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Jed Buchwald
Larry Stewart *Editors*

# The Romance of Science: Essays in Honour of Trevor H. Levere

Springer

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**Victor D. Boantza** is assistant professor in the Program for History of Science, Technology, and Medicine at the University of Minnesota. He works on the history of the early modern physical sciences, with interests in the relations between theory and practice in physics and chemistry in the seventeenth and eighteenth centuries. *Matter and Method in the Long Chemical Revolution: Laws of Another Order* (Ashgate, 2013) is his first book

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**Gregory A. Good** publishes mostly on the history of geophysics and other Earth sciences. He has been a fellow of the Smithsonian Institution and the Alexander von Humboldt-Stiftung and has received several grants from the National Science

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**Ernie Hamm** is a historian of science and associate professor in the Department of Science and Technology Studies, York University, Toronto, Canada. He works on the history of geology and on aspects of Enlightenment and Romantic science.

**Jennifer Hubbard** is associate professor of the history of science and technology at Ryerson University and specializes in the political, environmental, institutional, and economic history of fisheries and ocean science. Through the University of Toronto Press, she published in 2006 *A Science on the Scales: The Rise of Canadian Atlantic Fisheries Biology 1898–1939* and, in 2016, *A Century of Maritime Science: The St. Andrews Biological Station 1908–2008*, which includes chapters by scientists, technologists, and historians of science, which she coedited with Robert Stephenson and David Wildish. She has also published articles in *ISIS*, the *ICES Journal of Marine Science*, and *Environmental History*. She continues to find inspiration from the archives and influence of Archibald Gowanlock Huntsman, first director of the then-named Atlantic Biological Station.

**David Knight** Reading chemistry at Oxford, **David Knight** was tempted into history by Alistair Crombie and put to work on Humphry Davy with Sir Harold Hartley as my guide. Ignorantly supposing that the Romantics were hostile to science, he was astonished to find that Davy was a close friend of S. T. Coleridge and through him of William Wordsworth and Walter Scott: they all hoped for a dynamic science, especially chemistry. Coleridge and Davy had been brought together by the enthusiast for chemical medicine, Thomas Beddoes, and Trevor's researches and David's were complementary; they met and made friends. In 1964, he was appointed to start history of science in the Philosophy Department at Durham University, while Trevor went to Canada; both settled happily and have kept in close contact ever since. Both have focused especially on the Revolutionary and Romantic periods, but ranged more widely as one thing led to another. David remarks, "I'm very grateful to have had so good a friend and helpful critic as Trevor right through my career."

**Janis Langins** is an emeritus professor of history of technology at the Institute for the History and Philosophy of Science and Technology at the University of Toronto, where he also received his doctorate in the history of science and technology under Trevor Levere with a thesis on the early history of the Ecole Polytechnique during the French Revolution. Previously he graduated from McGill University with a master's degree in chemical engineering. His research interests are in the social history of engineering, in the history of the military engineering corps of Old Regime France and engineers in the late nineteenth and early twentieth centuries.

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**David Philip Miller** is an emeritus professor of history of science at the University of New South Wales and a fellow of the Australian Academy of the Humanities. He continues to work and publish on the life of James Watt. He also investigates the nature of discovery and invention, concerning which a recent publication is "Of Patents, Principles and the Construction of Heroic Invention: The Case of Neilson's Hot Blast in Iron Production," *Proceedings of the American Philosophical Society* **160** (December 2016), 1–62. As coeditor of *Annals of Science*, he was proud to succeed Trevor Levere.

**David Pantalony** is curator of physical sciences and medicine at the Canada Science and Technology Museum, Ottawa, Canada. His main research interest is in the history of scientific instruments. As adjunct faculty at the University of Ottawa, he also teaches a collection-based seminar for history students.

**Margaret Schabas** is a professor of philosophy at the University of British Columbia. She works primarily in the history and philosophy of economics and has published over 40 articles or book chapters. She is the author of two monographs, *A World Ruled by Number* (Princeton, 1990) and *The Natural Origins of Economics* (Chicago, 2005), both of which are in paperback. She is the recipient of a UBC Killam Research Prize (2015) and has given many keynote addresses, to the Hume Society, HOPOS, CPA, and as president of the HES (2013–2014).

**Larry Stewart** is professor of history at the University of Saskatchewan and is currently writing a study of experiment during the late Enlightenment and Industrial Revolution. His most recent work, edited with Erika Dyck, is *The Uses of Humans in Experiment. Perspectives from the 17th to the 20th Century* (Brill/Rodopi, 2016).

**Suzanne Zeller** is professor of history at Wilfrid Laurier University. Her research focuses on the history of science and environmental history in Canada.

# Chapter 1
# Trevor Levere, Affinities That Matter

**Ernie Hamm**

**Abstract** Trevor Levere's manifold contributions to the history of science are rooted in the history of chemistry and find important early expression in his foundational study of nineteenth-century ideas of affinity. Theories of matter took Levere to the all-encompassing romanticism and science of Coleridge and *Naturphilosophie*. From there he has proceeded to leave an important mark on many others interconnected areas of the history of science, including the study of scientific instruments, science and the Arctic, the history of science in Canada, and the utilitarian and political interactions of Enlightenment chemistry.

From the perspective of the early twenty-first century, it is all too easy to gaze wistfully upon the 1960s as a most propitious time to embark upon a life as an historian of science. The founding of departments, institutes and research centres for the history of science, the flourishing of conferences, societies and other scholarly fora, the dramatic expansion of universities over the past half century can take on a sense of inevitability when looking backward. Things must have looked rather different to a young English academic in 1968 moving from Oxford to the University of Toronto for a 1-year appointment as Lecturer in a field that had relatively few practitioners and limited institutional support. Fortunately, his new colleagues took the long view and recognized Trevor's outstanding preparation and promise. He was appointed Assistant Professor in 1969 and soon thereafter rose through the ranks, accumulating national and international honours along the way, and playing a crucial role in building an institutional base for the history of science at the University of Toronto. While his self-effacing style can belie such accomplishments, those who know him well—among them the colleagues, students and friends who have contributed to this collection—recognize a most unusual and endearing affinity between Trevor's unassuming manner and the insight, imagination and determination that characterize his intellectual life.

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It is hard to resist the temptation to see in Trevor's early work the seed that would grow into the work of the mature scholar. In his first monograph, *Martinus van Marum and the Introduction of Lavoisier's Chemistry into the Netherlands*, one can now see a number of fundamental themes and concerns that run through much of Trevor's work, including a focus on chemistry, especially pneumatic chemistry, and the elaborate scientific instruments that were developed alongside it and experimental philosophy more generally during the in so many ways revolutionary decades of the late eighteenth and early nineteenth centuries.[1] Van Marum and his location at Teyler's Museum in Haarlem, a linguistic and cultural crossroads of Europe, was ideally suited for someone with facility in languages and who eschewed the notion that the history of science could be fundamentally delineated by linguistic or national borders. However, this early work should also be looked at from the other direction, as the product of a young man who as a boy had the advantage of a good chemistry set and an excellent chemistry teacher at St. Paul's School in London before going up to Oxford to pursue his historical, philosophical and scientific interests. Remarkably, his work on van Marum was first presented as an *undergraduate* thesis—clearly this was a student who was going places.

Trevor went on to do a D.Phil. (1969) in Oxford's Department of Modern History under the supervision of A. C. Crombie. His thesis, published with substantial modifications as *Affinity and Matter: Elements of Chemical Philosophy 1800–1865* (Oxford: Clarendon, 1971), effectively reoriented our picture of much of nineteenth-century science, showing that affinity was the unifying concept of chemistry and was the basis for uniting "chemistry as a whole with physics." (*Affinity and Matter*, p. vi). Affinity, a protean idea with roots reaching well back into Renaissance hermeticism, seemed an unlikely candidate for such a prominent place in nineteenth-century science. However, through a study of the key figures such as Davy, Faraday, Berthollet and Berzelius, and other more unexpected ones such as Coleridge and Oersted, Trevor showed that affinity appealed to those who sought models for explaining chemical composition and decomposition, and that it was deeply intertwined with theories of matter. While *Affinity and Matter* is very much a contribution to the history of chemistry, it also challenges fundamentally the notion of a disciplinary history, for its balanced treatment of affinity reaches well beyond any particular discipline and involves natural philosophy and theology, physics and philosophy.

Trevor's eye for the interconnections of seemingly disparate branches of knowledge was ideally suited for his next major project, *Poetry Realized in Nature: Samuel Taylor Coleridge and Early Nineteenth-Century Science* (Cambridge: Cambridge University Press, 1981). This book removed any remaining doubts about the seriousness of Coleridge's engagement with science and made a compelling case that romanticism could no longer be dismissed as an anti-scientific movement, as a gigantic loss of intellectual nerve by people unable or unwilling to accept mech-

[1] "Martinus van Marum and the Introduction of Lavoisier's Chemistry into the Netherlands," in *Martinus van Marum: Life and Work*, Volume I, ed. R. J. Forbes (Haarlem: H. D. Tjeenk Willink & Zoon, 1969), 158–286.

anistic explanations of the Enlightenment. At the time, this was something of a revelation to literary historians; for historians of science it was an exciting development, an important demonstration that presentist concerns were an unreliable guide when grappling with the central concerns of different times and places.

Anyone who first encountered his work through *Poetry Realized in Nature*, as did I, might think of Trevor primarily as a historian of science with a focus on romanticism, rather than a historian of chemistry. Yet chemistry is a science with all sorts of unexpected connections. It turns out Trevor was first drawn to Coleridge through his connection with Davy, which then led him to seek the insight of his Toronto colleague Kathleen Coburn, one of the outstanding Coleridge scholars of the twentieth century. Coburn recognized that she had found just the person to make sense of Coleridge's unpublished notebooks, which are rife with chemical and natural philosophical entries. Trevor seized this opportunity and followed the notebooks where they led, including to libraries all over Britain and North America tracking down Coleridge's marginalia, at that point still unpublished. This was the work of a scholar's scholar and was recognized as such by his contribution to *Coleridge's Notebooks* and *The Collected Works of Samuel Taylor Coleridge*, definitive editions published in Princeton's Bollingen Series. Immersing himself in Coleridge's sources took him elsewhere as well, into the at turns marvelous, arcane and remarkable world of *Naturphilosophie*. This was heady stuff and Trevor's exemplary treatment of this material is always insightful and even-handed. *Poetry Realized in Nature* gives us a Coleridge with a dynamic and active view of nature and who saw unity in the various parts of science, a deep connection between mind and nature, and rejected simplistic distinctions between empirical science and speculative philosophy. This was inspiring work for those who would later contribute to the now large body of work on science and romanticism.

By the early 1980s Trevor was a full Professor, Fellow of the Royal Society of Canada and a much admired teacher and colleague in the University of Toronto's Institute for the History and Philosophy of Science. His intellectual breadth was much sought after in the classroom, particularly in seminars. His graduate course on the intellectual context of nineteenth century science was a favourite of many students, but the scope of his interests and knowledge already then reached well beyond Victorian science, from early modern to well into the twentieth century—as students in his seminars on the history of chemistry or on the history of science in Canada can attest.

Not many years after arriving in Toronto, Trevor saw and met a need to foster the study of science in Canadian history. Perhaps this was to be expected from an avid birder who loves spending time outdoors, including camping trips (summer and winter) with graduate students during his early years in Toronto. While doing his work on Coleridge he and a former graduate student, Richard Jarrell, co-edited *A Curious Field-book: Science & Society in Canadian History* (Toronto: Oxford University Press, 1974), a source book for the social history of Canadian science. Jarrell went on to take a leading role developing the history of Canadian science as a field of study, a field in which Trevor would also make a foundational contribution.

Somehow, in between writing his book on Coleridge, teaching, and exploring the history of science in Canada, Trevor developed his administrative skills and became an obvious choice for the directorship of the Institute for the History and Philosophy of Science, a role in which he served 2 five-year terms. The director of a small and young academic unit faces many challenges, not least securing resources in an environment where larger well-established departments have more institutional clout. One of the chief tasks facing Trevor was finding a new home for the Institute, and here he succeeded in securing an elegant suite of offices, including space for graduate students (on which he insisted) in Victoria College, a home that has lasted to this day. The only thing missing was air-conditioning, a problem the director broached with great success at the end of a lengthy meeting, carefully scheduled on a midsummer afternoon, with the more senior administration. Trevor maintained a most amiable, collegial tone and the festive end of term potluck dinners were a highlight for grad students, faculty, their partners and children, and did much more to make the Institute an amiable intellectual environment than any "self-study", external review, or any of the other inventions of high-level university bureaucrats. Trevor deserves nothing but admiration for walking the fine line between the demands of a large university and the needs of a small academic unit, all the while fostering a spirit of collegiality.

Trevor supervised at least 17 PhD students and many MA students, and as one of the former I can say that he is a most congenial *Doktorvater*: always prepared to offer guidance when needed, encouragement when appropriate, a nudge when required and, when the time is right, to let a student focus on research and writing. His aim is always to encourage his students to develop their interests and do good work, not create disciples or epigones, and in my experience he never sees supervision as an opportunity to promote a particular view or approach to the history of science.

One of the delights of my graduate education was having Trevor guide me through a number of the texts foundational for an understanding of *Naturphilosophie*. After working through those texts it became clear I needed to know more about the Enlightenment thinkers that seemed to be the foil for a generation of romantics and proposed as much to Trevor, who encouraged me to give him a reading list. By the time I did, I was pretty pleased with my list (which was probably not much more than the usual suspects). He looked it over, nodded, paused and told me since I was interested in the Enlightenment I needed to pay attention to technology. This not being the comment I was hoping for, I proceeded with what I imagined to be a vigorous defense of the Enlightenment as fundamentally about ideas, but what more likely sounded like a long-winded recapitulation of the hoary trope that history of science is about thinkers not tinkers. Trevor nodded, this time with his characteristic gentle smile, and said "Take a look at the *Encyclopédie*. The plates."

I did as I was told and eventually the lesson of the rich technological tableaux of the *Encyclopédie*, a work emblematic of the Enlightenment, took hold. Long before it had become a commonplace to say that the history of science was profoundly connected with technological change, Trevor knew that technology mattered. The practices and ideas of natural philosophers, chemists and natural historians, among others, were deeply intertwined with technologies of measurement, observation, classification and experimentation, to name but a few.[2] This was true, I would learn, even for many things that seemed purely intellectual, or were presented as such. Arguments for the utility, including technological utility, of science needed to be taken seriously, though not uncritically. Paying attention to technology, I learned, is good for thinking about the history of science.

After completing his work on Coleridge, Trevor emerged from the world of *Naturphilosophie* and romanticism prepared for something more bracing. *Science and the Canadian Arctic: A Century of Exploration, 1818–1918* (Cambridge: Cambridge University Press, 1993) once again showed its author was well ahead of the field, this time giving exploration a central place in the history of science some years before that became a trend. Trevor looked at the Canadian arctic as a field for collaboration and competition, usually the latter, by British, Scandinavian, American, German, Austro-Hungarian and, in the latter stages of the story he tells, Canadian (i.e. those who came from the south) expeditions. Scientific expeditions throughout the century he covers were bound up with imperial ambitions, national pride, international competition, commercial activity and sovereignty. Trevor is not the sort of historian who puts his craft to the service of activism, but in his understated way he made the case for the continuing relevance of these themes. The events of the intervening years have shown Trevor to be more prescient than ever. In his Afterword he noted there is "a real sense in which northern regions around the pole have colonial economies in relation to southern governments and industries." (427) Yet the Inuit, he suggested, could provide important evidence of Canadian sovereignty. *Science and the Canadian Arctic* is not a study of what is now known as indigenous knowledge, but Trevor noted that throughout the period he covers and beyond, those expeditions with the best chance for survival (a basic measure of success in the Arctic) were those that fostered contact with and made a point of trying to learn from the ways of the Inuit.

By the 1990s Trevor had mastered at least three distinct fields in the history of science and was on a trajectory to the highest echelons of the profession. For many professors this is the stage where they can with some justification focus on research and leave matters of professional and editorial service to others. This was never a possibility for Trevor, whose quiet sense of obligation to colleagues, students and the profession seems almost quaintly out of place in an era where advancement is increasingly measured by increments not by the quality of a contribution. During these years he served his second term as director and, among other things, devoted his editorial acumen to a number of project, including a book co-edited with William Shea, *Nature, Experiment and the Sciences: Essays on Galileo and the History of Science in Honour of Stillman Drake* (Dordrecht: Kluwer, 1990) and a three volume collection of Stillman Drake's essays, co-edited with Noel Swerdlow, *Essays on*

[2] For an early example of this see Gerard L'E. Turner and Trevor H. Levere, *Van Marum's Scientific Instruments in Teyler's Museum*, vol. 4 of *Martinus van Marum: Life and Work* (Leyden: Noordhoff, 1973), more recently in Frederic L. Holmes and Trevor H. Levere, eds, *Instruments and Experimentation in the History of Chemistry* (Cambridge, MA: MIT Press, 2000).

*Galileo and the History and Philosophy of Science* (Toronto: University of Toronto Press, 1999). In 1999 he also took over as editor of *Annals of Science*, the first and oldest history of science journal published in England, a position he held for a full 14 years.

*Annals of Science* gave Trevor the opportunity to encourage the work of young scholars, something in which he takes great pleasure. The same held true for the Ashgate book series "Science, Technology and Culture, 1700–1945," which he co-edited with David Knight. Over the years a number of colleagues and friends from Europe (including Britain) and North America have told me how grateful they are for his quiet and steadfast support.

Lest there be any doubt, editing did not keep Trevor from other writing projects. *Transforming Matter: A History of Chemistry from Alchemy to the Buckyball* (Baltimore: Johns Hopkins University Press, 2001) is a shrewd introductory study aimed at a non-specialist audience that begins with the premise that chemistry was and remains a practical science. Trevor's long experience teaching the history of chemistry allows him to cover the ground from a discussion of alchemy that will surely surprise the intended readership, through to environmental chemistry at the close of the twentieth century.

The practical character of chemistry, its concern with developing tools and instruments for manipulating matter, makes it a subject of considerable social and political import. This importance is amplified during times of revolutionary social change. *Discussing Chemistry and Steam: The Minutes of a Coffee House Philosophical Society, 1780–1787*, co-authored and edited by Trevor and Gerard L'E. Turner with contributions by Jan Golinski and Larry Stewart (Oxford: Oxford University Press, 2002) gives us a place at the table, as it were, of an eighteenth-century society devoted to promoting natural knowledge. In Trevor's pithy assessment, "The appetite of members for profitable science was intense." (7).

Of the chemists who were drawn to more than industrial revolution, one of the foremost was Thomas Beddoes, a crucial figure in the later stages of the English Enlightenment who, thanks to his connections with Davy and Coleridge, has long attracted Trevor's attention. Beddoes's interest in medicine, chemistry, geology and education, and his reforming tendencies and democratic politics made him a controversial figure at a time when, as Trevor has pointed out, the British authorities treated democracy with about as much enthusiasm as McCarthy treated communism. *The Enlightenment of Thomas Beddoes: Science, Medicine and Reform*, co-authored by Trevor, Larry Stewart and Hugh Torrens with Joseph Wachelder (London: Routledge, 2016), presents us with a Beddoes who saw medicine and chemistry as tools for pulling the poor out of poverty and who stayed true to his radical tendencies in an often hostile environment.

This brief tour of Trevor's life in the history of science is very far from complete. Space does not permit a discussion of all of his edited volumes, much less his scores of articles, or of the many encounters related by the contributors (students, colleagues and friends) to this volume. As one might expect, he has a long list of honours. Besides those already mentioned, he has held numerous visiting fellowships in North America, Europe and Japan, has been elected to the International Academy of the History of Science in Paris and the Royal Holland Society of Sciences, and is a Fellow of the Royal Geographical Society in London. He has held Killam and Guggenheim Fellowships and was awarded a D.Litt. by Oxford in 1999. In 2006 the University of Toronto appointed him University Professor and in 2009 the American Chemical Society recognized him with the Edelstein Award "for the breadth and depth of his historical interests, his research productivity, his understanding of the intellectual and contextual aspects of the history of chemistry, and his promotion of the history of science in Canada."

These stellar achievements reflect Trevor's place among the world's leading historians of science, but it is more appropriate to conclude with the man rather than his honours. Those of us fortunate enough to socialize with him admire him for his affinity for good conversation on any number of topics—the arts, politics, literature, science, family, nature—always enlived with his subtle and sly wit (akin to that of W.C. Fields, it has been said). Such qualities, together with his keen awareness that intellectual life is by no means limited to the academy, make him a most amiable dinner companion. No doubt his intellectual breadth serves him well, as does the way he has balanced his outstanding career with his devotion to his wife, children and grandchildren. Trevor knows what matters, and it is a genuine pleasure to present him this volume, a token of friendship and collegiality!

# Chapter 2
# Elements, Instruments, and Menstruums: Boerhaave's Imponderable Fire Between Chemical Masterpiece and Physical Axiom

**Victor D. Boantza**

> *Fire is a Body, and a Body in motion. Its Motion is argued from its expanding the Air; which is not effected without communicating Motion thereto: And its Corporeity is proven by Experiment. For pure Mercury being enclosed in a Phial with a long Neck, and kept in a gentle Heat for the space of a Year, is reduced into a Solid; and its Weight considerably increased; which Increase can arise from nothing but the accession of Fire … The Nature of Fire is so wonderful, and abstruse, that the Ancients generally revered it as a God: Among the moderns, we can scarce name one Point in all Philosophy of more importance, or less understood. ("Fire," Ephraim Chambers, Cyclopædia, 1728)*

> *Hence, in all physics, it is found exceedingly difficult perfectly to distinguish the very action of fire from that of other concurring causes; while yet the nature of fire is so very different from theirs, that to confound them together will introduce the utmost uncertainty and disorder. (Herman Boerhaave, A New Method of Chemistry, 1741)*

## 2.1 Introduction

In 1796, in the aftermath of the Chemical Revolution, 2 years after Lavoisier's execution and Priestley's flight to America, Lavoisier's close collaborator Antoine-François de Fourcroy (1755–1809) wrote:

An earlier version of this essay was presented at a workshop held at McGill University in 2010: "The Maker's Universe: Science, Art, and Instruments in Early Modern Europe." Trevor Levere acted as commentator and I thank him for his insightful questions and remarks.

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> In his noble work, entitled *Physica subterranea*, [Johann Joachim Becher] had collected all the chemical phenomena at that time known, and has described them with amazing accuracy … Stahl, who was born with a natural fondness for chemistry, undertook to illustrate the doctrine of Becher by commentary. His favourite subject, to which he more particularly directed his attention, was to demonstrate the existence of that inflammable earth which he denominated Phlogiston … His treatises on sulphur and salts, together with that which is entitled *Trecenta Experimenta*, have acquired him immortal honour … Boerhaave, amid his various engagements, found leisure to cultivate chemistry, and composed a very profound work on this science, which has long been highly celebrated. The treatises on the four elements, particularly that on fire, which form a part of this work, are each of them masterpieces, containing all that was at that time known on their particular subjects.[1]

The "masterpieces" on the "four elements, particularly that on fire" were part of Herman Boerhaave's *Elementa Chemiae* of 1732 (Fig. 2.1).[2] These were the developments, authors, and works Fourcroy regarded as most central to what he framed as the "Rise and Progress of Philosophical Chemistry, from the middle of the seventeenth to the middle of the eighteenth Century."[3] A few decades earlier, in the early 1750s, the Montpellier chemist Gabriel François Venel (1723–1775) mentioned the very same works and names, but in a tellingly different way and context. Fourcroy's words were meant as a historical reflection; Venel's allusions were part of an argument he advanced in his article "chimie" that appeared in the third volume (1753) of Diderot and d'Alembert's *Encyclopédie*.

Both Fourcroy and Venel, separated by a generation, recognized the importance of chemical research on fire. Where the two chemists differed, importantly, was in their understanding of what constituted chemical—versus physical—research. Drawing on fire's double role as a physical agent of repulsion and as a chemical substance whose definition was similar to traditional phlogiston, Venel remarked:

> As for fire, and its essential quality of rarifying all bodies by which Boerhaave, who has best treated it physically, characterizes this fluid, this property is clearly related to fire as

[1] Antoine-François Fourcroy, *Elements of Chemistry, and Natural History. To which is Prefixed the Philosophy of Chemistry,* 4th ed. trans. R. Heron (London: J. Murray et al., 1796), vol. 1, 31–2. This is the fourth edition. The first three editions appeared, with slightly different titles in 1782, 1788, and 1790.

[2] All the references and quotations in this essay are from the 1741 edition: *A New Method of Chemistry, Including the History, Theory, and Practice of the Art*. For details on Boerhaave's work and life see Arie G. Lindeboom, *Herman Boerhaave: The Man and His Work* (London: Methuen, 1968); Arie G. Lindeboom, ed., *Boerhaave and his Time: Papers Read at the International Symposium in Commemoration of the Tercentenary of Boerhaave's Birth* (Leiden: Brill, 1970). An insightful study of Boerhaave's chemistry in the context of his pedagogy and practice is John C. Powers, *Inventing Chemistry: Herman Boerhaave and the Reform of the Chemical Arts* (Chicago, 2012). See also Rina Knoeff, *Herman Boerhaave (1668–1738): Calvinist Chemist and Physician* (Amsterdam: Koninklijke Nederlandse Akademie van Wetenschappen, 2002); Mi Gyung Kim, *Affinity, That Elusive Dream: A Genealogy of the Chemical Revolution* (Cambridge, MA, 2003), 177–88. For a more narrowly focused study see Ursula Klein, "Experimental History and Herman Boerhaave's Chemistry of Plants," *Studies in History and Philosophy of Science*, **34** (2003), 533–67.

[3] Fourcroy, *Elements*, 30.

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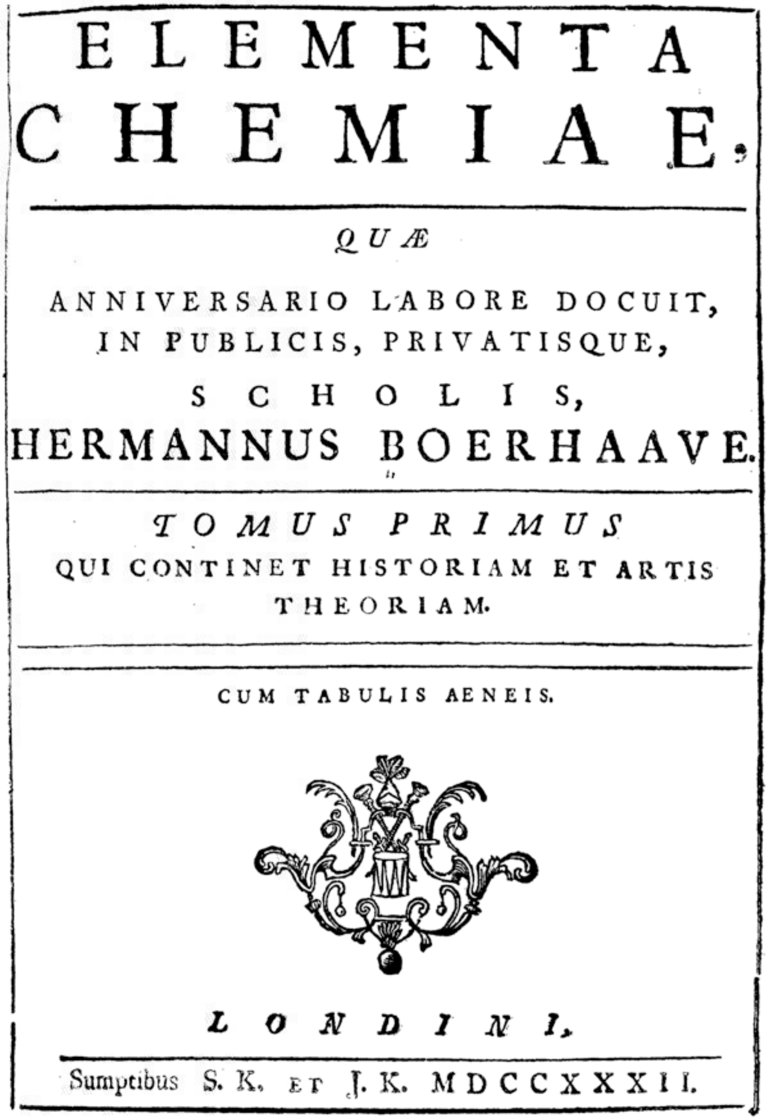


ELEMENTA
CHEMIAE,

QUÆ

ANNIVERSARIO LABORE DOCUIT,
IN PUBLICIS, PRIVATISQUE,
SCHOLIS,
HERMANNUS BOERHAAVE.

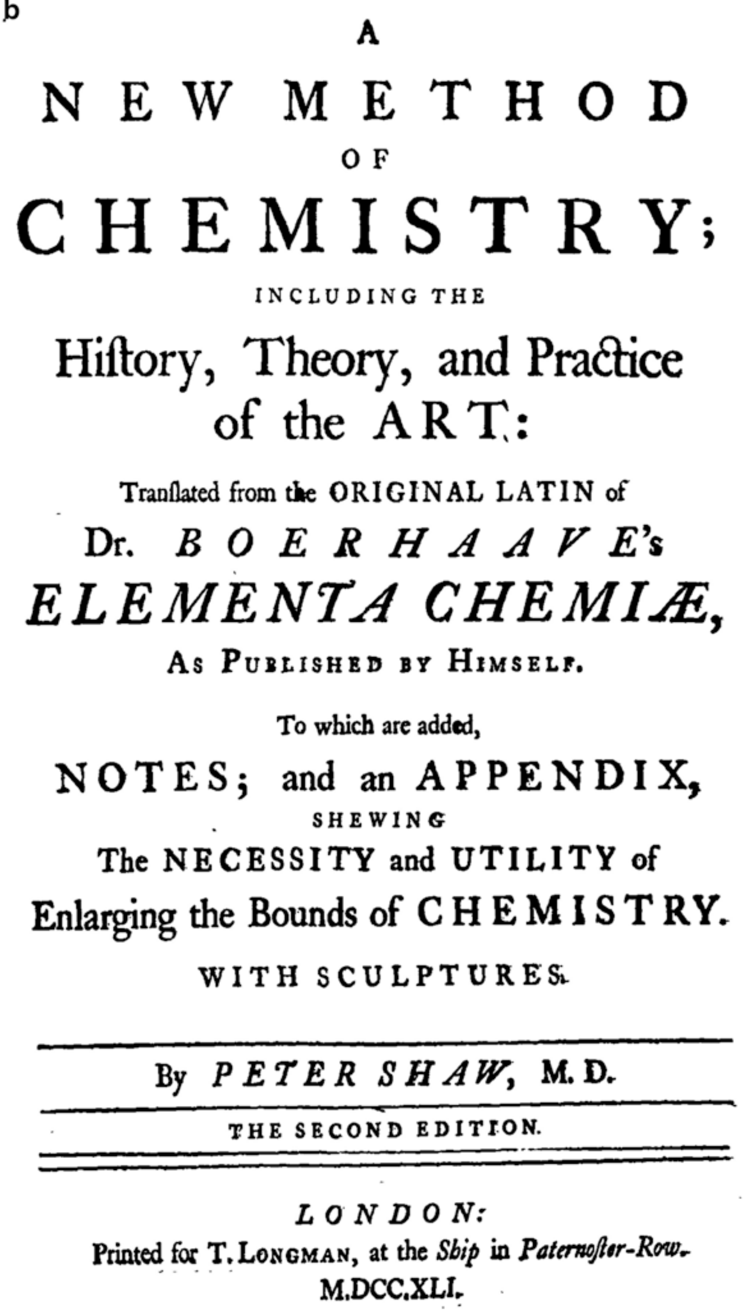
TOMUS PRIMUS
QUI CONTINET HISTORIAM ET ARTIS
THEORIAM.

CUM TABULIS AENEIS.

LONDINI,

Sumptibus S. K. ET J. K. MDCCXXXII.

**Fig. 2.1** Boerhaave's 1732 *Elementa chemiae above* and the second English edition *below*, translated by Peter Shaw and published in 1741 with his commentaries. The first English edition appeared in 1735, 3 years before Boerhaave's death; it was translated by Timothy Dallowe and published as *Elements of Chemistry, being the lectures of Herman Boerhaave, M.D. Formerly Professor of Botany, And at present, Professor of Physick in the University of Leyden*. Both editions are in two volumes b



A
NEW METHOD
OF
CHEMISTRY;
INCLUDING THE
Hiſtory, Theory, and Practice
of the ART:
Tranſlated from the ORIGINAL LATIN of
Dr. BOERHAAVE's
*ELEMENTA CHEMIÆ,*
AS PUBLISHED BY HIMSELF.
To which are added,
NOTES; and an APPENDIX,
SHEWING
The NECESSITY and UTILITY of
Enlarging the Bounds of CHEMISTRY.
WITH SCULPTURES.

By *PETER SHAW*, M.D.

THE SECOND EDITION.

*LONDON:*
Printed for T. LONGMAN, at the *Ship* in *Paternoſter-Row*.
M.DCC.XLI.

**Fig. 2.1** (continued)

> mass or aggregate; we can thus confirm that all but five or six lines of Boerhaave's treatise on fire deal with physics … [yet] fire, considered as a particular chemical object, is a principle capable of combination and precipitation, conferring to those mixts of which it is a principle color, inflammability, metallicity, etc., hence the treatise on fire, known as Stahl's *Trecenta* [*experimenta*], is fundamentally chemical.[4]

According to Venel, Georg Ernst Stahl (1659–1734) perceived fire "as a particular chemical object" whereas Boerhaave (1668–1738), the famous Leiden chemist and scientific educator, "treated it physically." We should of course guard against reading too much into Fourcroy's and Venel's generalized statements. But as the following analysis will demonstrate, their words embodied key features of the dialectics between scientific disciplines and styles of research in the physical sciences of the early eighteenth century. A careful examination of Boerhaave's influential account of fire in theoretical, experimental, and institutional contexts is at the center of the ensuing discussion.

Lavoisier began his *Elements of Chemistry* (1789) with a nod to Boerhaave that confirmed Venel's view. "That every body," the book's opening line read, "whether solid or fluid, is augmented in all its dimensions by any increase in its sensible heat, was long ago established as a physical axiom, or universal proposition, by the celebrated Boerhaave."[5] In the early 1750s Venel expressed considerable concern over the fact that the single most influential part of Boerhaave's celebrated chemical treatise—the chapter on fire—dealt with physics more than it did with chemistry. By the late 1780s, Lavoisier touted Boerhaave's study of heat as a staple of chemical theory. Despite momentous shifts in disciplinary boundaries, however, ontological challenges persisted. The significance of Boerhaave's "physical axiom" notwithstanding, Lavoisier still included in his new system a chemical and substantial form of heat—the vaguely defined element he named caloric. Both Lavoisier's chemical caloric and Boerhaave's fire were material and imponderable. They differed in that Lavoisier considered heat as an accumulation of caloric whereas Boerhaave believed that heat resulted from the motion of the particles of both ponderable matter and imponderable fire.[6]

Fourcroy, Lavoisier's ally in matters of experimental physics, grouped Stahl (alongside Becher) and Boerhaave together as the masterminds of early eighteenth-century chemistry. Venel, by contrast, situated them on the opposing sides of the physical–chemical divide. Although not rigid or impermeable, this divide was characterized by a stark imbalance, as Venel disconcertedly recognized. "Some chemistry can be found in the works of true physicists, for indeed many of them

[4] Gabriel François Venel, "Chymie ou Chimie," in Denis Diderot and Jean le Rond D'Alembert, eds., *Encyclopédie, ou dictionnaire raisonné des sciences, des arts et des métiers, etc.,* vol. 3, 414. Retrieved from <University of Chicago: ARTFL Encyclopédie Project (Spring 2011 Edition), Robert Morrissey,ed., http://encyclopedie.uchicago.edu/>.

[5] Antoine Laurent Lavoisier, *Elements of Chemistry, In a New Systematic Order; Containing all the Modern Discoveries*, trans. J. Kerr (Edinburgh, 1790 [1789]), 1.

[6] Robert Fox, *The Caloric Theory of Gases from Lavoisier to Regnault* (Oxford, 1971), 12.

deal with chemistry, including views on general systems and fundamental doctrinal principles … [but] what Boyle, Newton, Keill, Freind, Boerhaave, etc. have written is marked by lack of experimentation. Thus we cannot expect to get a true picture of chemistry by studying such people." The works of these "physicists," Venel added, were widely known, "quoted and praised, whereas the greater ideas and unique notions of Stahl, in both areas, are recognized by only a few chemists."[7] Physical theories and methods dominated contemporary natural philosophy; so much so, that even chemists, ignorant of their own scientific heritage, had been led astray.

An important disseminator of Stahlian ideas in France, Venel was also the most prominent writer on chemical topics for the *Encyclopédie*.[8] In his landmark article "chimie" he attempted to carve out an autonomous theoretical and practical space for a midcentury chemistry he sensed was misunderstood, misrepresented, and threatened by the rising influence of Newtonian physics. Venel's "chimie" became an important manifesto throughout the second half of the century; in 1796, the same year Fourcroy wrote the passage with which we have begun, he reprinted Venel's article in the *Encyclopédie Méthodique*, a revised and expanded version of the *Encyclopédie*.[9] Fourcroy's close acquaintance with Venel's midcentury assessment rendered his late eighteenth-century delineation of the disciplinary boundaries all the more instructive.

Chemistry's disciplinary struggle was not new. Venel traced its origins to Boyle's late seventeenth-century attempts to interpret chemical phenomena along mechanistic principles. In order to "assume the form of true science," Venel lamented, chemistry "accepted the prevalent physical systems, as it has become successively Cartesian, corpuscular, Newtonian, academic or experimental."[10] The latter denoted the growing authority of experimental physics in the early eighteenth century, a trend best represented by the first generations of Anglo-Dutch Newtonians. Singling out scientific demonstrators and popularizers like John Freind, John Keill, John Theophilus Desaguliers, Pieter van Musschenbroek, as well as Boerhaave, Venel remarked: "we cannot raise chemistry to the level it deserves by demonstrating its

[7] Venel, "Chymie ou Chimie," 408.

[8] Venel contributed more than 200 entries on various topics in chemistry (out of more than 800 dedicated to the subject), including entries on calcination, precipitation, mixts, elements, combustion, decomposition, fermentation, solvents, distillation, and niter. For the best study on chemistry in the *Encyclopédie*, including a detailed analysis of the "chemical corpus" see Jean-Claude Guedon, "The Still Life of a Transition: Chemistry in the Encyclopédie" (Ph.D. Thesis, University of Wisconsin, 1974); see also Rémi Franckowiak, "La chimie dans l'Encyclopédie: une branche tour à tour dépréciée, réévaluée et autonome," *Recherches sur Diderot et sur l'Encyclopédie* **40/41** (2006), 59–70.

[9] See Antoine-François Fourcroy, *Encyclopédie méthodique*, "chimie" (Paris, 1796), vol. 3, 262–303. Venel's association with the *Encyclopédie* is also discussed in Jacques Proust, *L'Encyclopédisme dans le Bas-Languedoc au XVIIIe siècle* (Montpellier: Faculté des Lettres et Sciences Humaines de Montpellier, 1968), 23–7 and 33–5.

[10] Venel "Chymie ou Chimie," 408–9.

philosophical side … we cannot do for chemistry what elegant machines, optics, and electricity have done for physics.".[11]

For Venel, experimental physics and chemistry offered causal explanations based on experimental inquiries. But he also drew a firm distinction between the two that rested on a sophisticated fusion of matter theoretical considerations and an operative epistemology. Tracing out the contours of physics and chemistry, Venel argued: "two sciences that consider objects from such different points of view will inevitably produce particular and distinct knowledge … and each will produce a different language, method, and operating procedure."[12] At its core, however, the distinction did not turn on linguistic or methodological divergences but on ontological concerns, as signified by Venel's reference to "objects." Important as methods and operating procedures might be, they were fundamentally dependent on a matter theoretical distinction—between the chemical *mixt* and the physical *aggregate* modes of matter, a distinction found in Stahl. Physics and chemistry conceived of and therefore manipulated matter in profoundly different ways. Physicists studied aggregates, or materially homogenous masses governed by universal forces of attraction and repulsion; chemists dealt with mixts, or materially heterogeneous compounds brought together by the force of affinity. The attempts to unite these two approaches, Venel stressed, have been equally detrimental to both sciences. Like Fourcroy, Venel considered Stahl as one of the pillars of eighteenth-century chemistry, even though Fourcroy's—post Chemical Revolution—association of Stahl with "that inflammable earth which he denominated Phlogiston" already foreshadowed the biases of a much later, enduring historiography.[13] Boerhaave, Venel emphasized, viewed "fire as mass or aggregate."

Boerhaave can be seen as a link between Boyle and Venel: chronologically, but also from a thematic and disciplinary standpoint. An examination of Boerhaave's views on elements, focusing on his treatise on fire, which became the standard account on the subject during much of the eighteenth century, provides valuable insights into the processes of disciplinary negotiation between chemistry and physics from Boyle to the midcentury crisis depicted by Venel. In his 1771 *Dictionary of Chemistry*, Venel's contemporary, the French chemist Pierre-Joseph Macquer portrayed Boerhaave's treatise on fire as "an astonishing master-piece, so complete, that the human understanding can scarcely make any addition to it." Although his language had likely inspired Fourcroy's depiction, Macquer also added an evocative juxtaposition: "Next to *Stahl* we place the immortal *Boerhaave*; though he excelled in a different way."[14] By highlighting their contributions to "Philosophical Chemistry," Fourcroy would later obscure this very contrast.

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[11] Ibid., 410.

[12] Ibid., 416.

[13] For a comprehensive survey of this see John G. McEvoy, *The Historiography of the Chemical Revolution: Patterns of Interpretation in the History of Science* (London: Pickering & Chatto, 2010).

[14] Pierre Joseph Macquer, *A Dictionary of Chemistry, Containing the Theory and Practice of that Science*, trans. J. Keir (London: T. Cadell and P. Elmsly, 1771), vol. 1, xi.

Stahl's phlogiston, and its various theoretical ramifications, has received ample scholarly attention, particularly in the context of the Chemical Revolution. Given how influential Boerhaave's account of fire was throughout the eighteenth century, it has been the subject of several studies, most of which center on the role of and effect on Newtonianism.[15] In what follows I am not interested in what earned Boerhaave the title of "immortal"—be it chemist or physicist. His clear aim, the culmination of which was the *Elementa Chemiae*, was to reform chemistry. And yet, contemporary chemists questioned his contributions to their science, as they perceived it. The view, which goes back to the eighteenth century, that Boerhaave introduced physicalist considerations into chemistry, is basically correct. My attempt here is to understand *why*, and in particular *how*, it is so. Following Venel's judgment, I explore the conflicts, challenges, and inconsistencies inherent in that endeavor. Tracing the origins of these ontological, epistemological, and institutional tensions back to the 1660s, I examine influences on Boerhaave's account of elements and instruments—fire was both—as well as his ideas about menstruums and solution chemistry.[16] The contributions of Samuel Cottereau Duclos and Wilhelm Homberg, two chemists and founding members of the French Royal Academy of Sciences, are considered as part of the story. I pay particular attention to Boerhaave's view of fire as an imponderable agent of material change in relation to various mechanistic and materialistic trends in matter theory. Reconstructing these contexts reveals diverging conceptions of the nature of elements, instruments, analysis, composition, and material change more generally, as these entities and categories straddled the shifting perimeters of the physical–chemical divide around the turn of the eighteenth century.

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[15] An exception is Rosaleen Love, "Some Sources of Herman Boerhaave's Concept of Fire," *Ambix* **19** (1972), 157–74. Otherwise see Héléne Metzger, "La théorie du feu d'après Boerhaave," *Revue Philosophique de la France Et de L'Étranger* **109** (1930), 253–85; I. Bernard Cohen, *Franklin and Newton: An Inquiry Into Speculative Newtonian Experimental Science and Franklin's Work in Electricity as an Example Thereof* (Cambridge, MA: Harvard University Press, 1966), 214–34; David R. Dyck, "The Nature of Heat and Its Relationship to Chemistry in the Eighteenth Century" (Ph.D. Thesis, University of Wisconsin, 1967), 101–17; Deirdre M. La Porte, "Theories of Fire and Heat in the First Half of the Eighteenth Century" (Ph.D. Thesis, Harvard University, 1970), 155–78; Bernard Joly, "Voltaire chimiste: l'influence des théories de Boerhaave sur sa doctrine du feu," *Revue de nord* **77** (1995), 817–43; Arnold Thackray, *Atoms and Powers: An Essay on Newtonian Matter-Theory and the Development of Chemistry* (Cambridge, MA: Harvard University Press, 1970), 111–113.

[16] For an excellent recent study of Boerhaave's 'skeptical' views of chemical elements and analysis, relating them to Boyle's early critiques as well as to chemistry in the second half of the century, see John C. Powers, "Fire Analysis in the Eighteenth Century: Herman Boerhaave and Scepticism about the Elements," *Ambix* **61** (2014), 385–406.

## 2.2 The Elements and Instruments of Chemistry

The relationship between chemical analysis, composition, and the nature of elements was a controversial issue in early modern chemistry. Practicing chemists faced a variety of questions in this context. What were the primary constituents of bodies? Could substances be broken down into a fixed and limited number of elements? Could such elements be obtained through chemical analysis? Could one be certain that the end products of chemical analysis—whether using fire (distillation) or solvents—did preexist in any given substance and were not created anew during the process? Could one know whether the products of analysis were elementary substances, the genuine building blocks of matter, and not just limits of a particular analytical setup?

Such questions were at the center of Boyle's critical manifesto, *The Sceptical Chymist* (1661). With respect to chemical composition, elements, and matter theory Boyle denounced the traditionally accepted Aristotelian Four Elements, the Paracelsian *tria prima* (salt, sulfur, mercury) as well as practically informed combinations thereof, most commonly represented by the *tria prima*, to which water and earth would be added occasionally as passive elements. Concerning chemical analysis, Boyle charged the traditional distillation practices, or fire analysis, that grew out of the iatrochemical and pharmaceutical traditions. The two sets of critiques, on elements and analysis, were clearly interlinked, as Boyle cautioned against "relying too much upon the Fire alone, for the resolving of Bodies, so without fruitlessly contending to force them into more Elements than Nature made Them up of, or strip the sever'd Principles so naked, as by making Them Exquisitely Elementary to make them almost useless."[17] In order to elevate chemistry to a more 'philosophical' status, Boyle looked to dissociate it from its technical and artisanal roots while introducing corpuscular and mechanical explanations.

The tenor of Boyle's criticism can be gleaned from the phrases he chose to convey his reservations. Chemical discourse was "obscure, Ambiguous and Aenigmatical"; chemists failed to write "intelligibly enough" and exhibited an "over great-reservedness"; "without proving" their arguments, the "validity" of their interpretations was questionable; given the "unreasonable liberty they give themselves of playing with Names at pleasure," chemical entities lacked fixed referents; finally, the "Un-Philosophical" chemists lacked "Clear and Distinct Notions" of the elements.[18]

Nearly a century later, Venel complained about the disciplinary state of chemistry. "Chemistry is scarcely cultivated among us," he lamented, "not even among scientists, despite the claim for universal knowledge, which is presently so dominant. Chemists made up a distinct group of people, not very numerous, having their own language, laws, mysteries, and living rather isolated within a large community

[17] Robert Boyle, *The Sceptical Chymist*, in Michael Hunter and Edward B. Davis, eds., *The Works of Robert Boyle* (London: Pickering and Chatto, 1999–2000), vol. 2, 375.

[18] Ibid., 209, 211, 213, 277, 291–2.

that shows little interest in their activities and expects almost nothing to come from their work." Few could "distinguish between chemists and glass-blowers" and most thought chemists were either mere pharmacists or "technicians dabbling in secret processes."[19]

Like Boyle, Venel thought chemistry's reputation was problematic. It was still being overly associated with 'lowly' practical arts like pharmacy and metallurgy, from which it had emerged during earlier times. But while Boyle felt that the "Un-Philosophical" chemists would benefit from adopting the physical tenets of the mechanical philosophy, Venel believed that the reason chemistry was so "scarcely cultivated" and so widely misunderstood was precisely because it has "accepted the prevalent physical systems." By submitting chemical phenomena to the duality of matter and motion, Boyle aimed to reformulate chemical discourse along what he had aptly designated as "physico-chymical" or "chymico-physical" principles, terms which he used interchangeably.[20] Venel thought that as chemistry "has become successively Cartesian, corpuscular, Newtonian, academic or experimental" it had given up its independence. This loss of autonomy was at the core of its midcentury crisis. "As long as chemists and physicists each philosophize in their own manner on the objects of their study … things will be fine," he continued, but "if one treats physical things as *more chimico*, and the other treats chemical things as *more physico* … then things are not well at all."[21] In the early eighteenth century Boerhaave still echoed some of Boyle's doubts but his views on fire and heat confirmed Venel's concerns about the unwarranted blurring of ontological and epistemological boundaries.

In his *New Method of Chemistry* (Fig. 2.1) Boerhaave wrote of physical corpuscles as the ultimate immutable elementary constituents of bodies. Regarding chemical "operations" and analysis—with particular reference to distinctly chemical processes like "calcination, fixation, vitrification, sublimation, fermentation, putrefaction, digestion, [and] purification"—he stated[22]:

> a separation of parts thus effected does not shew that those parts have pre-existed in the body, such as they now appear; since those very operations whereby the parts become separated and disengaged from the rest, may make great alterations in them: so that it is a false conclusion of the generality of chemists, that their elements were really contained in the compounds … it is by no means so clear as chemists imagine, that their art gives the true first elements of things; and that we may judge of the compounds by the principles into which they are chemically resolvable.[23]

[19] Venel "Chymie ou Chimie," 408.

[20] The first phrase is taken from the title of Boyle's "Essay on Nitre: A Physico-Chymical Essay … Redintegration of Salt-Petre"; the second from the subtitle to 1661 *The Sceptical Chymist*, which reads "Chymico-Physical Doubts & Paradoxes, Touching the Spagyrist's Principles […]."

[21] Venel "Chymie ou Chimie," 416 (italics in original).

[22] Herman Boerhaave, *A New Method of Chemistry; Including the History, Theory, and Practice of the Art: Translated from the Original Latin of Dr. Boerhaave's Elementa Chemiae, as Published by Himself. To which are added notes; and an appendix, shewing the necessity and utility of enlarging the bounds of chemistry*, 2nd edition, trans. P. Shaw (London: T. Longman, 1741), vol. 1, 157.

[23] Ibid., 158.

Even though Boerhaave was suspicious of the relation between chemical analysis and the elementary constituents of bodies, he avoided a mechanistic-reductive interpretation of chemical phenomena. In fact, he admitted the existence of several chemical elements.[24] "It must indeed be allowed that fire, air, water, earth, alcohol, mercury, the presiding spirit in each body [the "*Spiritus rector*"], and several others, do, when absolutely simple, appear to be fine, permanent elements." Boerhaave defined the "*Spiritus rector*" as a highly subtle, penetrable, and virtually insensible agent, peculiar to each body "whereby it is accurately distinguished from all others." Reminiscent of the traditional aerial niter, "when pure and single [this spirit] flies off, by its great mobility mixes with the air, and returns into the common chaos of volatiles … it falls down with snow, hail, rain, or dew … By such revolution it passes into new bodies, whose mass it animates and directs."[25] Unlike Boyle before him, Boerhaave did not rule out the possibility of a certain number of elements although "whether such bodies can by any contrivance be procured and exhibited perfectly pure, has not yet been demonstrated … [for] nothing of this simplicity is found in the common operations of the chemists."[26] Boerhaave's list of elements is intriguing. Despite being discussed in close relation to chemical analysis and practice, the inclusion of the "presiding spirit" suggests that Boerhaave, influenced more by Newton than by Boyle, did not perceive matter as thoroughly passive and inert.

Even more striking is the fact that this list of elements might seem at first glance like a throwback to the very systems that came under Boyle's forceful attack. Among Boerhaave's elements we find the four Aristotelian elements "fire, air, water, earth" alongside mercury, which was one of the Paracelsian *tria prima*. Subtle and spirituous, mercury, which was sometimes called spirit, has been conventionally associated with chemical reactivity. Why did Boerhaave invoke—as late as the 1730s–1740s and in a chemical textbook that linked chemical phenomena with corpuscular explanations—the elementary status of such traditional systems?[27] Why did he include spirits alongside material elements? He clarified, after all, that these elements have

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[24] On Boerhaave's view of instruments "as tools within the practice and philosophy of chemistry and as principles of organization within the structure of Boerhaave's chemical courses" see John C. Powers, "Chemistry Without Principles: Herman Boerhaave on Instruments and Elements," in Lawrence M. Principe, ed., *New Narratives in Eighteenth-Century Chemistry* (Dordrecht: Springer, 2007), 45–62 (on 47).

[25] Boerhaave, *New Method*, p. 168. Although he assumed this spirit to be largely insensible, Boerhaave suggested, at times, that it manifested itself through smell, being "so subtile as only to be perceivable by its smell or taste." (Ibid.). For historical background see Allen G. Debus, "The Paracelsian Aerial Niter," *Isis* **55** (1964), 43–61.

[26] Boerhaave, *New Method*, 167–68.

[27] It should be noted that Boerhaave was not unique in this regard. In fact, the 'elementary' status of the four elements remained uncertain throughout most of the century. But the later debates were conducted within a very different epistemological context, mostly related to greater questions about the relationship between matter, metaphysics, language, and chemical method. Cases in point are the debate on the composition of water between Priestley, Cavendish, Kirwan, and Lavoisier; the variety of phlogistic debates concerning the nature of fire; or the distinction between air as a gaseous state or as chemical species as seen in the increasing number of newly discovered gases.

not yet been "procured and exhibited perfectly pure" in the "common operations of the chemists." Boerhaave's elements encompassed material and immaterial, permanent and changing, theoretical and demonstrable dimensions. But how did they figure in his conception of matter and material change? Or, put differently, what was their chemical, and correspondingly physical, status?

The *New Method* consisted of three parts. The second part, which will concern us here, included Boerhaave's views on the goals of chemistry, observations on metals, salts, acids, and minerals, alongside substantial chapters on the operations and instruments of chemistry, where Boerhaave discussed the four elements, with particular focus on fire. These were the accounts Fourcroy referred to as "masterpieces." Boerhaave followed up the chapter entitled "Of the Operations of Chemistry" with a discussion of "The Effects, or Productions of Chemistry," especially in relation to natural philosophy, medicine, and the mechanical arts. Whereas the first and second subjects occupied less than three and four pages of the entire book, respectively, the third spanned 27 pages. The chapter on the mechanical arts included sections on painting, enameling, art of glass, metallurgy, natural magic, art of wine, brewing, and alchemy, in which Boerhaave professed his intention "to add a few, but candid and ingenious considerations, on the great use of chemistry to alchemy."[28] He explained:

> Those arts are vulgarly call'd mechanical, which are performed by the labour of the hands; being very different from that of mechanics, which lays down the powers of bodies, arising from the common properties of all bodies, which geometricians explain. Chemistry is of no service to this latter; but is of singular advantage to the former, which are employ'd in working upon, and making changes in bodies.[29]

Despite upholding a general corpuscular conception of matter—and despite Venel's lumping together of "Boyle, Newton, Keill, Freind, [and] Boerhaave" under the heading of "true physicists"—Boerhaave was not a reductive mechanist like Boyle had been early on, especially in the 1660s. The difference could be understood as one of emphasis. Like other mechanists, Boerhaave also appealed to matter and motion in explaining chemical phenomena. But whereas a mechanist like Boyle laid more emphasis on *matter*—on the sizes, shapes, and arrangements (to which he referred as textures) of particles—Boerhaave, finding this type of reasoning too speculative, stressed the generalized and universal action of *motion* within and upon matter, which could be described in a corpuscular way. "Chemistry is employed in changing the bodies contained in the three classes above specify'd [vegetal, animal, mineral], and the change it produces in them is effected by means of motion alone."[30] This tied in with Boerhaave's view of chemistry as being closer to a mechanical art "performed by the labour of the hands" than to "mechanics," which dealt with generalized abstractions and was the domain of "geometricians." The former was experimental and particular, the latter abstract and universal.

[28] Boerhaave, *New Method*, vol. 1, 200 (italics mine).

[29] Ibid., 178.

[30] Ibid., 155.

Further addressing the relationship between chemistry and the mechanical arts, Boerhaave proclaimed, "I shall begin with the instruments which are always required when any thing is to be done by art."[31] Boerhaave adopted and deployed "instruments"—a key feature of the mechanical arts and of contemporary experimental physics (also indicated above by Venel)—as a central metaphor in his chemical outlook. His detailed examinations of these instruments, comprising the main bulk of the first of two volumes of the *New Method*, was what related the discussion back to his conception of elements. We begin with his definition of chemical instruments, followed by their identification:

> In all arts which direct bodies to be chang'd, the name instrument is given to certain things capable of a particular motion; which being thence apply'd to the body intended to be chang'd, produces the requisite change therein: thus, in the present art [chemistry], there are certain bodies by whose means the requisite actions are produced. These, with the best chemists, we usually reduce to six principal ones; fire, water, air, earth, menstruums, and utensils.[32]

As we have seen, fire, water, air, and earth were regarded as "fine, permanent elements." But they also figured as instruments—for occasioning "requisite change[s]" within bodies—alongside "menstruums, and utensils." The list of utensils included "the furniture of a laboratory"; "crucibles and melting pots"; "evaporating vessels"; and lutes and furnaces.[33] This peculiar alignment implied a view of an instrument as a changeless agent of change in other bodies through motion. If an element or a menstruum was akin in this sense to a furnace or a retort it should facilitate a chemical process without engaging in it, like the slicing of bread with a knife or the boiling of water in a vessel. This view assumed not only the immutability but also the materiality of these elements-instruments.

This twofold nature of Boerhaave's elements (immutable and material) reflected his understanding of the relation between chemistry and physics. In view of the irreducible abundance of chemical particularities, he related chemical phenomena not to mechanistic agendas but to experimental physics. "Certain bodies have peculiar powers," he noted,

> from whence effects arise, that do not come within the compass of any general theorem; but depend on a certain constitution, peculiar perhaps to some one body. In forming such theory [in chemistry], a direct use may indeed be made of the demonstrations in physics, as particularly in mechanics, hydrostatics, and hydraulics; since the properties common to all bodies, and what further affections certainly flow therefrom, have their place in chemistry.[34]

In examining "the properties common to all bodies" Boerhaave avoided hypothesizing about the ultimate nature of matter. The limit was set at a mechanical-instrumental level, as it were, where properties "peculiar perhaps to some one body" should be

[31] Ibid., 205 (italics mine).

[32] Ibid., 205.

[33] Ibid., 580–93; titles of the subsections in the chapter "Of the Chemical Apparatus, and Vessels."

[34] Ibid., 3.