremes of naturalistic and secularist explanation, a fear of the decline

of religion, and an attempt to secure the boundaries between orthodoxy and heterodoxy.

Serious consideration of marginalized or neglected genres, like the revival of ignored disciplines, poses difficulties for the grand narrative of "revolution." For the canonical notion of Scientific Revolution privileged certain achievements through an analysis of propositions and arguments but undervalued the forms in which they were cast, the latter being considered largely uninteresting or irrelevant. In different ways Brian P. Copenhaver, in Chapter 6, and William B. Ashworth, Jr., in Chapter 7, seek an amnesty for exiled literary forms: the literature of invention and discovery, astrological medicine, magical objects, hieroglyphs, mythologies, adages and proverbs, and visual emblems. Along the way, their work collides with present demarcations between the scientific and the nonscientific, thereby highlighting what is modern about that distinction and calling attention to a shift in the notion of signification and reference. For example, what are we to make of Copenhaver's description of those strange creatures: the catoblepas, the basilisk, and the torpedo fish? Do they have, or did they have, references in the world of nature? Copenhaver thinks that perhaps they did: the African gnu, the spitting cobra, and the Mediterranean electric ray. However, he argues that these creatures are, above all, "textual objects" authorized by ancient doxographies, literary references that "came not merely to represent the evidence but actually to constitute the evidence." Ashworth takes the point farther, introducing Conrad Gesner's peacock in a brilliant panoply of encyclopedic associations. Gesner's peacock is also a textual object, assembled from a basket of woodcuts, aphorisms, and etymologies; for the later Ulisse Aldrovandi, it is an even richer mosaic, gathered from emblem lore, hieroglyphics, and iconology. Yet by 1650 the peacock was utterly stripped of its resemblances. As Ashworth makes clear, it is difficult to know how such a "natural history" might fit into the canonical version of the Scientific Revolution. The problem is evidently one of representation and leads to new questions: When and how did the webs of similitudes begin to disappear? How and why did natural historians come to remove the textual overlay from their subjects and begin to regard their descriptions as referring to the animate objects of everyday experience?

Criticism of a prevailing historiography inevitably raises consciousness about the writing of history itself. Various projects are now under way to scrutinize the history of science as a history. In this volume, each author pokes or stabs at established interpretations in his particular area. David C. Lindberg, however, takes a longer view in Chapter 1, analyzing images of sixteenth- and seventeenth-century

science, from those presented by the humanists of the Renaissance to the idealist synthesis of Burtt, Koyré, and Butterfield in this century. Although the work of these latter writers and their followers now constitutes the canon under attack, it is worth remembering that in their own time Burtt and Koyré were struggling to create a historicized representation of science against a then-dominant positivist orthodoxy. As historical epistemologists, they found their models, naturally, in the history of philosophy. In a sense, then, the present discussion is also a criticism of a specific tradition within the history of philosophy. And it may be no accident that today certain philosophers are questioning the histories of their own disciplines, just as intellectual history in general has been undergoing valuable self-criticism and reexamination.[21]

## Notes

1 Herbert Butterfield, *The Origins of Modern Science, 1300–1800* (London: Bell, 1949), pp. vii–viii; Richard S. Westfall, "The Scientific Revolution: Teaching in the History of Science, Resources and Strategies," *History of Science Society Newsletter*, 15 (1986):1. A similar claim regarding the significance of the Scientific Revolution had already been made by Preserved Smith, *A History of Modern Culture*, 2 vols. (New York: Holt, 1930), 1:6–7, 144–64.

2 Thomas Hobbes, *Elements of Philosophy* (London, 1655), in *The English Works of Thomas Hobbes*, ed. William Molesworth, 11 vols. (London: John Bohn, 1839–1845), 1:viii–ix.

3 See Roy S. Porter, "The Scientific Revolution: A Spoke in the Wheel?" in *Revolution in History*, ed. Roy Porter and Mikuláš Teich (Cambridge: Cambridge University Press, 1986), pp. 290–316, and I. Bernard Cohen, *Revolution in Science* (Cambridge, Mass.: Harvard University Press, 1985), pp. 481–8. See also David C. Lindberg, "Conceptions of the Scientific Revolution from Bacon to Butterfield," Chap. 1, this volume.

4 Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press, 1962). On the reception of Kuhn's work, see Gary Gutting, *Paradigms and Revolutions: Applications and Appraisals of Thomas Kuhn's Philosophy of Science* (Notre Dame, Ind.: University of Notre Dame Press, 1980).

5 See Westfall's recommendations for undergraduate texts in "Scientific Revolution," pp. 2–3.

6 A. Rupert Hall, *The Scientific Revolution, 1500–1800* (London: Longman, 1954). Hall, *From Galileo to Newton, 1630–1720* (New York: Harper & Row, 1963). Marie Boas, *The Scientific Renaissance, 1450–1630* (New York: Harper & Row, 1962). Richard S. Westfall, *The Construction of Modern Science: Mechanisms and Mechanics* (New York: Wiley, 1971).

7 Stillman Drake, "Galileo's New Science of Motion," in *Reason, Experiment, and Mysticism in the Scientific Revolution*, ed. M. L. Righini Bonelli and William R. Shea (New York: Science History, 1975), pp. 131–56. For other

interpretations of this hotly disputed material, see Ronald Naylor, "Galileo: The Search for the Parabolic Trajectory," *Annals of Science*, 33 (1976):153–74, and David K. Hill, "Dissecting Trajectories: Galileo's Early Experiments on Projectile Motion and the Law of Fall," *Isis*, 79 (1988):646–68. See also Marie Boas Hall, "Koyré and the Development of Empiricism in the Later Renaissance," *History and Technology* (special issue: *Science: The Renaissance of a History*), 4 (1987):225–33.

8 See Richard S. Westfall, "Newton and Alchemy," in *Occult and Scientific Mentalities in the Renaissance*, ed. Brian Vickers (Cambridge: Cambridge University Press, 1984), pp. 315–36; "The Role of Alchemy in Newton's Career," in *Reason, Experiment, and Mysticism*, ed. Righini Bonelli and Shea, pp. 189–232; and Paolo Casini, "Newton, a Sceptical Alchemist?", in *Reason, Experiment, and Mysticism*, ed. Righini Bonelli and Shea, pp. 233–8.

9 E. J. Aiton, "Johannes Kepler in the Light of Recent Research," *History of Science*, 14 (1976):77–100; David C. Lindberg, "The Genesis of Kepler's Theory of Light: Light Metaphysics from Plotinus to Kepler," *Osiris*, 2nd ser., 2 (1986):5–42.

10 See Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton: Princeton University Press, 1985); Jeffrey Sturchio, "Artifact and Experiment," *Isis*, 79 (1988):369–72; Steven Shapin, "The House of Experiment in Seventeenth-century England," *Isis*, 79 (1988):373–404.

11 For an interesting attempt to define the Scientific Revolution, see Paolo Rossi, "Hermeticism, Rationality, and the Scientific Revolution," in *Reason, Experiment, and Mysticism*, ed. Righini Bonelli and Shea, pp. 250–1.

12 But see two quite different recent attempts to revise the story: A. Rupert Hall, *The Revolution in Science, 1500–1750* (London: Longman, 1983), and Margaret Jacob, *The Cultural Meaning of the Scientific Revolution* (New York: Knopf, 1988).

13 See Larry Laudan, *Progress and Its Problems* (Berkeley and Los Angeles: University of California Press, 1977).

14 Steven Shapin, "History of Science and Its Sociological Reconstructions," *History of Science*, 20 (1982):157–211; John E. Toews, "Intellectual History after the Linguistic Turn: The Autonomy of Meaning and the Irreducibility of Experience," *American Historical Review*, 92 (1987):879–907.

15 See Mordechai Feingold, *The Mathematician's Apprenticeship: Science, Universities and Society in England, 1560–1640* (Cambridge: Cambridge University Press, 1984), p. 87; Henry Power, *Experimental Philosophy* (London, 1664).

16 See, for example, Charles Schmitt, *Aristotle and the Renaissance* (Cambridge, Mass.: Harvard University Press, 1983); *John Case and Aristotelianism in Renaissance England*, McGill-Queen's Studies in the History of Ideas, no. 5 (Kingston: McGill-Queen's University Press, 1983); T. H. Aston, ed., *The History of the University of Oxford*, vol. 3, *The Collegiate University*, ed. James McConica (Oxford University Press [Clarendon Press], 1983); Feingold, *Mathematician's Apprenticeship;* and William A. Wallace, *Galileo and His Sources: The Heritage of the Collegio Romano in Galileo's Science* (Princeton: Princeton University Press, 1984).

17 Thomas Kuhn, *The Essential Tension: Selected Studies in Scientific Tradition and Change* (Chicago: University of Chicago Press, 1977), pp. 30–65.
18 John Heilbron, *Electricity in the Seventeenth and Eighteenth Centuries: A Study of Early Modern Physics* (Berkeley and Los Angeles: University of California Press, 1979). See his *Elements of Early Modern Physics* (Berkeley and Los Angeles: University of California Press, 1982), p. viii, for the quoted phrase.
19 See especially Lynn Thorndike, *A History of Magic and Experimental Science*, 8 vols. (New York: Columbia University Press, 1923–1958); D. P. Walker, *Spiritual and Demonic Magic from Ficino to Campanella* (London: Warburg Institute, 1958); Frances Yates, *Giordano Bruno and the Hermetic Tradition* (London: Routledge & Kegan Paul, 1964).
20 Roger Cotes, Preface to the second edition of Newton's *Principia*, in *Newton's Philosophy of Nature: Selections from His Writings*, ed. H. S. Thayer (New York: Hafner, 1953), p. 134.
21 Richard Rorty, *Philosophy and the Mirror of Nature* (Princeton: Princeton University Press, 1979); Toews, "Intellectual History after the Linguistic Turn."