An Introduction to *Chemical Knowledge in the Early Modern World*

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THE SCOPE OF EARLY MODERN CHEMICAL KNOWLEDGE

The essays in this volume collectively cover the development of chemistry in the "early modern world," that is to say, from the fifteenth century through the eighteenth century. Until comparatively recently, this period was of less interest to historians of chemistry than the succeeding era of the emergence of "modern" chemistry, with its familiar chemical elements, compounds, and equations. But recent research, exemplified by the essays of this volume, has shown how exciting and complex this era in the history of chemistry was in its own right. And its backdrop of early modern European and world history was critically significant for the development of the modern world. The beginning of this period witnessed the high water mark of the Renaissance, the inception of global "outreach" of sea voyages and explorations by Europeans, the Protestant Reformation, and the beginning of bureaucratic national monarchies and smaller political entities. Its conclusion was marked by those revolutionary sequels to the Age of Enlightenment that also ushered in the modern world: the French and Industrial Revolutions.

Our "early modern" centuries, in turn, divide up into two fairly distinct research epochs for the history of early modern chemistry. The first is late fifteenth- through seventeenth-century "chymistry."[1] The second is the chemistry of the eighteenth century. About half of the essays present research dealing primarily with the first epoch. The rest of the essays treat aspects of eighteenth-century chemistry, except for the final essay (Bensaude-Vincent), which offers a general commentary on the entire early modern period.

CHEMISTRY AND HISTORY

The past century has witnessed a number of significant changes in the ways in which scholars have written about the history of chemistry. Long before the history of science developed as a professional field, the history of chemistry was pursued

[1] This use of "chymistry" for the early modern field of alchemy-chemistry is now widely accepted in the scholarly world and has been acknowledged by the *Oxford English Dictionary* (see the entry in the electronic *OED* for "Chemistry"). See also William R. Newman and Lawrence M. Principe, "Alchemy vs. Chemistry: The Etymological Origins of a Historiographic Mistake," *Early Sci. Med.* 3 (1998): 32–65.

vigorously. The nineteenth century was replete with major historical writings and editions;[2] Hermann Kopp's *Geschichte der Chemie*[3] served as a standard reference work well into the twentieth century. Even a cursory glance at these works would reveal that they are different kinds of histories from those being written about chemical knowledge today. What brought about this change? In this section we would like to note the changes in the history of alchemy and chemistry that occurred over the previous century with a view to showing the historiographical background to the themes covered by the essays in this volume.

Most of the historians of chemistry before the mid-twentieth century had been trained as scientists. Perhaps the most recognized of these was the English physical chemist James Riddick Partington (1886–1965). Best known in the history of science for his four-volume *History of Chemistry*,[4] he also did research on important aspects of eighteenth-century chemistry, such as the evolution of the phlogiston theory.[5] Indeed, a number of British chemists, including Partington's collaborator in the phlogiston study, Douglas McKie, contributed to the development of what might be seen today as the "standard view" of eighteenth-century chemistry, that is to say, a narrative that centered around the phlogiston theory, the development of pneumatic chemistry in Britain, and the Chemical Revolution (against the phlogiston theory), associated with Antoine-Laurent Lavoisier (1743–94) and his French disciples.[6]

As in other pre-twentieth-century scholarly endeavors, research in the history of chemistry was primarily a male domain. By the twentieth century, however, women scholars entered the field,[7] and the publications of one of them, Hélène Metzger (1889–1944), were to become transformative.[8] Metzger treated the history of chemistry as a species of intellectual history very much a part of the milieu of French historical and philosophical studies being carried out by her contemporaries, such as Gaston Bachelard, Émile Meyerson, and Alexandre Koyré. What they did—particularly Metzger and Koyré—was to historicize their subject matter. A specialist of seventeenth- and eighteenth-century French chemistry, Metzger attempted to get into the mindsets of her seventeenth- and eighteenth-century protagonists with as little reference as possible to whether they were ultimately "right."[9] This approach gained influence, and by the 1960s it was being discussed by Thomas Kuhn, who, early on in *The Structure of Scientific Revolutions*, cites Metzger (along with Meyerson and Koyré) as having shown him "what it was like to think scientifically in a period when the canons of scientific thought were very different from those current

[2] E.g., Thomas Thomson, *The History of Chemistry*, 2 vols. (London, 1830–1); Albert Ladenburg, *Vorträge über die Entwicklungsgeschichte der Chemie in den letzten hundert Jahren* (Brunswick, 1869); Jean Baptiste Dumas and Eduard Grimaux, *Oeuvres de Lavoisier*, 6 vols. (Paris, 1862–93); Marcellin Berthelot, *Les origines de l'alchimie* (Paris, 1885).

[3] Kopp, *Geschichte der Chemie* (Brunswick, 1843–7).

[4] Partington, *A History of Chemistry* (London, 1961–70).

[5] James R. Partington and Douglas McKie, "Historical Studies on the Phlogiston Theory," *Ann. Sci.* 2 (1937): 361–404; 3 (1938): 1–58, 337–71; 5 (1939): 113–49.

[6] McKie himself published important studies on Joseph Black and Joseph Priestley and wrote extensively on Lavoisier. He was also important in establishing the history of science as an academic discipline in the United Kingdom.

[7] I. Freund, *The Study of Chemical Composition: An Account of Its Method and Historical Development* (Cambridge, 1904).

[8] Metzger's major works in the history of chemistry were *La genèse de la science des cristaux* (Paris, 1918); *Les doctrines chimiques en France du début du XVII^{e} à la fin du XVIII^{e} siècle* (Paris, 1923); *Newton, Stahl, Boerhaave et la doctrine chimique* (Paris, 1930).

[9] For recent scholarship, see G. Freudenthal, ed., *Études sur Hélène Metzger* (Leiden, 1990).

today."[10] Metzger's perspective on eighteenth-century chemistry was, consequently, different from the above-mentioned "standard view." In some ways, it prefigured the perspectives of the contributors to this volume.[11]

By the mid-twentieth century, the history of science emerged as a distinct academic discipline in the United States, the United Kingdom, and the rest of Europe. In the United States, one of the principal "enablers" was the chemist and administrator (president of Harvard University) James Bryant Conant. He produced one of the first recognizable syntheses of the standard view as a chapter titled "The Overthrow of the Phlogiston Theory: The Chemical Revolution of 1775–1789" in his own *Harvard Case Histories in Experimental Science.*[12] Framed as a duel between the phlogistonist, Joseph Priestley, and the antiphlogistonist revolutionary, Lavoisier, Conant's standard view was adopted by Thomas Kuhn in *The Structure of Scientific Revolutions*.

By the time Kuhn's work appeared (1962), historians and historically trained scientists were writing about the history of science. This influenced the history of chemistry, and scholars began to look at wider cultural influences at play in early material theories. The most prominent historian in the United States was Henry Guerlac, who, the year prior to the publication of Kuhn's book, had published a major study of the origins of Lavoisier's Chemical Revolution, *Lavoisier—the Crucial Year: The Background and Origin of His First Experiments on Combustion in 1772*.[13] During the 1960s and 1970s, Guerlac and his students developed something of a research industry on Lavoisier and the Chemical Revolution, in which the historical context, the "background" in Guerlac's words, and the details of the life, career, and scientific development of Lavoisier were fleshed out.[14]

During the 1960s and 1970s, there were a few attempts to provide an alternative to the standard "overthrow of the phlogiston theory" view of eighteenth-century chemistry, and there were a number of social studies of chemistry that looked at national or social factors.[15] But while some books like Archibald Clow and Nan L. Clow's

[10] T. S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (Chicago, 1996), viii.

[11] One should note that historians of alchemy were also employing a value-neutral approach independently of Metzger. For the valuable scholarly corpus of Julius Ruska, see http://juliusruska.digilibrary.de/digital_library.html (accessed 16 November 2013). Ruska's student Paul Kraus was one of the giants of twentieth-century Islamic scholarship. See his remarkable *Jābir ibn Ḥayyān: Contribution à l'histoire des idées scientifiques dans l'Islam*, Mémoires présentés à l'Institut d'Egypte, vols. 44–5 (Cairo, 1942–3). Moreover, the historical perspective of historians like Metzger (and Koyré) was not quite that of twenty-first-century historians, as will be detailed in this volume. For example, despite her pioneering attempt to empathize with her premodern chemical protagonists, she did give privilege to certain "modern" components of their thought, such as Nicolas Lémery's seemingly mechanical corpuscularian explanations of chemical reactions. And her approach was very much in terms of the history of ideas; chemical laboratory practice, not to mention chemical artisanal and industrial interests, did not figure in her studies.

[12] James Bryant Conant and Leonard K. Nash, eds., *Harvard Case Histories in Experimental Science*, 2 vols. (Cambridge, Mass., 1950), 1:67–115, case 2.

[13] Guerlac, *Lavoisier—the Crucial Year: The Background and Origin of His First Experiments on Combustion in 1772* (Ithaca, N. Y., 1961).

[14] These included Rhoda Rappaport, Jerry B. Gough, and Carlton Perrin. Mention should also be made of Maurice Dumas, *Lavoisier, théoricien et expérimentateur* (Paris, 1955).

[15] The phlogiston historiography was challenged by Robert Siegfried and Betty Jo Dobbs, "Composition, a Neglected Aspect of the Chemical Revolution," *Ann. Sci.* 24 (1968): 275–93; and Arnold Thackray, *Atoms and Powers: An Essay on Newtonian Matter Theory and the Development of Chemistry* (Cambridge, Mass., 1970). For socio-institutional histories, see Arthur Donovan, *Philosophical Chemistry in the Scottish Enlightenment: The Doctrines and Discoveries of William Cullen and Joseph Black* (Edinburgh, 1975); and Karl Hufbauer, *The Formation of the German Chemical Community, 1720–1795* (Berkeley and Los Angeles, 1982).

Chemical Revolution focused on the artisanal, medical, and industrial components of chemistry,[16] the standard view continued to hold sway until the mid-1980s. Moreover, it remained firmly intellectualist in that chemical ideas were largely treated as disembodied entities operating relatively free of any social or cultural constraints. To a certain extent this intellectualist tradition was a reflection of the general tenor of the history of science in the United States during its first decades as an academic field, when the intellectualist exemplar of Alexandre Koyré was dominant.

THE REHABILITATION OF ALCHEMY

From the 1980s forward, a number of significant changes occurred in the historiographical methods used to investigate early modern chemical knowledge. Perhaps the biggest changes occurred at first in the history of alchemy. Whereas the standard Chemical Revolution view provided a shared focal point with the eighteenth century, frameworks that addressed the nature and scope of alchemical knowledge for the preceding two centuries were more diffuse. A good part of the reason for this was that these centuries were classified under the temporal framework of the Scientific Revolution. Historical study of this revolution, centering on the development of astronomy and physics (and, to a degree, experimental anatomy), was a central component in the emergence of history of science as an academic discipline.[17] But the chemical sciences were at best an outlying domain in the master narrative of the Scientific Revolution before the 1970s.[18] Moreover, alchemy, today recognized as a vital component of the "chymical" sciences of these centuries, was derided and dismissed. This sentiment can be seen, for example, in A. R. Hall's *Scientific Revolution* (1954):

> The most remarkable feature of all alchemical writings is that their authors prove themselves utterly incapable of distinguishing true from false, a genuine observation (according to our modern knowledge) from the product of their own extravagant imaginations. . . . The theoretical contribution of alchemy to science was very small.[19]

In Hall's book, Paracelsus, soon to become a locus of research on early modern "chemical philosophy," was also treated negatively, if more ambivalently than alchemy generally:

> His was not in any sense a modern mind. He believed in the philosopher's stone. He believed in the alchemical theory of transmutation, and in others yet more wonderful. . . .

16 Archibald Clow and Nan L. Clow, *The Chemical Revolution: A Contribution to Social Technology* (London, 1952). This book dealt with the industrial role of chemistry in the first Industrial Revolution. Curiously, one of the earliest articles of Henry Guerlac, who became the leading scholar of an intellectualist standard Lavoisian model of the Chemical Revolution, "Some French Antecedents of the Chemical Revolution," *Chymia* 5 (1959): 73–112, actually details the mid-eighteenth-century transfer of metallurgical chemical technology from Germany to France through the translation of technical treatises that contained, among other things, the phlogiston theory.

17 Two works of the 1950s were emblematic: A. R. Hall, *The Scientific Revolution 1500–1800: The Formation of the Modern Scientific Attitude* (Boston, 1954); and Thomas S. Kuhn, *The Copernican Revolution: Planetary Astronomy in the Development of Western Thought* (Cambridge, Mass., 1957).

18 The pervasive disparagement of alchemy by early historians of the Scientific Revolution and its surprising echoes in more modern surveys of seventeenth-century science have been discussed at length in William R. Newman, *Atoms and Alchemy*: *Chymistry and the Experimental Origins of the Scientific Revolution* (Chicago, 2006), 6–12.

19 Hall, *Scientific Revolution* (cit. n. 17), 307.

> He had in full measure the faculty for self-deception characteristic of the Hermetic tradition.[20]

As noted above, historical research in the last decades of the twentieth century on science in the early modern period moved away from the progressivist and presentist perspective exhibited so prominently in Hall's *Scientific Revolution* toward serious and sympathetic study and assessment of those domains dismissed by Hall as not "modern": the so-called Hermetic tradition[21] and Paracelsus.[22] In many ways, the work of Allen Debus on Paracelsus and his followers[23] established the contours of the historical narratives for this period just as Guerlac and his students had done for the eighteenth century.

The alchemical scholarship of the past quarter century has significantly widened and enriched the purview established by these major researchers. Although Debus was alive to the importance of the worldviews of Paracelsus and the Paracelsians to early modern chemical thought and considered very seriously their medical aspects and activities, he was less interested in exploring the details of the chrysopoetic (gold-making) traditions of the early modern period. To some degree, Debus still presented a "sanitized" picture of early modern chemistry in which the content that did not conform to modern chemistry was minimized or pushed aside.[24]

It was left to the next generation of scholars to delve more deeply into the material and conceptual logic of alchemy. An early and sympathetic treatment of alchemy in the context of the Scientific Revolution was provided by Betty Jo Teeter Dobbs and her studies on Newton;[25] subsequent scholarship has resulted in a comprehensive reassessment of the very meaning of "alchemy." Far from being a peripheral figure sequestered from the public eye, the "alchemist," as shown in the research of Pamela Smith and others, was an artisanal "expert" who played a core role in regulating and disseminating natural knowledge across Europe.[26] Likewise, the work of William R.

[20] Ibid., 309–10. Hall did give Paracelsus the credit of being an "iconoclast" and of being the originator of medical chemistry, which, as it developed, away from Paracelsus's own "incoherent, obscure, megalomanic writings," did point the way to rational chemistry.

[21] The term "Hermetic tradition," popularized by Yates and widely used by historians in the decades after her groundbreaking work, has lost credence among more recent scholars. See Frances Yates, *Giordano Bruno and Hermetic Tradition* (London, 1964).

[22] Walter Pagel, *Paracelsus: An Introduction to Philosophical Medicine in the Era of the Renaissance* (Basel, 1958).

[23] Allen G. Debus, *The English Paracelsians* (London, 1965) and many subsequent books.

[24] This had been noted in the 1960s and 1970s in reviews of his books; e.g., "It is rash to assert that in England 'the occult aspects of his work were rejected while the new [chemical] remedies were eagerly adopted, provided they proved their worth'; C. H. Josten, review of *The English Paracelsians*, by Allen G. Debus, *Brit. J. Hist. Sci.* 3 (1967): 296. Consequently, he did not focus on the alchemical aspects of Paracelsianism. Charles Webster, reviewing Debus's *The Chemical Philosophy: Paracelsian Science and Medicine in the Sixteenth and Seventeenth Centuries*, 2 vols. (New York, 1977), took Debus to task on this point: "Debus has disregarded the extensive surviving body of Renaissance alchemical literature which was circulating in manuscript form, and he has not taken account of the fact that the educated elite possessed a ready knowledge of Latin, so that the absence of alchemical or natural philosophical works was no barrier to their acquaintance with the various traditions of Renaissance philosophy"; Webster, Essay Review, *Isis* 70 (1979): 588–92, on 590.

[25] Betty Jo Teeter Dobbs, *The Foundations of Newton's Alchemy: or, "The Hunting of the Greene Lyon"* (Cambridge, 1975). This project was initiated in the late 1960s. Unfortunately, in this book Dobbs adopted the approach of Carl Jung; the Jungian analysis of alchemy has come under withering criticism in more recent scholarship.

[26] See Pamela H. Smith, *The Business of Alchemy: Science and Culture in the Holy Roman Empire* (Princeton, N.J., 1994).

Newman and Lawrence M. Principe revealed that, instead of being based on abstruse or even nonsensical theories, alchemy was a serious experimental enterprise that was coextensive with sixteenth- and seventeenth-century "chymistry."

Over the past two decades, historians have come to recognize that chymistry was an early modern field that incorporated a wide range of productive chemical and medical technologies as well as a long-standing belief in the transmutability of metals and other materials.[27] It is now much easier to see why it was no accident that scientific luminaries such as Isaac Newton, Robert Boyle, Gottfried Wilhelm Leibniz, and John Locke involved themselves deeply in the chrysopoetic side of chymistry—if anything, this subject was the idée fixe of the Age of Gold. Furthermore, it has emerged in the last few years that even late medieval alchemy seriously challenged the widely held antiatomist matter theory of Thomist and Scotist writers, creating a dialectic that became even more apparent in the sixteenth century after the Society of Jesus adopted Thomas Aquinas as their master in theology. Centuries before Lavoisier, alchemists were already employing analytical processes to arrive at a sort of "chymical atomism" that regarded a range of material substances to be operationally indivisible and capable of retrieval from seemingly "perfect" mixtures.[28] Needless to say, a discipline that challenged contemporaneous views in such a fundamental way could hardly fail to have further repercussions as well. Accordingly, as our historical knowledge of chymistry as an early science has broadened, it has come increasingly to include textual, literary, and religious themes alongside a deepening appreciation of alchemical experimentation.[29]

CHEMICAL REVOLUTIONS

The previous volume of *Osiris* devoted to the history of chemistry appeared in 1988 and was titled *The Chemical Revolution: Essays in Reinterpretation*.[30] Published at a time when the history of chemistry was becoming more introspective, the subtitle suggests a sense of disquiet with the standard view of the Chemical Revolution as simply the "overthrow of the phlogiston theory."[31] Indeed, a number of essays broadened the connections of this episode with other (and earlier) features of eighteenth-century chemistry.[32] But the primacy of the Chemical Revolution as the telos of eighteenth-century chemistry remained unchallenged. However, in the following year (the bicentenary of the publication of Lavoisier's *Traité élémentaire*

[27] See Newman and Principe, "Alchemy vs. Chemistry," and their "Some Problems with the Historiography of Alchemy," in *Secrets of Nature: Astrology and Alchemy in Early Modern Europe*, ed. William R. Newman and Anthony Grafton (Cambridge, Mass., 2001), 385–431.

[28] The significance of the European alchemical tradition for important features of the Scientific Revolution, such as the corpuscular philosophy of matter, has been stressed particularly in the publications of William R. Newman and Lawrence M. Principe. For the role of late medieval alchemy in reframing atomism, see Newman, *Atoms and Alchemy* (Chicago, 2006).

[29] A work of major importance that relates early modern chemistry to humanistic and literary contexts is Owen Hannaway, *The Chemist and the Word: The Didactic Origins of Chemistry* (Baltimore, 1975). As the subtitle indicated, Hannaway's narrative traced "the invention of chemistry as a discipline" back to the work of the humanist Andreas Libavius, who initiated a didactic chemical textbook tradition with his own textbook, the *Alchemia* (Frankfurt, 1597).

[30] Arthur Donovan, ed., *The Chemical Revolution: Essays in Reinterpretation*, vol. 4 of *Osiris* (1988).

[31] Arthur Donovan, "Introduction," in ibid., 6

[32] Notably, J. B. Gough, "Lavoisier and the Fulfillment of the Stahlian Revolution," and John G. McEvoy, "Continuity and Discontinuity in the Chemical Revolution," both in Donovan, *The Chemical Revolution* (cit. n. 30), 15–33 and 195–213, respectively.

de chimie and, of course, the start of the French Revolution), Frederic L. Holmes launched a challenge to precisely this perspective in *Eighteenth-Century Chemistry as an Investigative Enterprise*. There he stated,

> Historians of science have found it difficult to view eighteenth century chemistry as anything other than the stage on which the drama of the chemical revolution was performed. So strong has the disposition been to identify the advent of the modern science with the chemical system established by Lavoisier between 1772 and 1789 that all earlier activity has been treated most often as a prologue to these climactic events.[33]

In many respects, Holmes's view extended a rising sentiment, expressed by other historians of chemistry like Rhoda Rappaport and Rachel Laudan,[34] that the Chemical Revolution narrative downplayed the overarching material models that united chemical theories and practices in the laboratory and in the field. Over the course of the book, Holmes outlined a much broader view of eighteenth-century chemistry, focusing on the larger traditions of early modern chemistry pursued at the Paris Académie Royale des Sciences (as well as German and Swedish chemical developments). Regarding chemical research, Holmes's purview extended far beyond the traditional triune foci of phlogiston theory, pneumatic chemistry, and the Lavoisian Chemical Revolution. In particular, he focused on salts and plant materials, which, he showed, had their own independent, progressive research traditions, producing important conceptual and methodological developments. This led him to give serious and sympathetic attention to chemists such as Wilhelm Homberg, Nicolas and Louis Lémery, and Etienne-François Geoffroy, who had not figured prominently in discourses on eighteenth-century chemistry since Metzger.[35]

Holmes also foregrounded historical research on other aspects of eighteenth-century chemistry that had lain somewhat submerged because of the primacy of the standard view. One was chemical laboratory instruments and techniques.[36] He pointed out that, although the development of the pneumatic trough for the collection of "airs" had been highlighted in the standard view, other kinds of substances had not figured prominently. Holmes gave particular attention to an important analytical laboratory technique called the "wet" way, or analysis through liquid (usually watery or humid) agents or mediums. Another feature that Holmes reintroduced was "chemistry and industry," where he tried to connect eighteenth-century chemical technology

33 Frederic Lawrence Holmes, *Eighteenth-Century Chemistry as an Investigative Enterprise* (Berkeley, Calif., 1989), 3. Significantly, Holmes lauded Metzger as "the most conspicuous exception to the historiographic patterns that have dominated the treatment of eighteenth-century chemistry" (8).

34 See the collection of Rhoda Rappaport's early essays in *Studies in Eighteenth Century Geology* (Aldershot, 2011). Rachel Laudan also wrote a number of notable essays during the 1980s and 1990s, laying the foundation for *From Mineralogy to Geology: The Foundations of a Science, 1650–1830* (Chicago, 1994).

35 Geoffroy had received attention in connection with his *Table des differents rapports observés entre differentes substances* and the subsequent development of chemical affinity theory. Holmes also highlighted hitherto neglected German chemists such as Johann Pott, Andreas Marggraf, as well as Georg Ernst Stahl and his student, Caspar Neumann.

36 In this connection, he cited the important but neglected study of Jon Eklund, *The Incomplete Chemist: Being an Essay on the Eighteenth-Century Chemist in His Laboratory, with a Dictionary of Obsolete Chemical Terms of the Period*, Smithsonian Studies in History and Technology no. 33 (Washington, D.C., 1975). More recently, the topic of chemical experimental practice has been addressed in a book of essays, a number of which deal with the early modern period; Frederic L. Holmes and Trevor H. Levere, eds., *Instruments and Experimentation in the History of Chemistry* (Cambridge, Mass., 2000).

and industry "to a story of eighteenth century chemical science that has been less adequately told."[37]

In a concluding reconsideration of the Chemical Revolution, Holmes laid down a position that is echoed strongly—and developed—in this volume: "If my portrayal of earlier eighteenth century chemistry is valid, then the chemical revolution cannot have overturned the science of chemistry as a whole, or have established a science for the first time."[38] In recent decades this assessment has been taken in many directions, and the concept of a singular Chemical Revolution has been transformed into a more pluralistic notion, one that is not confined to the late eighteenth century and which is more properly construed as a series of chemical revolutions that drew strongly from theories, practices, and instruments that grew out of the "chymical" tradition that emerged in the late seventeenth century. The chemists who drove this change were not only polite, financially independent savants like Lavoisier, they were also professionals and artisans who used chemical knowledge on a daily basis in both iterative and innovative ways.

In recent years the themes of Holmes's work have been extended so that we now have a much better idea of what eighteenth-century chemists were actually doing, that is to say, what they were reading, analyzing, and synthesizing. Key to this extension was the notion that advances in what might be seen as "pure" chemistry were intimately tied to "practical" concerns of mining, industry, and medicine. In other words, chemistry was a technoscience, a hybrid of science and technology that engendered a host of instrumental, managerial, and experimental revolutions during the eighteenth and nineteenth centuries. As shown in the influential works of Ursula Klein and Bernadette Bensaude-Vincent, many of the key players in this climate, like their forebears in alchemy, were artisans and professionals, a large number of whom worked in mines, apothecary shops, and factories.[39]

OVERARCHING THEMES

It is clear that, by the 1990s, the historiographical perspectives and purviews of early modern alchemy and chemistry were undergoing profound transformations. Moreover, the changes mirror broader thematic developments taking place in the history of science, as well as the history of technology and medicine, such as an increasing emphasis on experimental and artisanal practice and a broadening of what constituted "science" in the early modern period. This has entailed the abandonment of normative viewpoints emanating from presentism or progressivism that derided and dismissed out-of-date science, much less scientific activity, such as alchemy, that fell on the wrong side of constructed demarcations between science and pseudosci-

[37] Holmes, *Eighteenth-Century Chemistry* (cit. n. 33), 102.

[38] Ibid., 107. The passage continued: "It must instead have transformed certain extensive areas of a science whose scope exceeded these areas. Lavoisier himself recognized, within contexts conducive to such recognition, that what he had transformed represented only large parts within a larger whole."

[39] Ursula Klein and Wolfgang Lefèvre, *Materials in Eighteenth-Century Science: A Historical Ontology* (Cambridge, Mass., 2007); Bernadette Bensaude-Vincent, *A History of Chemistry* (Cambridge, Mass., 1996). Klein and Bensaude-Vincent also coedited a number of important works, including Ursula Klein and Emma Spary, eds., *Materials and Expertise in Early Modern Science* (Chicago, 2010); Bernadette Bensaude-Vincent and Christine Blondel, eds., *Science and Spectacle in the European Enlightenment* (Aldershot, 2008).

ence. The essays in this volume both testify to these transformations and expand on them.

Thus, many of the essays demonstrate interest in how chemical knowledge was gained, lost, preserved, and circulated. Chemical knowledge itself is treated as a set of skills and routines that required specific kinds of artifacts such as instruments and substances that gained and lost meaning over time. In a word, knowledge is something you *do*. This perspective has generated an intense interest in the history of material culture, with scholars asking which substances, specifically, were used in experiments and what did experimentalists actually do to manipulate them. As can be seen by the materials examined in this volume, historians are now fascinated with the expanding array of substances and compounds that were bought and sold in the service of early modern chemical knowledge. Thus, as will be shown, the materials (and the instruments used to study and manipulate them) are as much objects of society, culture, and commerce as of nature.[40]

Theoretical issues concerning the nature and hierarchy of material substances range from the challenges of identifying mysterious substances derived from venerable texts in the earlier era to delineating the natures of the tangible materials used in the laboratory and in commerce in the eighteenth century. The role of instruments for studying and manipulating chemical substances figures prominently in some of this volume's essays on eighteenth-century chemistry. Of particular note are the active interactions between the artisanal craftsmen of these instruments and the laboratory chemists who commission and employ them.

An aspect of material culture specific to the history of early modern chemistry is alchemy, especially chrysopoeia. We have already spoken about the "rehabilitation" of alchemy as a rational investigative enterprise for the sixteenth and seventeenth centuries. Many essays concerned with this era focus on or deal with alchemy. What is more surprising is that, as some of the essays demonstrate, alchemical investigations were pursued by major chemists throughout much of the eighteenth century. But changing institutional and cultural contexts, namely, the ascendancy and proliferation of public scientific societies and state institutions requiring the deployment of chemical knowledge, had an impact on the relationship between alchemical and chemical activities and interests. The most striking aspects of this were the increasing "privatization" of alchemy, the concern to promote a positively scientific and utilitarian public image of chemistry, and the tensions within individual chemists over how to deal with (and conceal) their persistent alchemical interest. This had precedence in the work and activities of Robert Boyle; it is only in recent decades that we have come to appreciate how much of an alchemical "adept" he was. But in the eighteenth century, these changes—and tensions—became more marked.

One particularly important aspect of materials is their consideration as objects of commerce. This is the focus of our third theme: the artisanal, industrial, and commercial aspects of the early modern chemical enterprise, both for the pre-eighteenth-century era and the eighteenth century itself. Chemists were often craftsmen and tradesmen by occupation (e.g., apothecaries) and as such were as much involved in commercial as in natural philosophical activities both on their own and in the service of the state. One of our contributors goes so far as to consider eighteenth-century

[40] Klein and Lefèvre, *Materials in Eighteenth-Century Science* (cit. n. 39).

French chemistry as prefiguring (and paralleling), to a degree, contemporary technoscience.[41] The commercial aspect of the chemical enterprise has also begun to attract scholarly attention to broader contexts such as (*a*) the emergence of bureaucratic nation-states (with mercantilist objectives) and national scientific institutions; (*b*) worldwide exploration and colonization and the appearance of new, commercially valuable materials; and (*c*) the incorporation of chymistry/chemistry in educational institutions, both at the university level in the medical faculty and in the formal (and informal) instruction of craftsmen.[42] Indeed, the most striking changes from the earlier to the later era are the role of the bureaucratic nation-state and its science-related institutions and of the university as a locus of chemical pedagogy. Both sets of institutions served as patrons and facilitators of interactions between chemists (now legitimated as "experts" by these institutions) and craftsmen.

The issue of chemical pedagogy, academic and artisanal, naturally leads to the consideration of the construction and delineation of an "expert," and who was recognized or certified as the authoritative possessor and imparter of chemical knowledge, both natural knowledge (and practice) and artisanal knowledge. The term "expert"—like "scientist"—was not in use before the nineteenth century, at least in English, but we can recognize progenitors of "experts" (and "scientists") in many of our fifteenth- to eighteenth-century actors.

THE ESSAYS

In his essay, John Norris examines the life and works of the Lutheran preacher Johann Mathesius, author of the famous *Sarepta, oder Bergpostill* (1562). The collection was composed while Mathesius was pastor of Joachimstal (now Jáchymov), then a boomtown in the rapidly developing mining area of the Erzgebirge (Krušné hory). By considering Mathesius's seemingly novel concept of "gur," a putative Ur-substance out of which metals were thought to grow, Norris provides a sensitive study of the relationship between miners' beliefs and traditional alchemical ideas of metallogenesis in sixteenth-century Germany. As Norris convincingly shows, gur was not just an empirical discovery of unlearned miners, but a fusion of mineralogical observation and the already old theory of the alchemical principles of mercury and sulfur. Norris's study has important implications for the relationship of early modern artisanal and learned culture more generally, and particularly for the evolving study of the subterranean world that one witnesses in Central Europe during this period.

Whereas the word gur seems to have been a new term in Mathesius's day, Jennifer Rampling's essay examines a very different linguistic phenomenon—the fact that alchemists typically used the same terms over long periods of time to describe very different concrete referents and practices in the material world. The fortuna of George Ripley's fifteenth-century corpus is a particularly apt vehicle for studying this feature because of his marked authority in the world of early modern al-

[41] Bernadette Bensaude-Vincent, "Concluding Remarks: A View of the Past through the Lens of the Present," in this volume.

[42] For craftsmen, see Jonathan Simon, *Chemistry, Pharmacy and the Revolution in France, 1777–1809* (Aldershot, 2005); Klein and Spary, *Materials and Expertise* (cit. n. 39). For the incorporation of chemistry into university settings, see Matthew Daniel Eddy, *The Language of Mineralogy: John Walker, Chemistry and the Edinburgh Medical School, 1750–1800* (Farnham, 2008); and John C. Powers, *Inventing Chemistry: Herman Boerhaave and the Reform of the Chemical Arts* (Chicago, 2012).

chemy: his was a "name to conjure with." Hence, when Ripley's work was read and used in the sixteenth and seventeenth centuries, there was a need to bring him up to date by interpreting his alchemical terms to fit the most current techniques and materials available to alchemists. Ripley's practice was heavily based on "sericon," an obscure term that seems to have originally meant minium or red lead oxide, but when his authority was appropriated by George Starkey, the American alchemist and friend of Robert Boyle whose popular works circulated under the name "Eirenaeus Philalethes," Starkey argued that the key material behind Ripley's alchemy was crude antimony or stibnite. Rampling points to the new interest among historians of science in the material culture of alchemy and the complex interaction between text and practice.

While Bruce Moran shares a focus on language with Rampling, his concern is not the ongoing transformation of referents while the terms remain unchanged. Moran's focus lies rather in the interaction of learned chymistry, represented by the Saxon pedagogue Andreas Libavius, and various less polished chymical authors, such as the little-known Italian physician Joseph Michael. Libavius expended huge efforts in decoding medieval alchemists such as pseudo-Raymond Lull and pseudo-Arnold of Villanova, so he considered himself an expert in the art of deciphering *Decknamen*. Michael, in the view of Libavius, had focused too exclusively on a single meaning for the elixir described in the alchemical works of Roger Bacon, and in the process Michael had reduced the scope of chymistry to a single, monolithic practice. Combining humanist concepts of art as a multifarious endeavor, Libavius argued that chymistry should actually engage in a host of different technological and medical pursuits. Libavius's emphasis on the multiple utility of the discipline lay behind his important role in establishing the pedagogical foundations of the discipline in the form of chymical textbooks.

Anna Marie Roos also takes us into the world of chymical expertise, but in a rather different way from the expertise that Andreas Libavius employed in deciphering pseudo-Lull or that George Starkey demonstrated by arriving at the "true" meaning behind George Ripley's alchemy. Roos's paper focuses on Robert Plot, "first keeper of the Ashmolean, secretary of the Royal Society, and Oxford's first professor of chymistry." Despite these various public roles based on his scientific expertise, Plot was also seriously involved in the more secret pursuit of the philosophers' stone, as Roos's examination of his manuscripts reveals. Plot was not just a private aspirant to chrysopoetic and medical secrets, however; like the alchemical employees of many a Continental prince, he entered into alchemical contracts with various parties in order to finance his research. Roos has unearthed several examples of these fascinating documents that reveal the close interaction between commerce and "the searching out of secrets" in the minds of early modern chymists. It is no accident that Plot's legal arrangements with his backers remind us of the consulting agreements between university chemists and industry today.

Kevin Chang's contribution carries us well into the eighteenth century and fills an important gap in our previous understanding of the relationship between Georg Ernst Stahl's chemistry and contemporaneous work being done at the Académie Royale des Sciences. It has long been known that the mid-eighteenth century witnessed a strong French reception of Stahl's phlogiston theory, but was this the sudden discovery of a previously isolated German figure's work, or the culmination of a much longer interest? Chang shows convincingly that the latter was the case, and that significant elements of Stahl's theory had already been incorporated into the famous *Table des differents rapports* of Etienne-François Geoffroy, published in 1718. More than this, Geoffroy continued to insert features of Stahlian chemistry throughout his career, as did many other chemists at the Académie. It would appear that Stahl's influence was even more pervasive than previously thought, and that there was a hitherto little noted network of communications between German chemists and their French counterparts operating throughout the first half of the eighteenth century.

Whereas Chang deals with the transmission of ideas and practices between Germany and France, William Newman's paper considers the influence of Robert Boyle on the German chymists Johann Joachim Becher and Stahl. Since the publication of a seminal paper of the 1950s by Thomas Kuhn, it has repeatedly been claimed by prominent historians of science that Boyle, for all his fame as a mechanical philosopher, exercised little real influence on the history of chemistry. Newman gives a close analysis of Becher's corpus as it evolved from the 1650s through the 1660s and shows that in all probability the German polymath's main source for his hierarchical theory of matter was Boyle's work, especially *The Sceptical Chymist*. This matter theory was subsequently adopted by Stahl and—in modified form—by French Stahlians such as Pierre-Joseph Macquer. Newman also argues that Boyle's corpuscular theory and indeed "chymical atomism" more generally often went hand in hand with a belief in chrysopoeia; the phenomenon is not surprising when one understands the theoretical and practical needs that chymical atomism served.

The essay by Bernard Joly addresses some of the same characters adduced by Chang, especially Etienne-François Geoffroy, about whose biography Joly has extracted interesting new information. Joly goes into considerable depth to show that Geoffroy's famous debate with Louis Lémery about the supposed resynthesis of iron in plant ashes had ramifications extending far beyond the specifics of this experiment. Allying himself with the mechanistic physics of the seventeenth century, Lémery advertised the fact that the iron experiment derived from J. J. Becher's work in order to link Geoffroy to chrysopoetic attempts that had fallen into public disrepute at the Académie Royale des Sciences. As Joly points out, Geoffroy did in fact owe a strong debt to Becher, along with the numerous French *Cours de chimie*, which provided much of the empirical data that would be formulated in Geoffroy's famous *Table des differents rapports*. Joly makes the important point that Geoffroy's *Table* was a synopsis of previous knowledge rather than a revolutionary new advance. As in Chang's essay, the picture of Geoffroy that begins to emerge is one of a figure far more connected to existing chymical traditions than one might expect from reading other scholarship in the history of chemistry.

Lawrence Principe's paper extracts a wealth of new archival and manuscript data to enrich and expand upon the same general conclusion drawn by Joly. Not only was Geoffroy employing alchemical sources in his famous debate with Louis Lémery and in his 1722 attack on chrysopoetic frauds, "Des supercheries concernant la pierre philosophale," but Geoffroy was actively pursuing alchemical goals himself. Under the tutelage of Wilhelm Homberg, himself an avid student of alchemical authors such as Eirenaeus Philalethes (George Starkey), Geoffroy published on the old alchemical desideratum of potable gold. Principe presents considerable additional evidence to show that other mainstream French chemists after Geoffroy, such as Pierre-Joseph Macquer and Guillaume-François Rouelle, were also interested in chrysopoeia; the latter may even have kept a private laboratory for his alchemical project. This new information leads Principe to the surprising conclusion that alchemy did not die at the hands of Geoffroy and his intellectual heirs as often asserted—it merely "went underground." This is a startling observation indeed about a man whose supposed rejection of transmutation and alchemical matter theory has been claimed elsewhere as a decisive step that led him to discover the concept of the chemical bond.

Perhaps the chemistry teacher par excellence at the beginning of the eighteenth century was Professor Hermann Boerhaave of Leiden University. Focusing on Boerhaave's lectures, John Powers's chapter argues that, rather than being a dry and pedestrian concern, pedagogy played an important role in reshaping the experimental techniques of chemistry. He shows that Boerhaave actively employed new, innovative instruments such as Daniel Gabriel Fahrenheit's thermometers. Powers reveals how such instruments became a central part of chemical theory and practice through their use in the classroom. In making this point, Powers identifies a flexible way of thinking about new instruments that emerged long before the experimental innovations traditionally associated with the Chemical Revolution.

From the seventeenth century there was a significant early modern shift in what leading chemists like Boerhaave counted as the basic building blocks of matter. Hjalmar Fors looks at how this ontological transformation unfolded in the chemical mineralogy practiced in northern European mines during the eighteenth century. He shows how influential chemists such as Georg Brandt and Axel Fredrik Cronstedt combined the artisanal practice of assaying with the more scholarly tradition of natural history to create a form of classification that treated individual metals as foundational units of matter. He argues that this move was motivated by the pragmatic epistemology of what might be called "mining knowledge" and that it laid the foundation for the concept of elementary substance advocated by Lavoisier.

During the twentieth century, one of the most neglected aspects of the history of early modern chemistry was pharmacy, especially in French historiography of chemistry. This neglect elided the important contributions of chemically trained apothecaries and physicians. Jonathan Simon addresses this negligence by arguing for the importance of pharmacy as an ensemble of essential practices that affected how French chemists and the reading public viewed the discipline of "chimie." Using widely read publications like the French pharmacopoeia and the textbooks of Nicolas Lémery and Antoine Baumé, Simon argues that the reading public played a crucial role in shaping how pharmacists conceptualized and communicated chemical knowledge. By reflecting on the changing nature of the audience and content of chemistry, he helps us understand the continued presence of pharmacy in chemistry.

Unlike the recent rediscovery of pharmaceutical chemistry, the close relationship between eighteenth-century chemistry and industry has long been recognized by historians of science, technology, and society. This relationship, however, is often portrayed as a unidirectional flow of knowledge in which the findings and theories of experts trickled down into industry. Ursula Klein's chapter turns this historiographical model on its head by arguing that there were many kinds of chemical "experts" and that many of them gained their expertise on the floors of factories. In making this argument, she sets aside the traditional association often made between chemistry as pure science and technology as an applied science. Concentrating on the many different kinds of chemists operating in the large Royal Prussian Porcelain Manufactory, she avers that chemistry was a "technoscience" and that chemical expertise was not confined to elite settings like the academy.

Christine Lehman also examines the prominence of mid-eighteenth-century chemical experts, many of whom operated as agents of government *and* industry. Whereas Klein explains how a range of actors developed different kinds of chemical expertise in one setting, Lehman's chapter uses the impressive career of the French chemist Pierre-Joseph Macquer to show how the many roles of one person generated useful, and important, chemical knowledge. She points out that Macquer was a physician, teacher, academician, and inspector and that these roles allowed him to showcase his expertise in settings such as a classroom, garden, study, and even the Château de Saint-Germain-en-Laye. Following him on his public inspections and even on secret missions for the crown, Lehman presents a geography of chemical knowledge in which material facts and theories traveled side by side on the roads of France and the Low Countries.

As intimated above, the ideas of Antoine-Laurent Lavoisier played a central role in the standard model used to frame the Chemical Revolution. This tradition tended to portray him as a wealthy chemist whose prescient theories of combustion and composition triumphed over the supposedly antiquated chemistry of artisanal settings. Focusing on Lavoisier's instruments and experimental techniques, Marco Beretta's chapter problematizes this view by showing that Lavoisier relied on the technical input of the instrument makers and artisans who were employed in his laboratory. Beretta argues that these artisans, rather than being unseen technicians, were Lavoisier's collaborators. In making this argument, Beretta reconstructs for the first time the network of instrument makers who worked in Lavoisier's laboratory, showing that, instead of being a solitary genius, Lavoisier was intimately dependent upon a chorus of collaborators for his experimental successes.

Whereas Beretta's essay raises the importance of the material culture of instrumentation, Matthew Crawford's chapter underscores the imperial origins of the material substances used by chemists. He points out that there were many people living in Asian and American colonies who paid very close attention to the composition of pharmaceuticals and industrial materials. More specifically, he tells the story of how cinchona bark became a chemical commodity in Spain's South American colonies. Focusing on the career of a "botanist-chemist" who acted as an agent of the Spanish Crown, Crawford explains how chemistry was an imperial science and highlights the informal, but vital, pathways through which chemical techniques circulated in early modern colonial settings.

As the many illustrations included with the essays of this volume clearly show, we are currently living at a time when early modern historians pay much more attention to the role of visual culture. Of course, the world of alchemical imagery has long attracted the attention of historians of art and science alike. Yet aside from research on the depiction of instruments, the visual culture of eighteenth-century chemistry has remained relatively unexplored. Matthew Daniel Eddy's chapter addresses this lacuna by focusing on the diagrammatic pictures used by Scotland's Joseph Black to teach hundreds of students from the 1750s to the 1790s. Treating Black's affinity diagrams as a collective system, Eddy approaches them via a visual anthropology that allows him to reveal how Black skillfully appropriated preexisting visualizations to teach his students chemical attraction and repulsion, that is, two core chemical forces that formed the theoretical basis for late Enlightenment chemistry.

In the concluding historiographical reflection, Bernadette Bensaude-Vincent focuses on the current interest among historians of chemistry in the material, artisanal, and commercial aspects of early modern chemistry, interests certainly well represented in this volume. She sees this upsurge of interest as related to the ascendant "technoscientific" nature of much of present-day science and industry, notably chemical "technosciences." In these technoscientific enterprises, scientific research, application, and commercial development are almost seamlessly melded. Bensaude-Vincent herself perceives and explores deep parallels between modern technoscience and eighteenth-century French chemical practices and activities. She also notes differences—often cultural—such as the radically altered valuation of chemical activities (highly regarded in the eighteenth century; highly problematic today) and the transformed perception of temporal change and destiny (optimistic in the eighteenth century; problematic today).

Our intent in this volume is to bring to an audience wider than the cognoscenti of the history of early modern chemistry the historical visions of pre-nineteenth-century chemistry that have begun to emerge. These portrayals of chemistry (and "chymistry") are much more complex and even amorphous than they were before the reconstructions of the past quarter century. In part, this reflects the liberation of the historiography of chemistry from the clearly defined shadow cast by the more mathematical sciences. Although some attempts were formerly made to shoehorn chemistry into the highly mathematical story of physics and astronomy extending from Copernicus to Newton and their heirs, the fact is that Lavoisier himself required nothing more sophisticated than arithmetic to quantify his experimental results. Neither eighteenth-century chemistry nor its forebears in the realm of medieval alchemy and early modern chymistry can be seen as waves emanating from a central event such as the Cartesian geometrizing of nature or the development of calculus by Leibniz and Newton. Instead, mining technology, chrysopoeia, chymical medicine, pigment making, refining of salts, and the trade in distilled spirits all played a part, along with other pursuits, in the development of chemistry. To an earlier generation of scholars, this meant that early modern chemistry was theoretically underdeveloped, dominated by ad hoc "rules of thumb," and hence largely unworthy of study by professional historians of science. With the current emphasis on material and visual culture, the integration of scientific practice with theory, and the role of expert knowledge in the developing industry and commerce of early modern Europe, the table has been turned. The present volume underscores the diversity and richness of early modern chemical traditions, sometimes undeniably bewildering in their approaches and goals. To anyone familiar with chemistry of the past century, this should not be too surprising, for it, too, is an enormous and polymorphous entity.