Introduction

Transformation and tradition are the dialectic of scientific activity. The tension that exists between these two necessary attributes has been the focus of study for the modern history of science. If change is valued, as it so obviously is in science, and rewarded, as the annual Nobel Prize pageant attests, there is also a secret admiration of stability, a reluctance to part with comfortable and often useful current understandings and practices. It is the examination of the fine structure of the processes of change that has shaped I. Bernard Cohen's work in the history of science.

Although the work of very few scholars shows an undeviating commitment from the earliest to the most recent productions, central lines of development are often apparent. This certainly is true for Bernard Cohen. The history of the physical sciences in the seventeenth and eighteenth centuries is the locus, and the approach has included both careful textual scrutiny and the analysis of concepts and practices. No attempt will be made here to analyze in detail the full corpus; rather we identify important high points in Bernard Cohen's work, especially those that have influenced his students and the field as a whole.

Benjamin Franklin's electrical experiments were the basis of Cohen's first significant publication. He prepared a new edition of Franklin's *Experiments and Observations on Electricity* and added to it a substantial historical introduction setting this electrical experimentation and theory construction in the context of the development of experimental traditions in eighteenth-century science.[1]

This publication set the major theme for Cohen's sustained examination of Franklin and also of the links of the experimental approach of the eighteenth century to the strong theories propounded by Isaac Newton a century earlier. It would be nice to periodize neatly Bernard Cohen's work and thereby identify a progression backward in time from Franklin to Newton. The careful bibliographer will note, however, at least several early if brief articles on Isaac Newton that rapidly followed the publication of the Franklin edition.[2]

Several other diversions from the "main path" occurred during, and immediately after, the Second World War. They are worth mentioning because they reflect a secondary theme of Bernard Cohen's interests, namely, the relations between science and society, particularly in the context of United States history. In a set of four brief articles, clearly influenced by the war and the role of

science in it, Cohen explored the relations between science and war in the United States from the Revolution to 1942.[3] Another book dealt with other aspects of American science: instruments and collections, as exemplified by those held in Harvard's museums, attics, and basements.[4] This concern with science in the American context remained an interest, if subdued, in Bernard Cohen's scholarly and teaching career over the years and periodically brought forth suggestive articles, including an important series that explored the nineteenth-century conflict between the tradition of the basic and applied sciences in the United States.[5]

But the real commitment of Cohen's scholarly life was made clear by the full and detailed book he published in 1956, *Franklin and Newton, An Inquiry into Speculative Newtonian Experimental Science and Franklin's Work in Electricity as an Example Thereof.*[6] The eighteenth-century experimental tradition is explored at length and is related directly to theoretical sources in the seventeenth century. Several themes emerge in the book that remain commanding ones in Cohen's subsequent work: his interest in "the scientific personality" of key figures in science (Franklin and Newton in this case),[7] and an explicit concern for the conditions of the emergence of novelty, treated in the book in an appendix.[8] If it was Benjamin Franklin who captured Bernard Cohen's imagination in the first phase of his career,[9] it became clear with this book that Isaac Newton would dominate the next phase. Newton obviously fascinated and challenged Cohen. In his preface he alluded to the Newton projects then underway (W. H. Turnbull was undertaking publication of Newton's correspondence) and closed by indicating that he had agreed to participate in the preparation of a critical and variorum edition of the *Principia* in collaboration with Alexandre Koyré.[10] Just one year earlier Koyré had identified the need for such an edition of Newton's works and an important collaboration was begun.[11] It brought together two scholars with some obviously shared interests but also with different backgrounds and scholarly approaches. Koyré's influence as a historian of philosophy and ideas focusing on conceptual analysis in the sciences was just beginning to be felt in the Anglo-American community of historians of science and the commitment to a joint project with Bernard Cohen brought his work even greater attention.[12]

For Bernard Cohen the Newtonian phase of his career involved not only the joint preparation of the critical variorum in two volumes, but also the construction of a 380-page introduction to the text of the *Principia.* These were joined by a steady stream of papers examining aspects of Newton's scientific development and on occasion involving a form of historical detective work as in the joint paper with Koyré, "The Case of the Missing *tanquam:* Leibniz, Newton, and Clarke."[13]

The text of the *Principia* and the *Introduction* were published in 1972 and 1971, respectively, and mark one of the high points of what became a veritable "Newton industry" among historians of science.[14] Unfortunately, Koyré died in 1964 and Cohen saw the jointly edited *Principia* through the publication process and prepared the *Introduction* on his own. It is fair to say that although he has been

joined by many other talented scholars Bernard Cohen remains one of the recognized doyens of Newtonian studies.

If attention to detail was the necessary mark of the work on the *Principia* critical edition and the *Introduction,* Cohen was given an opportunity to step back from the editor's role and take a broader look at the meaning of Isaac Newton's work when in 1966 he was invited to give the Wiles Lectures at Belfast University. These lectures as originally delivered and then revised over some dozen years, prior to publication in 1980, intertwined two important themes, namely, the development and meaning of Newtonian science and the concept of scientific change. In a supplement to the main text of his book, *The Newtonian Revolution,* Cohen added a personal account of his efforts to come to grips with what he referred to at the time as "transformations" of scientific ideas.[15] In fact, in the bibliography of the *Introduction* he refers to the forthcoming publication of the Wiles Lectures, giving them the provisional title, *Transformations of Scientific Ideas: Variations on Newtonian Themes in the History of Science.*[16] But Cohen also tells us that in the Autumn of 1966, he had privately circulated texts of the lectures, including one dealing with the "doctrine of transformation," under the title, *Isaac Newton: The Creative Scientific Mind at Work.*[17] This locates for us Cohen's meaning, as he links the creative scientific personality directly to the processes of scientific change and transformation.

By the time of publication of the Wiles Lectures in 1980, now in much altered form, Cohen had recast and refined his ideas of change and moved from the word "transformation" to the word "revolution" to denote the Newtonian impact. But he has gone further and has added many comments on the concept of revolution as it refers to the sciences in general, and promises that in a forthcoming book, *Revolution in Science: History, Analysis, and Significance of a Name and a Concept,* he will deal at length with ideas of scientific change as they have developed in history.[18] Several sections of the *Newtonian Revolution,* his "supplement," and several articles give a foretaste of his foray into the unscrambling of the concept of scientific revolution.[19] He is quite precise in stating his view, a focus on the "fine structure of the scientific revolution" produced by a work like the *Principia,* not on a macroscopic scale but rather on the microscopic scale of the history of science.

> My concern is with the role of the individual in scientific change, even in scientific revolution, as a means of understanding how science may undergo radical alterations of its systems of concepts, laws, and explanations. The analysis of revolutions into a series of transformations shows the continuity within the change, but does not thereby diminish the magnitude of the net change itself.[20]

That his concepts of revolution and transformation will be challenged is certain as this aspect of the history of science has been rife with dispute. But by locating his claims firmly in the microanalysis of the work of Isaac Newton, he has ensured that the role of the creative scientific personality cannot easily be cast aside.

To the scholarly world at large Bernard Cohen is now best known for his

significant contributions to Newtonian studies. To historians of science, however, there are other important contributions that have brought him recognition. *Isis*, the official journal of the History of Science Society founded and originally edited by George Sarton, Bernard Cohen's own teacher at Harvard, plays a central role in publications in the discipline in the United States. First as managing editor (1947–52) and then as editor (1953–8), Cohen took the journal through transition to its modern form. He has been active as well in the affairs of the History of Science Society in the United States as a long-term member of the executive council, as vice-president, and ultimately as president. He has similarly served the discipline at an international level through terms as vice-president and president of the International Union of the History and Philosophy of Science.

For several generations of students at Harvard University, Bernard Cohen is best known as an outstanding lecturer and dedicated apostle of the history of science. He taught large undergraduate courses, first in the general education program, where he used the history of science to introduce nonscience students to the nature of the physical sciences, and later in the Core program, where he focused on the Scientific Revolution. Physical demonstrations, audiovisual materials, and a high degree of lecturing drama made his courses memorable. But in addition to "teaching out" to nonspecialist students he also played a major role in departmental courses at both undergraduate and graduate levels. The courses and seminars he taught were wide ranging, from the traditional surveys, (Aristotle to Einstein) through science in the United States, to such specialized interests as seventeeth-century physics, the history of computing, and relations between the natural and social sciences. He regularly impressed students in his courses, especially in seminars, with the depth and breadth of his knowledge and with his vast acquaintance with the literature in the field. There were often "surprises": Alchemy was not one of his favorite fields, but he became knowledgeable about it and ultimately even produced a significant article about one of its American practitioners, Ethan Allen Hitchcock.[21]

Although he has not published extensively in the field of science policy, Bernard Cohen has been a regular teaching participant, in Harvard's Program on Science, Technology and Public Policy, since its foundation in 1960. Working together with the program's directors, Dean Don K. Price of the Kennedy School of Government and Professor Harvey Brooks, Cohen has added the historical dimension to their project. This activity picked up an early interest that Cohen had demonstrated in a book written for the public on the role that scientific discovery has played in modern societies.[22]

Bernard Cohen's whole academic career has been linked to Harvard University. He arrived in Cambridge as a freshman in 1933 and received his undergraduate degree in 1937. He stayed on as a graduate student with the Committee on Higher Degrees in the History of Science on Learning; he remained in Cambridge during the Second World War teaching physics and mathematics in the program arranged for the navy; and in 1947 he received his doctorate and took up his post in history of science and general education. His profes-

sorship came in 1959 and in 1977 he was given additional recognition by apointment as Victor S. Thomas Professor of the History of Science, becoming emeritus in June 1984. His second intellectual home was England, initially as a Special University Lecturer at University College, London (1957), and subsequently at Cambridge University (the source of so many Newton manuscripts), where he has returned on numerous occasions with longer stays as Visiting Fellow at Clare Hall (1965) and as Overseas Fellow of Churchill College (1968).

Although it is customary in accounts of academic careers to give pleasant passing reference to the devoted spouse, in Bernard Cohen's case it is not possible to fully understand his career without understanding the role of his wife, Frances Davis Cohen. She was, as expected, a vigorous supporter of the history of science and of the Harvard department. But she was also a tough-minded individual with pronounced views of her own who could and did at one and the same time provide a lovely dinner and a rich and pointed discussion. She was herself an author and almost certainly a sharp and constructive critic of Bernard Cohen's written words.[23]

The history of science itself has come through important transformations in the years since the Second World War. As a subject of teaching and research it has grown from an exotic interest of a few scholars to a strong discipline represented in many centers of learning. Its publications, both journal articles and books, now enjoy a readership that crosses the boundaries between the "two cultures" and finds itself firmly fixed as an important element in the history of cultures. Intellectually and conceptually the field has developed new approaches and methods that incorporate philosophical analysis and sociological scrutiny. Bernard Cohen's own career has been a part of this transformation and his own teaching and scholarship have made him a vigorous participant in it. The essays that follow honor his contributions and demonstrate the intellectual vitality and the emerging perspective in the history of science.

NOTES

1 I. Bernard Cohen (ed.), *Benjamin Franklin's Experiments. A New Edition of Franklin's "Experiments and Observations on Electricity,"* Edited with a critical and historical introduction (Cambridge, Mass.: Harvard University Press, 1941).

2 I. Bernard Cohen, "Newton and the Modern World," *American Scholar* II (1942): 328–38; "Isaac Newton (1643–1727)," *Sky and Telescope* 2 (1943): 3–5; "Authenticity of Scientific Anecdotes," *Nature* 157 (1946): 196–7. The last deals with the story of Newton and the falling apple.

3 I. Bernard Cohen, "American Physicists at War: From the Revolution to the World Wars," *American Journal of Physics* 13 (1945): 223–35; "American Physicists at War: From the First World War to 1942," *American Journal of Physics* 13 (1945): 333–46; "Science and the Revolution; the Vital Interplay of Engineering and Science with Government had its Beginning in War Necessities," *Technology Review,* 47 (1945): 367–8, 374–8; "Science and the Civil War, First Large-scale Organizations of Technical and Scientific Re-

sources of Manpower during the Civil War marks that Conflict as the turning Point in the Technology of Warfare," *Technology Review* 48 (1946): 167–70, 192–3.

4 I. Bernard Cohen, *Some Early Tools of American Science, An Account of the Early Scientific Instruments and Mineralogical and Biological Collections in Harvard University* (Cambridge, Mass.: Harvard University Press, 1950).

5 I. Bernard Cohen, "The New World as a Source of Science for Europe," *Actes de IXe Congres International d'Histoire des Sciences* (Barcelona, 1959), 95–130. I. Bernard Cohen, *Science and American Society in the First Century of the Republic* (Columbus: Ohio State University Press, 1961)

6 I. Bernard Cohen, *Franklin and Newton, an Inquiry into Speculative Newtonian Experimental Science and Franklin's Work in Electricity as an Example Thereof* (Philadelphia: American Philosophical Society, 1956).

7 See Ibid. Chapter 3, "The Scientific Personality of Franklin and Newton," pp. 42–88.

8 Ibid. Appendix 2, "Originality in Scientific Discovery, with Special Reference to Franklin's Experiments and his Concepts of the Electric Fluid," pp. 590–600.

9 He prepared a book-length biography in 1953, *Benjamin Franklin: His Contribution to the American Tradition.* Makers of the American Tradition Series. (New York: Bobbs-Merrill, 1953). It has been followed by other biographical volumes and, most recently, the Franklin entry in the *Dictionary of Scientific Biography.*

10 I. Bernard Cohen, *Franklin and Newton,* Preface, p. xii. The book is jointly dedicated to Alexandre Koyré (who represented the new interest in Newton) and Perry Miller, the Harvard literary and intellectual historian, whose works on the development of the American mind and culture can be linked to Cohen's interests in Franklin and American science.

11 Alexandre Koyré, "Pour une édition critique des oeuvres de Newton," *Revue d'Histoire des Sciences* 8 (1955): 19–37.

12 See especially Alexandre Koyré, *Etudes Galiléenes* (1939; reprint Paris: Hermann, 1966) and also his, "The Significance of the Newtonian Synthesis," *Archives Internationales d'Histoire des Sciences* 3 (1950): 291–311. His most influential text for American students was, *From the Closed World to the Infinite Universe* (Baltimore: Johns Hopkins University Press, 1957).

13 Alexandre Koyré and I. Bernard Cohen, "The Case of the Missing *tanquam:* Leibniz, Newton, and Clarke," *Isis* 52 (1961): 555–66.

14 Alexandre Koyré and I. Bernard Cohen (eds.), *Isaac Newton's Philosphiae Naturalis Principia Mathematica,* 2 vols. The third edition (1726) with variant readings assembled by Alexandre Koyré, I. Bernard Cohen, and Anne Whitman. (Cambridge: Cambridge University Press, and Cambridge, Mass.: Harvard University Press, 1972); I. Bernard Cohen, *Introduction to Newton's "Principia"* (Cambridge: Cambridge University Press, and Cambridge, Mass.: Harvard University Press, 1971).

15 I. Bernard Cohen, *The Newtonian Revolution with Illustrations of the Transformation of Scientific Ideas* (Cambridge: Cambridge University Press, 1980); "Supplement: History of the Concept of Transformation: a Personal Account," pp. 280–9.

16 I. Bernard Cohen, *Introduction,* p. 358. The Preface to the *Introduction* also gives a useful account of Cohen's developing Newtonian scholarship.

17 I. Bernard Cohen, "Supplement," p. 280.

18 I. Bernard Cohen, *Newtonian Revolution,* p. xiv; see also his discussions of "transformation" in Part II, esp. pp. 194–221.

19 See, for example, I. Bernard Cohen, "The Eighteenth-Century Origins of the

Concept of Scientific Revolution," *Journal of the History of Ideas* 37 (1976): 257–88; and "The Copernican Revolution from an Eighteenth-Century Perspective," in Yasukatsu Maeyama and W. Saltzer (eds.), ΠΡΙΣΜΑΤΑ: *Festschrift für Willy Hartner* (Wiesbaden: Steiner, 1977), 43–54.

20 I. Bernard Cohen, *Newtonian Revolution*, p. 219.

21 I. Bernard Cohen, "Ethan Allen Hitchcock, Soldier, Humanitarian Scholar, Discoverer of the 'True Subject' of the Hermetic Art," *Proceedings of the American Antiquarian Society*, 61 (1951): 29–139, published separately by the society in 1952.

22 I. Bernard Cohen, *Science, Servant of Man: A Layman's Primer for the Age of Science*, (Boston: Little, Brown, 1948).

23 Frances Davis, *My Shadow in the Sun* (New York: Carrick and Evars, 1940); Frances P. Davis, *A Fearful Innocence* (Kent, Ohio: Kent State University Press, 1981).

PART I

The history and philosophy of the exact sciences and mathematics

1

Compounding ratios

Bradwardine, Oresme, and the first edition of Newton's Principia

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I propose in this paper to look at one link between fourteenth-century science and Newton – namely, a concept of compounding ratios common to Thomas Bradwardine's *De proportionibus velocitatum in motibus,* to Nicole Oresme's *De proportionibus proportionum,* and to the first edition of Isaac Newton's *Principia.* My purpose in doing this is not to give Bradwardine or Oresme credit for any of the achievement represented by Newton's *Principia.* In fact, the link between Bradwardine, Oresme, and Newton that I want to demonstrate concerns an area in which Newton was old-fashioned and in which he was rapidly superseded, he himself conforming, at least superficially, to newer ways almost immediately after 1687. I do want to show, however, that the "old-fashioned" concept of the compounding of ratios common to Bradwardine, Oresme, and Newton was not false, misguided, or inconsistent, but rather was a mathematically viable alternative to the concept of the compounding of ratios that prevailed after 1700. Although I cannot even broach the subject here, this history of changes in the dominant concept of compounding ratios should eventually be incorporated into the history of the transition from the ancient and medieval custom of representing physical relationships in terms of proportionalities to the modern use of equations and functions for the same purpose.

In what follows, I will first look at the concept of ratio and of compounding ratios used in Newton's *Principia* and at changes Newton made in the *Principia*'s terminology of ratios as the result of an early complaint about the book. In the second main section of this essay I will examine two traditions within the Greek and medieval treatment of ratios, one associated with theoretical mathematics, with music, and with physics, particularly as found in Bradwardine's *De proportionibus,* and the second associated with practical calculations using ratios and with astronomy. In the last section I will make a preliminary survey of the conflicts between these two traditions that developed in the seventeenth century with the resulting eclipse of the first tradition concerning compounding and the emergence of the modern concept.

GILBERT CLERKE AND THE REVISION OF THE *PRINCIPIA*

Newton's *Principia* is a work belonging to the transitional period between the medieval and modern treatment of ratios. This can be seen very easily thanks to the work of I. Bernard Cohen and Alexandre Koyré in producing their edition of the *Principia* with variants.[1] I hope that this essay will pay a small tribute to that edition and its editors in showing that there are terminological and notational changes in the *Principia* that would be very hard to find without the help of the new edition but which in fact echo noisy struggles within seventeenth-century mathematics, in the process of which much of the distinctively medieval science of ratios was, along with some inferior seventeenth-century conceptions of ratio, left behind.

Soon after the publication of the first edition of the *Principia* in 1687, Newton received a letter from one Gilbert Clerke, mathematician and Presbyterian minister, Fellow of Sydney Sussex College, Cambridge, 1648–55, and author of *Oughtredus explicatus* (1682), a commentary on William Oughtred's *Clavis mathematicae* (1631).[2] Clerke is generally overlooked by historians of mathematics as a very minor figure, but he may claim our attention as possibly the first critic to propose changes in the *Principia* after its publication.[3]

On the whole, the modern reader, aided by Clerke's own expressed modesty, may be inclined to smile indulgently at his questions concerning the text of the *Principia.* Thus the passage about which Clerke first wrote concerned a continued equation to which Newton had added a complicated expression.[4] Clerke added this expression to the quantities on either side of the last equals sign, found that the algebra did not work out as Newton stated, and so suspected a printer's error.[5] But, just as the modern reader would expect and as Newton explained in his reply to Clerke, Newton had meant that the expression should be added to the original quantity before the continued equation, as well as to the last quantity.[6]

But although Clerke was a mathematician of modest ability, he did lead Newton to make systematic changes throughout the *Principia* in the terminology concerning the ratios. In the first edition of the *Principia,* Newton had, for the most part, used the same medieval terms to refer to powers and roots of ratios as he used to refer to multiples of integers or fractions. Thus *dupla* or double was the square of a ratio in modern terms, but it referred to two times an integer or fraction. *Dimidiata,* or half, was the square root of a ratio, but an integer or fraction divided by two. *Sesquialtera* was a ratio to the 3/2 power, in modern terms, but it was a number multiplied by 3/2.[7] Newton did have a different set of terms, namely *duplicata, subduplicata, sesquiplicata,* and so forth, which he might have used to distinguish taking the powers or roots of ratios from taking multiples of numbers, but he did not do this consistently.[8]

That Newton did not distinguish between what appears to us quite different operations is not as surprising as it may seem at first sight. For Newton, ratios are relations and, as such, are different from numbers, just as, for instance, lines are different from numbers. The "same operation" is quite naturally expected to