THE CHEMICAL REVOLUTION AND THE MODERN IMAGE OF SCIENCE

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During the last quarter of the eighteenth century the study of chemistry was transformed by the introduction of a new general theory of combustion and a new system of nomenclature. Historians of science have long referred to this transformation as The Chemical Revolution and have honored the French chemist Antoine Lavoisier (1743-94) as its chief architect.[1] The image of revolution is, of course, protean and in modern thought cannot be entirely separated from our understanding of the last few centuries of Western political history. We think of revolutions as events that disrupt established ways of doing things and signal new beginnings: modern liberalism struck political root in the aftermath of the English Revolution, the United States emerged from the American Revolution, the modern nation-state sprang from the dramatic conflicts of the French Revolution. And so it was with modern chemistry. The study of chemistry did not begin with the Chemical Revolution, but the Revolution marked the moment at which the study of chemistry became modern. Just what is meant by this claim continues to be a matter of considerable dispute among specialists in the history of chemistry. Other questions continue to provoke discussion as well, such as the extent to which chemistry as a whole was transformed, the causes of this transformation, the processes by which it permeated the science, and the relative importance of the roles played by the many contributors to the Revolution. Yet while the origins and nature of the Chemical Revolution are open to reinterpretation, its significance is seldom seriously questioned.

In this paper I wish to focus on the nature and meaning of the Chemical Revolution as it was perceived by certain scientists and commentators during the age of revolution that stretched from roughly 1775 to 1830. Rather than take up questions that pertain to the internal history of chemistry, I will focus on the perceived significance of the Chemical Revolution for science as a whole. This subject merits attention because the Chemical Revolution has long been recognized not only as a pivotal event in the construction of modern chemistry, but also as one of the defining moments in the history of modern science. Since the Revolution occurred in the period under examination, I will look at both the intentions of its primary author, Lavoisier, and the significance attached to his achievement by certain of his contemporaries and successors. My central claims will be 1) that the modern image of science, by which I mean the modern understanding of how the investigation of natural phenomena should be organized and pursued, was a product of the period 1775-1830, and 2) that chemistry, as reconstructed in the Chemical Revolution, was widely perceived in that era and on into the nineteenth century as the paradigmatic modern scientific discipline.

Because the idea of revolution in science has been conceptualized in so many different ways, I will not come at the subject directly.[2] My ultimate goal, as you will have discerned, is to problematize and reflect on the meaning of modernity in science. My strategy for getting to that goal will be to use the concept of revolution as a lever to pry open the black box of modern science. Therefore, rather than starting with a particular definition of revolution in science, I will begin by indicating how we might go about historically deconstructing a series of conceptions of scientific revolution that have been prominent in the history of science since World War II. These concepts of revolution have in turn generated a series of master narratives designed to validate distinctive images of the origins and nature of modern science. And these competing images of science have, of course, been deployed in various ways in more general debates concerned with the role of science in contemporary culture in the latter half of the twentieth century.[3] Since these topics are intensely contested, I wish to point out at the outset that my purpose in scrutinizing selected narratives and images of science is not to delegitimate science itself, but rather to clear the ground for the construction of one or more new images of science, images that are more nearly equal to the demands of the post-modern culture that is taking shape around us today.

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Historicizing "The Scientific Revolution"

Most students of the Chemical Revolution study this event in relative cultural isolation, and it certainly was sufficiently complex and extensive to justify such concentration. But for historians who, for whatever reason, wish to situate this event in a larger conception of the development of modern science, problems soon arise. Two options present themselves. We might call one the process option and the other the world-historical-event option. The first of these approaches, the process option, seeks to represent the advancement of science as a process that once begun, and when properly nurtured, continues to carry the science forward indefinitely. This progressive view of science is itself a child of the enlightenment and was given canonical form in nineteenth-century positivism. While each science concentrates on a distinctive domain of phenomena, all sciences are united in employing a common method. Disciplinary autonomy and methodological rigor, with a heavy emphasis on experimentation, lead to objective knowledge and steady improvement in the understanding and mastery of nature. This is the optimistic and progressive image of science that inspired so many investigators, teachers, and reformers during the nineteenth and twentieth century, and it is an image that appeared to be completely validated by the success of the Chemical Revolution. Lavoisier's achievement was to make chemistry a proper science; he lead not so much a revolution in science as a revolution *into* science. From that point on the way forward was clear.[4] It was thus quite natural for James Bryant Conant, himself a distinguished chemist, to draw most of his examples from chemistry when selecting the *Harvard Case Histories in Experimental Sciences* that he and his colleagues used when teaching science to humanities and social science students at Harvard in the decades following World War II.[5]

While many scientists consider the progressive positivist image of science plausible and largely correct, many historians have been made uncomfortable by its lack of critical self-awareness and cultural sophistication, especially with regard to the perennial problems of philosophy. Of course long before the middle of the twentieth century critics of the enlightenment were voicing their dismay over the secularization of culture, the commercialization of society, and the utilitarianism of science. While a few radicals did call for the abolition of science as it came to be practiced in the early nineteenth century, most of those who found positivism repugnant sought to civilize science by re-embedding it in a broader understanding of Western culture. One way to do so was to make the story of the rise of modern science part of a more comprehensive master narrative, one that would make it undeniably evident that the origins and concerns of science transcend mere utilitarianism and pragmatism. Several world-historical-event starting points for such a narrative were available. One could, for instance, argue that since modern science is uniquely Western, at least in its origins, the roots of its essential character should be traced back to the rational naturalist traditions of classical Greece. Alternatively, one could say that while the classical heritage was certainly important, science did not become distinctly modern and Western until fused in the Latin Middle Ages with essential elements of the Christian tradition. But the world-historical-event conception of science that most directly addressed issues raised by the Chemical Revolution was not fully developed until after World War II. This was the narrative, now in considerable disarray but not yet displaced in academic history of science, that presents modern science as arising from a single global scientific revolution that occurred in the seventeenth century. Whereas positivism, with its ever expanding federation of sciences, can easily accommodate multiple disciplinary revolutions that can occur, at least in principle, at any point in time, this new master narrative in the history of science spoke for the first time of THE scientific Revolution. It was no longer necessary to add "of the seventeenth century".[6] For the historian of the Chemical Revolution, taking The Scientific Revolution as the decisive moment in the history of science raises real problems. Herbert Butterfield, in the pioneering set of lectures he read in Cambridge University in 1948, began the construction of this new master narrative by describing *The Origins of Modern Science* as being located in the period 1300 to 1500. In his notorious chapter titled "The postponed Scientific Revolution in Chemistry," Butterfield stretched the fabric of the seventeenth-century revolution to the breaking point so as to incorporate an event he felt compelled to include in his narrative. His student A.R. Hall then carried forward the construction of this new image of the origins of modern science in his widely read text *The Scientific Revolution. 1500-1800;*;Hall too devoted a chapter, omitted in the second edition, to the Chemical Revolution.[7] The important feature of these accounts of the Chemical Revolution is not that they are strained and inadequate, but rather that they mark early steps in the long march by which the history of science, while transforming itself into an academic specialty in Great Britain and the United States, came to concentrate more and more on the achievement of the seventeenth century. This focus was greatly intensified by the extraordinary erudition and brilliant Hegelian interpretations of Alexander Koyré.[8] Unlike Butterfield and Hall, Koyré was not primarily interested in providing an account of the history of science that would be immediately accessible to undergraduate students not majoring in the sciences. It was largely under his aegis, however, that scholarly studies in the history of science came to focus almost exclusively on early modern philosophies of nature. It was in many ways a fruitful research strategy, not least because it enabled historians of science to create new academic programs and compete successfully for academic positions in history and philosophy departments, but it also had its costs, one being the radical separation of the images of science held by historians and by scientists. Descartes, Galileo, Kepler, Newton, and Leibnitz moved to center stage in the history of science, while the connections between The Scientific Revolution and the achievements of later scientists such as Lavoisier, who was still distantly revered, slowly dissolved.[9]

The establishment of the new master narrative of The Scientific Revolution is not the end of our story, for it raised a number of problems that the next generation of scholars felt compelled to address. Thomas Kuhn, a physicist turned historian and philosopher of science, was one of these. Kuhn, while working in the didactic tradition Conant had begun at Harvard, sought a general account of how science develops. Although persuaded by historians of science that the positivist account of scientific progress was fundamentally inadequate, he was not willing to restrict himself to the study of the achievements of the seventeenth century. He insisted instead on seeing science as a process, but one that depends on and incorporates beliefs and practices that cannot be completely reduced to experiments, methods, and fully explicated reasoning. Kuhn struggled to synthesize the process image of science with the broader history-of-ideas image, which had demonstrated irrefutably that early modern scientists were deeply affected by extra-scientific concerns and beliefs. The result was his immensely influential *The Structure of Scientific Revolutions.*[10] Theorists of scientific change now correctly consider Kuhn's account of the dynamics of scientific revolutions as post-positivist. And although it has long been recognized that Kuhn's sketch of how scientific revolutions occur is plagued with conceptual and evidential difficulties, his book continues to provide a stimulating point of departure for those who believe that any account of modern science must focus on the processes by which knowledge of nature is discovered and validated.[11] Like all great teachers, Kuhn set himself a challenging task and demonstrated how his readers could come to grips with important problems.

While Kuhn was adapting the process image of science in a way that made it possible to incorporate the historical insights of Koyré and his disciples, other historians of science were beginning to wonder if The Scientific Revolution [of the seventeenth century] was quite as unique as was claimed. I.B. Cohen, after summarizing the by-then canonical view of The Scientific Revolution in chapter 5 of his book *Revolution in Science*, went on to ask if, as Thomas Kuhn, Roger Hahn, and others had previously suggested, there was a Second Scientific Revolution in the early nineteenth century. Historians are, of course, familiar with the multiplication of conceptual entities; any number of events once considered global and unique, such as the Renaissance, the Reformation, and the Enlightenment, have been subdivided in the burgeoning literature of academic history into multiple specific movements. Having started down this path, Cohen went on to propose that there were in fact four general scientific revolutions, each of which occurred in a specific historical period and all of which were more comprehensive than the revolutions that transform single scientific disciplines.[12] Charles Gillispie, after deeply immersing himself in eighteenth-century French science, also suggested there was a Second Scientific Revolution in the period 1775-1830. However, being unwilling to break with the Koyrean claim that the essential move to philosophical modernity had been achieved in the seventeenth century, Gillispie restricted his Second Scientific Revolution to organizational modernization.

> During the half-century between the Turgot ministry and the Revolution of July 1830, or (to embrace the interval in dates with scientific significance) between the last years of d'Alembert and the death of Laplace in 1827, the French community of science predominated in the world to a degree that no other national complex has since done or had ever done. . . From the perspective of history of science, . . . it is possible to see a second scientific revolution in what then began to transpire. Manifesting in science the displacements and renewals of revolutionary Europe, the thrust proved to be organizational rather than cognitive, as it had been in the seventeenth century.[13]

While I disagree with Gillispie's claim that the transformation of science during this period was not cognitive as well as organizational, I believe he has made an important point about the preeminence of French science during this era. Looking back at England and France around 1775, we see England on the cusp of industrial revolution, world maritime hegemony, and economic transformation. France, on the other hand, is nearing the end of the era of Bourbon greatness and will soon be swept up in the turmoil of a revolution that, after giving birth to the modern nation state and a consummate imperial general, marked the beginning of the end of her status as what we would today call a world superpower. But before the French Revolution reached a crescendo of radical fury, which is to say before Lavoisier was executed 200 years ago, France, and more particularly Paris, was the unrivaled world center of high culture, including science. Paris certainly was not the source of all truth, but knowledge of international significance was definitively organized and canonized in the highly structured, authoritative academic world of Parisian culture, again including science. Lavoisier and his colleagues set out to do for chemistry what Buffon had done for natural history, that is to say name and order its phenomena in a way that made them accessible and intelligible to all learned men and women of their age. Lavoisier had the great benefit of making his career in a cosmopolitan city that was just reaching its peak as the center of Western Civilization, and he made very good use of his advantages.

At this point I must briefly mention my own work. Gillispie's characterization of the Second Scientific Revolution, except for its dismissal of the epistemological significance of that event, fits so well with my own view of what occurred in French science during the period 1775-1830 that I have previously made use of this organizing idea.[14] I now think this a mistake, however. The concept of a Second Scientific Revolution now seems to me to be unwarrantedly dependent on the presumed primacy of an earlier Scientific Revolution [of the seventeenth century]. While I do not deny that history is continuous or that the achievements of seventeenth-century natural philosophers are monumental, I see no reason to privilege the events of that century in a comprehensive narrative of the rise of modern science. Indeed, it now seems to me that while the achievement of the eighteenth century, and more particularly of the Chemical Revolution, obviously built on the achievements of the preceding century, modern science, as that term was understood in the nineteenth and twentieth century, is fundamentally a product of the transformation of science that occurred in the period 1775-1830. I say this not triumphantly, for we now realize that the modern image of science is seriously inadequate in many ways, but rather descriptively, as a matter of accurate history. I am not proposing a new master narrative that takes its departure from a previously undervalued world-historical-event, I am rather seeking to grasp when Europeans began to think about science in the way we call modern. The issue of historical accuracy in this matter is an important one.

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Lavosier's Strategy; His Successors' Appraisals

Skepticism, a tool much favored by philosophers oppressed by the synthetic doctrines of their predecessors, was widely deployed in the eighteenth century. It was used to puncture and deflate seventeenth-century natural philosophers' faith in the mathematical rationality of the universe, in their ability to use reason to move from knowledge of observables to the essential properties of imperceptible matter, and in the possibility of constructing comprehensive systems of natural philosophy that are in principle capable of explaining all natural phenomena. Much of the science of the seventeenth century sought to provide a God's-eye view of the natural world, which was appropriate to an age that put great stock in divine omniscience and omnipotence. But many eighteenth-century philosophers were simply not convinced that human knowledge could ever reach the levels of comprehensiveness and certainty to which the seventeenth century aspired. David Hume insisted not even Newton could know for sure what lies behind perceptible phenomena, and he called instead for an experimental study of human nature. And this was indeed the key shift, for while experiments certainly had been performed in the seventeenth century, in the eighteenth century they became the sole reliable point of departure for investigating physical phenomena. Experiments also provided the sole means by which one could certify that each inductive step in the creation of a theory was justified and the sole resource for testing and thereby verifying the adequacy and accuracy of a theory. Experiment, and when possible experimental quantification, took center stage in eighteenth-century science generally, just as they did in Lavoisier's chemistry.

Unlike some Lavoisier specialists, I believe experimental physics was of overwhelming importance to Lavoisier well before he committed himself to chemistry. I won't parade the evidence for this claim here, for I summarize a good deal of it in my recent biography. But you well may ask if I can make any relevant connection between Lavoisier and Hume. My response is twofold. In the first place, I have no evidence that Lavoisier found in Hume anything that directly informed his understanding of chemical phenomena. But Lavoisier was interested in much more than chemistry and he brought to the study of physical phenomena the same epistemological guiding assumptions he brought to the other subjects he studied, such as finance, agriculture, public administration, gunpowder production, institutional reform, and so forth. Thus if we can demonstrate that Lavoisier followed Hume in one field, we can reasonably assume that he would apply the same intellectual methods and standards in other fields. Now we do happen to know, and this is my second point, that in 1772 Lavoisier made an intense study of Hume's *Essays on Commerce* and that he was vastly impressed by the informed and moderate liberalism of Hume's views.[15] This specific instance of intellectual filiation happily reinforces nearly everything else we know about Lavoisier's attitudes toward knowledge and reform. He was, in short, a well-informed, enlightened *philosophe* whose natural friends and allies were men such as Pierre-Samuel Dupont, Adam Smith, Condorcet, David Hume, Benjamin Franklin, and Joseph Black. These were all men of the eighteenth, not the seventeenth, century, and they would have found it odd were one to suggest there was no essential difference between the conception of science they championed and that of their grand-fathers' or great-grandfathers' generations. If Hume brought natural science back to the surface, where experiments could provide reliable data, his friend and disciple Adam Smith explained why it was best to avoid constructing comprehensive systems of natural philosophy and focus instead on the investigation of carefully delimited problems. As everyone knows, Smith, in his epochal *Wealth of Nations* (published in 1776), sang the praises of the division of labor. But it was not simply pin factories he had in mind. "In the progress of society," he wrote,

> philosophy and speculation becomes, like every other employment, the principal or sole trade and occupation of a particular class of citizens. Like every other employment too, it is subdivided into a great number of different branches, each of which affords occupation to a peculiar tribe or class of philosophers; and this subdivision of employment in philosophy, as well as in every other business, improves dexterity, and saves time. Each individual becomes more expert in his own peculiar

> branch, more work is done upon the whole, and the quantity of science is considerably increased by it.[16]

Francis Bacon had a similar dream in the seventeenth century when imagining Solomon's house, but Bacon's dream certainly lacked the economic, and to us entirely contemporary, rationale that Smith gives it. Smith here presents himself as the philosopher of expertise, of the disciplinary sub-division of research and teaching, of science as the production of knowledge rather than the construction of comprehensive systems of understanding. One could well imagine him serving as Dean of Research in a modern university. An interesting question is, would he provide funds to the philosophy department?

I have been proceeding impressionistically in an effort to convey how the larger community of which Lavoisier was a part conceived of its relationship to nature and knowledge. My claim, fundamentally, is that while one can find many old-fashioned natural philosophers in the eighteenth century, Joseph Priestley and James Hutton being two examples, Lavoisier and his intellectual peers simply never took on the burdens of seventeenth-century natural philosophy and the metaphysical and theological entanglements it involved. This left them free to develop their skills as specialists - one thinks of Lavoisier's considerable investment in novel chemical instruments - and to focus their attention on solvable problems. The liberal model of disciplinary, public-spirited, and problem-oriented collaborative science was well established in the last generation to came to maturity before the French Revolution.[17] This way of thinking about and doing science was a child of the eighteenth century and it established a pattern for organizing research, both institutionally and intellectually, that to a very large extent we still employ today.

Let us now jump to the other end of the age of revolution, that is to say the period 1775-1830, and look there for evidence that Lavoisier's achievement was seen as representing a distinctively eighteenth-century reorientation of science. I will not focus on the hagiography of Lavoisier which was beginning to come into full bloom about 1830, for that is a subject Professor Bensaude-Vincent has made her own. Nor will I concentrate on August Comte's classic *Cours de Philosophie positive*, the first volume of which appeared in 1830. I will turn, rather, to an English work that like Comte's, but less ambitiously, sought to summarize and make accessible to interested amateurs what had been happening in science during the past two generations. I am speaking, of couse, of John Herschel's *A*

Preliminary Discourse on the Study of Natural Philosophy, published in London in 1830 as the first volume of Dionysius Lardner's *Cabinet Cyclopedia*. It is worth noting in passing that the appearance in the same year of the first volume of Comte's great work and of Herschel's penetrating study are reminders that the modern tradition of philosophy of science really begins in that year as well. One might say that as the age of revolution was brought to a close, systematic reflection on what modern science is and how it came to be that way began.

Although Herschel used the traditional phrase "natural philosophy" in the title of his book, the work itself is concerned solely with the physical sciences. When he takes up Lavoisier's achievement, he presents it as a paradigmatic example of what leading physical scientists had achieved by the end of the century. "The third age of chemistry -that which may be called emphatically modern chemistry -commenced ... when Lavoisier, by a series of memorable experiments, ... placed chemistry in the rank of one of the exact sciences, -a science of number, weight, and measure" [19] According to Herschel, science advances by using the methods and techniques Lavoisier employed: precise experimental measurement, cautious inductive generalization, careful use of analogies, frequent verification of hypotheses, checking deductions against observations, and ultimately the discovery of true laws and causes. His conception of science glows with the confident optimism of the enlightenment and is notably unconcerned with the ontological and theological issues that troubled early-modern natural philosophers. The physical sciences employ a common method. Knowledge of nature is now to be grounded solely on positive facts; natural philosophy has become a federation of autonomous scientific disciplines.

Herschel goes on to explain briefly how this new vision of science emerged. Many of the historical factors he mentions were already widely acknowledged in liberal circles in the 1820s: That the seventeenth century saw a turning away from theology to the study of nature, that progress in science accompanied the advancement of wealth and civilization, and that the establishment of appropriate institutions and journals had greatly accelerated the advancement of science. More novel and informative, however, is Herschel's discussion of advances in experimental precision.

> One of the means by which an advanced state of physical science contributes to accelerate and secure its further

> progress, is the exact knowledge acquired of physical data, . . . There is no surer criterion of the state of science in any age than the degree of care bestowed, and discernment exhibited, in the choice of such data, ... There is scarcely any thing by which science can be more truly benefited than by researches directed expressly to this object....[20]

The great increase in instrumental accuracy and experimental precision that Herschel considered the distinguishing features of the new physical sciences was, he emphasized, a product of eighteenth-century advances.[21] When one contrasts the means available to measure weights, distances and time in the nineteenth century "with what could be procured a few generations ago, by the rude and clumsy workmanship of even the early part of the last century," Herschel wrote, "it will be no matter of astonishment that the sciences which depend on exact measurement should have made a proportional progress."[22] In brief, Herschel, writing at the close of the age of revolution, has identified what is distinctive about the new physical sciences, the exemplars for all progressive sciences in the nineteenth century. And he has recognized that this novelty is a product not of the seventeenth but of the eighteenth century. Furthermore, this distinctive contribution is not simply organizational and institutional, it lies at the cognitive core of science itself, where evidence is transformed into knowledge.

Since we live in an age properly fearful of the Faustian power over nature that science has bestowed upon us and deeply suspicious of the optimism of positivism, which is now thought to be hopelessly simpleminded, it is fitting that we recall, when remembering Lavoisier, that it was above all chemistry that carried the torch of modern science at the beginning of the nineteenth century. Jan Golinski recently noted that at the beginning of the new century chemistry "was widely believed to have proved the most spectacularly successful science of recent times."[23] And as Roland Barthes has noted, the nineteenth-century French historian Jules Michelet took the new science of chemistry as his model for the "modern" and "scientific" history that he wished to write.[24] Lavoisier's achievement, his contribution to the recasting of chemistry, epitomized and embodied the broader transformation of science that was realized in the age of revolution, much as the work of Newton synthesized and symbolized the achievement of the Scientific Revolution of the seventeenth century. To appreciate the significance of Lavoisier's achievement beyond the borders of chemistry itself, we must recapture the sense, so widespread in the nineteenth century, that chemistry was the most modern of the modern sciences. It was the very paradigm of a successful scientific discipline.

Today there are indications that the modern image of science created in the age of revolution may be fading into oblivion. The disciplinary conception of science has been extraordinarily important in the organization and growth of the modern research university, nowhere more so than in the United States, but it may be that new ways of organizing knowledge, of understanding nature, and of educating future generations are now needed. In March of this year the *New York Times*, America's closest approximation to a national newspaper, reported that interdisciplinary studies are flourishing in American universities. The Chairman of the National Endowment for the Humanities, who was previously President of the University of Pennsylvania, reported that "the boundaries between disciplines are becoming blurred." A former research director at IBM who is now teaching at the Massachusetts Institute of Technology announced more portentously that "we're beginning to recognize that God did not create the universe according to the departmental structure of our research universities." When a spokesman for IBM and MIT reveals God's intentions, we mere mortals had best pay attention.

While it would be premature to abandon the image of science bequeathed to us by Lavoisier and his successors, it may be that the sun is indeed setting on this particular manifestation of modernity. Perhaps only now, as the long hegemony of the modern image of science is drawing to an end, can we begin to recognize just how profoundly the modern image of science is itself an historical construction. Minerva's owl is taking wing in the gathering dusk. It appears that the bicentennial of Lavoisier's death provides us with a singularly auspicious moment for beginning the reappraisal of Lavoisier's impact on the emergence of the modern image of science.

NOTES

1. See Bernadette Bensaude-Vincent, *Lavoisier, Memoire d'une revolution,* Paris: Flammarion, 1993.
2. See I. Bernard Cohen, *Revolution in Science*, Cambridge, Mass.: Harvard University Press, 1985.
3. See, e.g., C.P. Snow's famous book on *The Two Cultures.*
4. I have explored this theme in my "Lavoisier and the Origins of Modern Chemistry," in Arthur Donovan, ed., *The Chemical Revolution: Essavs in Reinterpretation*, vol.4, second series, of *Orisis*, Philadelphia: History of Science Society, 1988, pp. 214-31.
5. James Bryant Conant, ed., *Harvard Case Histories in Experimental Science*, 2 vols., Cambridge, Mass.: Harvard University Press, 1957.
6. My thoughts on this topic were considerably augmented by discussions with Simon Schaffer in May, 1994. He tells me that Roy Porter has convincingly argued that the concept of a single scientific revolution (in the seventeenth century) was first propounded by Herbert Butterfield and his students in Cambridge University following World War II - see Porter, "The Scientific Revolution of the Seventeenth Century - Another Spoke in the Wheel," in a collection of essays Porter edited on the enlightenment.
7. For citations, see my *Osiris* article, p. 214, n.l.
8. See the essay on Koyré by Charles Gillispie in *The Dictionary of Scientific Bioqraphy*, vol.
7, pp. 482-90.
9. One suspects that Henry Guerlac in his last years turned his attention from Lavoisier to Newton partly because of this marginalization of modern science in academic history of science.
10. Chicago: University of Chicago Press, 1962.
11. For an historical assessment of selected theoretical claims about how science changes, including some of Kuhn's, see Arthur Donovan, Larry Laudan, and Rachel Laudan, eds., *Scrutinizinq Science*, Baltimore: Johns Hopkins, 1992, Part I; for an examination of Kuhn's treatment of the Chemical Revolution, see C.E. Perrin, "The Chemical Revolution: Shifts in Guiding Assumptions", in ibid., pp. 105-24.
12. See Cohen, chapter 6.
13. *Science and Polity at the End of the Old Reqime*, Princeton: Princeton University Press, 1980, p. 74.
14. I have addressed this topic previously in "Newton and Lavoisier - From Chemistry as a Branch of Natural Philosophy to Chemistry as a Positive Science," in *Action and Reaction Proceedings of a Symposium to Commemorate the Tercentenary of Newton's Principia*, Paul

Theerman and Adele F. Seeff, eds, Newark, Delaware: University of Delaware Press, 1993, pp. 255-76; and, more briefly, in my *Antoine Lavoisier -Science, Administration, and Revolution*, Oxford: Blackwell, 1993, pp. 185-7.

15. See Jean-Pierre Poirier, *Lavoisier*, (Paris, Pygmalion, 1993), pp. 44-5.

16. *Wealth of Nations*, chapter 1 (Penguin edition, p. 115).

17. In the 1780s Lavoisier's determination to transform chemistry into a science was echoed by the parallel efforts of his academic colleagues Charles-Augustin Coulomb and Rene-Just Haüy to "found", respectively, sciences of electricity and magnetism and of crystallography; see Christine Blondel, "La mécanisation de l'èlectricité: ideal de mesures exactes et savoir-faire qualitatifs," in C. Blondel and Matthias Dörries, eds., *Restaging Coulomb: Usaqes, controverses et replications - autour de la balance de torsion*, Florence: Olschki, 1994 (forthcoming). I take this point and citation from a forthcomlng article by Bernadette Bensaude-Vincent, "Commemorating Lavoisier: A Historiographical Survey of Two Hundred Years".

18. Citations are to the facsimile reprint published by the University of Chicago Press in 1987.

19. Herschel, pp. 301-Z.

20. *Ibid.*, p. 353.

21. Cf. Tore Frängsmyr, J.L. Heilbron, and Robin Rider, eds., *The Quantifying Spirit in the 18th Century*, Berkeley: University of California Press, 1990.

22. Herschel, p. 356.

23. Jan Golinski, *Science as Public Culture,* Cambridge: Cambridge University Press, 1992, p. 236.

24. Roland Barthes, *Michelet,* trans. by Richard Howard, New York: Farrar, Straus & Giroux.