

Enlightenment Chemistry as an ‘Experimental Science’*

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Chemistry aspired to become an “experimental science”—a new kind of ‘science’ in which all opinions are verified by experiments and therefore distinct from the sciences based on observation (e.g. astronomy)—during the French Enlightenment.¹ The push to transform what was regarded as an esoteric ‘art’ practiced by alchemists, metallurgists, and apothecaries into a ‘science’—a genre of systematic knowledge that could be codified and communicated to the literary public and contribute to the maintenance of the state²—came from the elite chemists [*savant-chimiste*]³ who belonged to the royal institutions such as the Académie royale des sciences and the Jardin du roi where chemistry was instituted as one of the three medical sciences [*les sciences physiques*] along with botany and anatomy.⁴ The Académie played a criti-

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¹ This was the definition for “la science expérimentale” given by Jean Baptiste Sénac in his *Nouveau Cours de chymie, suivant les principes de Newton & de Stahl* (Paris: Jacques Vincent, 1723), liii. I have not found the phrase “experimental science” in eighteenth-century English usage, although the Latin term *scientia experimentalis* (not focused on laboratory experiments) had been introduced by Roger Bacon; Jeremiah M.G. Hackett, “The Meaning of Experimental Science (*scientia experimentalis*) in the Philosophy of Roger Bacon,” unpublished Ph.D. Dissertation (University of Toronto, 1983).

² This is my definition based on eighteenth-century French usage, quite distinct from the twentieth-century use of the term ‘science,’ often deemed liberal and independent of the state.

³ For the compromised character of the French savant in serving the absolutist state, see David J. Sturdy, *Science and Social Status: The Members of the Académie Royale des Sciences, 1666-1750* (Woodbridge, Suffolk, UK: Boydell, 1995); Vincenzo Ferrone, “The Man of Science,” in Michel Vovelle ed., *Enlightenment Portraits* (Chicago: University of Chicago Press, 1997), 190-225.

⁴ Roger Hahn, *The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666-1830* (Berkeley: University of California Press, 1971); Alice Stroup, *A Company of Scientists: Botany, Patronage, and Community at the Seventeenth-Century Parisian Royal Academy of Sciences*

cal role in forging a path to the modern experimental science of chemistry by cultivating a symbiosis between practice-oriented theories and theory-oriented experiments, which set the perimeters of a stable chemical reality independent of philosophical speculation. The chemists teaching at the Jardin complemented the Academics' systematic research by sustaining an active pedagogical culture that helped stabilize a core repertoire of chemical operations while enlarging the public for chemistry.⁵ These two royal institutions helped forge chemistry as a proto-modern 'experimental science' by legitimizing the main locales of chemical practice—the classroom, the laboratory, and the public forum.⁶ In other words, French royal institutions provided a loose coordination between research and teaching in chemistry already in the eighteenth century, although historians have usually attributed such coordination to Justus von Liebig's laboratory in the nineteenth century.⁷

The elite chemists employed at French royal institutions also cultivated a symbiotic relationship between theory and experiment—a significant facet of modern laboratory sciences—by moving away from the discourse of (Aristotelian, Paracelsian, or Cartesian) 'chemical philosophy' which sought to subsume chemical reality under the speculative truth of natural philosophy.⁸ In order to forge an 'experimental science,' chemists had to discipline their laboratory practice through reliable analytic methods and reconcile the disparate products for a coherent laboratory reality they could present to the public. Such malleable path of chemistry—modulated simultaneously by changing methods, theories and laboratory realities—is quite different from the one idealized in modern physics with a clear differentiation between facts and theories.⁹ Twentieth-century physicists commonly asserted that facts "remain firmly entrenched" once established correctly, while theories are in "a constant pro-

(Berkeley: University of California Press, 1990); Anita Guerrini, *The Courtiers' Anatomists: Animals and Humans in Louis XIV's Paris* (Chicago: University of Chicago Press, 2015); Emma C. Spary, *Utopia's Garden: French Natural History From Old Regime to Revolution* (Chicago: University of Chicago Press, 2000).

⁵ For the productive interaction between these two institutions and their chemists, which shaped the contour of French Enlightenment chemistry, see Mi Gyung Kim, *Affinity, That Elusive Dream: A Genealogy of the Chemical Revolution* (Cambridge, MA: MIT Press, 2003).

⁶ Mi Gyung Kim, "Labor and Mirage: Writing the History of Chemistry," *Studies in History and Philosophy of Science* 26:1 (1995), 155-165.

⁷ Frederic L. Homes, "The Complementarity of Teaching and Research in Liebig's Laboratory," *Osiris* 5 (1989), 121-164; Georg Schwedt, *Liebig und seine Schüler: Die neue Schule der Chemie* (Berlin: Springer, 2002); Alan J. Rocke, "Origins and Spread of the 'Giessen Model' in University Science," *Ambix* 50:3 (2003), 90-115.

⁸ Russel McCormmach, *Speculative Truth: Henry Cavendish, Natural Philosophy, and the Rise of Modern Theoretical Science* (New York: Oxford University Press, 2004).

⁹ For a telling portrait of such relationship, see the autobiography of Andrew Streitwieser, *A Lifetime of Synergy with Theory and Experiment* (Washington, D.C.: American Chemical Society, 1997).

cess of change, expansion, improvement, updating and adjustment." When anomalies proliferate and cause severe contradiction, a new theory must come into existence.¹⁰ Thomas S. Kuhn in his *Structure of Scientific Revolutions* (1962) refuted such a deeply internalized view that science develops through an accumulation of data and consequent falsification/adjustment of the existing theoretical structure.

In order to fully appreciate the theory-experiment symbiosis in the 'chemistry of salts,' as Frederic L. Holmes named the eighteenth-century effort to stabilize and multiply acid-alkali combinations, we must pay close ethnographic attention to what the contemporary chemists meant by 'theory' and 'experiment'¹¹ and elucidate the importance of stable analytic methods in producing both.¹² Solution methods engendered a model 'experimental system'¹³—the displacement reaction of acids and alkalis—which configured the two main domains of chemical theory (composition and affinity) rooted in laboratory practices. They also gave rise to a comprehensive theoretical scheme (the affinity table) which transformed chemistry into an experimental science that could generate its own objects of inquiry and organize them in an intelligible mode of representation—a field of inquiry akin to Kuhn's notion of 'normal science.' With a stable repertoire of analytic methods, well-defined theory domains and a clear mode of representation, eighteenth-century chemists could make a steady progress and multiply chemical species, which promoted their utility outside of the laboratory. Chemistry with its inalienable dependence on analytic (and later synthetic) methods offers a model of scientific development quite different from physics and more germane to other laboratory sciences.¹⁴

Chemistry's enlightened path to becoming an 'experimental science' required, then, not just its evolving material culture but also the elite chemists' conscious effort to articulate a theoretical structure that could organize their laboratory practices in a predictable manner. Although the recent 'material turn' in the historiography

¹⁰ Pyotr L. Kapitsa, *Experiment, Theory, Practice* (Dordrecht: D. Reidel, 1980), 14.

¹¹ Robert Halleux, "Theory and Experiment in the Early Writings of Johan Baptist Van Helmont," in Diderik Batens and Jean Paul van Bendegem eds., *Theory and Experiment: Recent Insights and New Perspectives on Their Relation* (Dordrecht: D. Reidel, 1988), 93-101.

¹² Frederic Lawrence Holmes, *Eighteenth Century Chemistry as an Investigative Enterprise* (Berkeley: Office for the History of Science and Technology, 1989); Mi Gyung Kim, "The Instrumental Reality of Phlogiston," *Hyle* 14:1 (2008), 27-51.

¹³ On the experimental system, see Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford: Stanford University Press, 1997); for the model system, see Angela N. H. Creager, *The Life of a Virus: Tobacco Mosaic Virus as an Experimental Model* (Chicago: University of Chicago Press, 2002).

¹⁴ Mi Gyung Kim, "Stabilizing Chemical Reality: The Analytic-Synthetic Ideal of Chemical Species," *Hyle* 20:1 (2014), 117-139.

has rightfully downplayed the role of theory as understood in the conventional historiography centered on physics,¹⁵ early modern practitioners in empirical fields often claimed their reasoning power and theoretical prowess to enhance their social status and the cognitive prestige of their field.¹⁶ Although the Aristotelian/Paracelsian discourse of ‘chemical philosophy’ served to legitimize the art of ‘sooty empirics’ in the seventeenth century, it could not manage the complex laboratory reality chemists continued to expand and refine. While appropriating the British and continental innovations to establish their chemical expertise and public/state relevance, French elite chemists under royal patronage engaged in a systematic scrutiny of the relationship between their (literary, social, and laboratory) practices and chemical ‘theory’, which charted a unique path to modern chemistry by excluding ontological hypotheses such as Aristotelian elements, Paracelsian principles or Cartesian particles. Newton’s natural philosophy built on attractions came closer to chemists’ experimental realm but his (and our) notion of theory would have been too general to meet their needs.¹⁷ The elite chemists’ multi-pronged practices helped demarcate the object of chemical inquiry, foster a systematic representation (the affinity table) that could coordinate them, and produce a public culture that could translate the esoteric laboratory practice of chemistry for their patrons—the state and the public. Although they appropriated the reigning philosophical systems to this end, these systems could not function as chemical theories in the laboratory. The growing distance between the discourse of chemical philosophy and the laboratory practice of chemistry called for a theoretical system attuned to chemists’ evolving material practice.

Chemistry’s evolution as a state-sponsored ‘science’ in eighteenth-century France challenges the taken-for-granted liaison between science and the Enlightenment, often construed as the core liberal legacy of Western civilization.¹⁸ The ascent of chemistry from an ‘art’ to an ‘experimental science’ required an active coordination of the intellectual and institutional resources the ancien régime offered. Not only were the central academic institutions of research and teaching patronized by the

¹⁵ Pamela H. Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2004); Ursula Klein and Wolfgang Lefevre eds., *Materials in Eighteenth-Century Science: A Historical Ontology* (Cambridge, MA: MIT Press, 2007); Ursula Klein and E.C. Spary eds., *Materials and Expertise in Early Modern Europe: Between Market and Laboratory* (Chicago: University of Chicago Press, 2010); Emma C. Spary, *Eating the Enlightenment: Food and the Sciences in Paris, 1670-1760* (Chicago: University of Chicago Press, 2012); Pascal Schillings and Alexander van Wickeren, “Towards a Material and Spatial History of Knowledge Production. An Introduction,” *Historical Social Research* 40:1 (2015), 203-218.

¹⁶ Alistair C. Crombie, “Experimental Science and the Rational Artist in Early Modern Europe,” *Daedalus* 115:3 (1986), 49-74.

¹⁷ For an example of our commonsense notion of theory, as applied to Newton, see Roberto de Andrade Martins and Cebel Celestino Silva, “Newton and Colour: The Complex Interplay of Theory and Experiment,” *Science and Education* 10 (2001), 287-305.

¹⁸ Thomas L. Hankins, *Science and the Enlightenment* (Cambridge: Cambridge University Press, 1985).

royal government but also an active public culture of chemistry sprang up in the royal garden. Successful French scientists were skillful *bricoleurs* who turned the institutional mandate to their career advantages, although their aspirations to shine in the Republic of Letters sometimes modified their strategies of 'self-fashioning.'¹⁹ In contrast to the conventional Enlightenment historiography that characterizes science and philosophy as the rationalizing forces that opposed the absolutist state,²⁰ that is, Enlightenment 'sciences' were defined by the state, or at least nurtured by the desire to serve the state, as is evident in the 'science' of politics or economy.²¹ Ken Alder has shown how mathematics became an indispensable tool of technocracy.²² In the generation preceding Lavoisier's, Pierre-Joseph Macquer represented the persona of the *savant-chimiste* in supervising royal factories, directing academic research, and supporting the centralizing pharmaceutical enterprise of his associate Antoine Baumé.²³

Lavoisier's revolution and the subsequent development of modern chemistry need to be understood in this context when chemistry became a shining example of state-sponsored sciences under the most advanced absolutist regime to pave the way for the Napoleonic regime.²⁴ His 'Chemical Revolution' at the end of the Enlightenment, which is often regarded as the foundational event for modern chemistry, was built on decades of academic practice which stabilized main theory domains of chemistry, refined analytic methods for defining chemical species, and promoted a systematic investigation and expansion of chemical territory. By annexing the new domain of

¹⁹ Mario Biagioli, *Galileo Courtier* (Chicago: University of Chicago Press, 1992); Mary Terrall, *The Man Who Flattened the Earth: Maupertuis and the Sciences in the Enlightenment* (Chicago: University of Chicago Press, 2002); Spary, *Utopia's Garden* (cit. n. 4); Antoine Lilti, *The World of the Salons: Sociability and Worldliness in Eighteenth-Century Paris* (Oxford: Oxford University Press, 2015).

²⁰ Jonathan Israel, *Radical Enlightenment: Philosophy and the Making of Modernity, 1650-1750* (Oxford: Oxford University Press, 2001). For a critique, see Mi Gyung Kim, "Material Enlightenment," *Historical Studies in the Natural Sciences* 44:4 (2014), 424-433.

²¹ Gilbert Faccarello and Philippe Steiner, "Interest, Sensationism, and the science of the legislator: French 'philosophie économique,' 1695-1830," *European Journal of the History of Economic Thought* 15:1 (2008), 1-23.

²² Ken Alder, *Engineering the Revolution: Arms and Enlightenment in France, 1763-1815* (Princeton: Princeton University Press, 1997).

²³ Claude Viel, "Pierre-Joseph Macquer," *Janus* 73 (1986-1990), 1-27; Pierre Julien, "Sur les relations entre Macquer et Baumé," *Revue d'histoire de la pharmacie* 39 (1992), 65-77; Kim, *Affinity* (cit. n. 5), 201-218; Christine Lehman, "Pierre-Joseph Macquer: Chemistry in the French Enlightenment," *Osiris* 29 (2014), 245-261.

²⁴ Maurice P. Crosland, *The Society of the Arcueil: A View of French Science at the Time of Napoleon I* (Cambridge, MA: Harvard University Press, 1967); Patrice Bret, *L'État, l'armée, la science: l'invention de la recherche publique en France, 1763-1830* (Rennes: Presses universitaires de Rennes, 2002); Charles C. Gillispie, *Science and Polity in France: The Revolutionary and Napoleonic Years* (Princeton: Princeton University Press, 2004).

gases to the existing chemical domains of liquids and solids and by integrating physical instruments into chemical practice, Lavoisier's revolution radically altered the boundaries of chemical reality and the criteria for determining chemical species. His most important contribution to modern chemistry consisted, that is, in defining the chemical substance as one that could exist in three different physical states without losing its identity, which underlined his nomenclature reform. While the more visible features of his reform (e.g. the oxygen theory of acids) met serious resistance, this fundamental transformation in the definition of chemical species expanded chemical territory and shaped the field of stoichiometry to lay the foundation of modern chemistry.²⁵ Lavoisier's legacy would be sustained throughout the nineteenth century by a series of master Academicians who wished to claim his authority to strengthen their own, which also established the main historiographical threads of interpreting the 'Chemical Revolution' in the twentieth century.²⁶

The Evolving Status of Experiments

The social status of experiments began to change with the emergence of 'experimental philosophy' in Restoration England (1660s), ostensibly following Francis Bacon (1561-1626), which also transformed the cognitive status of chemistry. As a statesman devoted to philanthropy, Bacon had advocated an intrusive manipulation, if not the "torture," of nature for the public good.²⁷ All inhabitants of Bensalem in his utopian fiction *New Atlantis* (1626) devote themselves to improving human (as opposed to divine) knowledge for the benefit of their fellow citizens. The Salomon's House sets up experimental regions on the ground, underground, and in the air in order to organize the entire commonwealth as a cooperative laboratory and to enlarge "the bounds of Human Empire."²⁸ The laboratory, which entered public consciousness at the turn of the seventeenth century,²⁹ helped articulate the notion of

²⁵ Kim, "Stabilizing Chemical Reality" (cit. n. 14).

²⁶ Mi Gyung Kim, "Lavoisier, the Father of Modern Chemistry?," in Marco Beretta ed., *Lavoisier in Perspective* (München: Deutsches Museum, 2005), 167-191.

²⁷ William Leiss, *The Domination of Nature* (New York: George Brazziller, Inc., 1972), 45-72; Carolyn Merchant, *The Death of Nature: Women, Ecology, and the Scientific Revolution* (San Francisco: Harper & Row, 1979).

²⁸ Francis Bacon, *New Atlantis* (1626) in Brian Vickers ed., *Francis Bacon: The Major Works* (Oxford: Oxford University Press, 1996), 457-489 on 480; Charles Whitney, "Francis Bacon's *Instauratio*: Dominion of and over Humanity," *Journal of the History of Ideas* 50:3 (1989), 371-390; Timothy Paterson, "The Secular Control of Scientific Power in the Political Philosophy of Francis Bacon," *Polity* 21:3 (1989), 457-480; Markku Peltonen, "Politics and Science: Francis Bacon and the True Greatness of the State," *The Historical Journal* 35:2 (1992), 279-305.

²⁹ Owen Hannaway, "Laboratory Design and the Aim of Science: Andreas Libavius versus Tycho Brahe," *Isis* 77:4 (1986), 585-610; John Shanahan, "Ben Jonson's 'alchemist' and Early Modern Laboratory Space," *Journal of Early Modern Culture* 8:1 (2008), 35-66.

philanthropy based on useful sciences and configure an ideal commonwealth for Francis Bacon, a statesman who wished to be a king “invested of that *triplicity* ... ascribed to the ancient Hermes; the power and fortune of a King, the knowledge and illumination of a Priest, and the learning and universality of a Philosopher.”³⁰ Bacon imagined that a harmonious union of England and Scotland had to be like a chemical *Miltio* (perfect union in quality) rather than a physical *Compositio* (mere juxtaposition in place).³¹ In the context of intensifying British imperial dreams, which often failed miserably,³² Bacon envisaged a utopian commonwealth organized as an efficient laboratory at the hidden imperial center to organize the entire globe as a ‘knowledge space.’³³ The scientific *imperium* would serve his lifelong goal of *philanthropia*—not mere charity but a vast project of building an ideal commonwealth/empire through a fundamental reform of the knowledge system.

To realize this Baconian dream in the aftermath of the Civil War, the Fellows of the Royal Society of London made experiments a key component in their reform of natural philosophy, but their ideal notion of experiment differed substantially from Bacon’s. In their respective efforts to legitimize the experimental enterprise, Bacon relied on prophetic, often violent, metaphors of conquest while the gentlemen of the Royal Society, in searching for a mode of consensual knowledge-making, called for a circumspect, methodical probing for the secrets of nature.³⁴ The laboratory, the previously hidden and socially denigrated domain of *chemical* labor, became in the Restoration context the site of judging and resolving upon the ‘matters of fact’ that would determine the truth of nature—the domain of natural philosophy—through the collective authority of the Royal Society.³⁵ Thomas Sprat pitched in his propagandistic “history” of the Royal Society that experimenters and inventors, or the practitioners of “vulgar arts,” should enjoy a higher reputation than that of the speculative philosophers or dogmatists—ancient and modern—who exercised tyranny on human reasoning. True philosophy practiced by “modern experimenters” was

³⁰ Francis Bacon, *Advancement of Learning* (1605), Book one, in Vickers ed., *Francis Bacon*, 122.

³¹ Francis Bacon, *A briefe discourse, touching the happie vnion of the kingdomes of England, and Scotland Dedicated in private to his Maiestie* (London: R. Read, 1603); cf. Stanton J. Linden, “Francis Bacon and Alchemy: the Reformation of Vulcan,” *Journal of the History of Ideas* 35:4 (1974), 547–560.

³² For an overview of British imperial attempts, especially in contrast to the successful Iberian ventures, see John H. Elliott, *Empires of the Atlantic World: Britain and Spain in America, 1492–1830* (New Haven: Yale University Press, 2006).

³³ David Turnbull, “Cartography and Science in Early Modern Europe: Mapping the Construction of Knowledge Spaces,” *Imago Mundi* 48:1 (1996), 5–24.

³⁴ Peter R. Anstey, “Philosophy of Experiment in Early Modern England: The Case of Bacon, Boyle and Hooke,” *Early Modern Science and Medicine* 19:2 (2014), 103–132; Peter Pesic, “Proteus Unbound: Francis Bacon’s Successors and the Defense of Experiment,” *Studies in Philology* 98:4 (2001), 428–456.

³⁵ Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump* (Princeton: Princeton University Press, 1985).

slated to receive the “noblest improvements” from chemists’ labor, except alchemists.³⁶ Robert Boyle’s ‘philosophical chemistry’ or a disciplined experimental interrogation of nature, as opposed to the Aristotelian/alchemical/Paracelsian ‘chemical philosophy,’ was meant to forge a “confederacy” between chemists and corpuscularians. The alliance would dress up chemical practice in the respectable language of mechanical philosophy and transform speculative natural philosophy into a ‘true’ or ‘experimental’ philosophy whose perfection would require a path of “slow, and sure *experimenting*.”³⁷ Such interventionist studies of nature, which involved substantial and instrumental transformation (rather than passive observation) of natural processes, became a privileged part of the new philosophical-political-theological project.³⁸

Boyle and the Royal Society sought to appropriate chemists’ material expertise and the laboratory to rehabilitate natural philosophy and Anglican polity.³⁹ If chemistry emerged in their rhetoric as socially respectable knowledge, it was also linked to the truth claims of experimental philosophy and Anglican theology. The practice of chemistry failed to acquire an autonomous cognitive space, then, in the gentlemanly pursuit of the truth that could refurbish the commonwealth. Experimental philosophy had to serve as a secure guide to a constitutional monarchy. Chemistry as an experimental philosophy *par excellence* was no exception. If Isaac Newton shared the Royal Society’s agenda of strengthening the Anglican polity through experimental philosophy, his mathematical approach differed significantly from Boyle’s. By re-defining the vacuum as the space devoid of air (rather than of all corporeal substance), Boyle demarcated experimental practice from metaphysics and sought to persuade the public through a detailed ‘experimental narrative.’⁴⁰ Newton favored a more definitive (almost mathematical) demonstration—a ‘crucial experiment’—that would prove a clearly defined ontological hypothesis.⁴¹ In laying down the “mathematical principles of natural philosophy,” he wished to “derive the rest of the

³⁶ Thomas Sprat, *The History of the Royal-Society of London, for the Improving of Natural Knowledge* (London: J. Martyn, 1667), 37-38, 99; On the political condemnation of alchemy, see Andrew J. Mendelsohn, “Alchemy and Politics in England,” *Past and Present* 135:1 (1992), 30-78.

³⁷ Kim, *Affinity* (cit. n. 5), 36-47.

³⁸ James G. Lennox, “Robert Boyle’s Defense of Theological Inference in Experimental Science,” *Isis* 74:1 (1983), 38-52; Thomas Holden, “Robert Boyle on Things above Reason,” *British Journal for the History of Philosophy* 15:2 (2007), 283-312; Michael Ben-Chaim, *Experimental Philosophy and the Birth of Empirical Science: Boyle, Locke and Newton* (London: Routledge, 2016).

³⁹ Scott Mandelbrote, “The Uses of Natural Theology in Seventeenth-Century England,” *Science in Context* 20:3 (2007), 451-480.

⁴⁰ Discussed in James Bryant Conant, *Robert Boyle’s Experiments in Pneumatics* (Cambridge, MA: Harvard University Press, 1950), 33-38.

⁴¹ Simon Schaffer, “Glass Works: Newton’s Prisms and the Uses of Experiment,” in D. Gooding, T. Pinch and S. Schaffer eds., *The Uses of Experiment: Studies in the Natural Sciences* (Cambridge: Cambridge University Press, 1989), 67-104.

phenomena of Nature by the same kind of reasoning" or to show that all actions in nature followed the laws of "attraction"—gravitational, magnetic, electrical, and chemical. Newton's infinite universe was organized by a set of forces that evinced the unity of God's design—perhaps the inverse square law. Inter-atomic or chemical attractions would support such 'analogy of nature'—that nature as God's dominion must be "simple and always consonant to itself"—which explains in part his intense devotion to chemical experiments.⁴² The truth of natural religion, articulated in a series of Boyle lectures which sought to reconcile Newtonian philosophy and Anglican theology, would bolster the moral foundation of the British Empire.⁴³ If Anglican Newtonians shared a dream of rational theodicy with Leibniz, they sought to dictate the terms of engagement so that Newtonian philosophy would remain at the core of Anglican polity.⁴⁴

French Royal Institutions and the Decline of Chemical Philosophy

In France where royal institutions provided more prestigious positions for select apothecaries and physicians, medical utility (rather than philosophical truth or political ideals) offered an indispensable rhetorical resource in the effort to transform chemistry into a public 'science.' If medicine provided the institutional niche, utilitarian purpose, and social legitimation for chemical practice, apothecaries supplied sophisticated medicaments and standardized materials for theory-minding chemists and their effort at developing rigorous experimental practice. Established by chemical/royal physicians, the Jardin du roi maintained a public lecture in chemistry from 1647 and taught pharmaceutical operations to prospective physicians, which established chemistry as a "practical or operational science" that could help physicians by cultivating an active interaction between theory and practice.⁴⁵ In other words, chemistry had to be more than an art of pharmaceutical operations to become a field of active concern for elite physicians. The Académie royale des sciences appointed upon its organization in 1666 Claude Bourdelin (apothecary to the duc d'Orléans) and Samuel Cottureau Du Clos (royal physician) as pensioners of the chemistry section to carry out systematic analyses of medical plants (via distillation) and mineral waters (via solution methods). While Bourdelin distilled thousands of plants over the following decades in concert with Denis Dodart's project on the natural history

⁴² H.S. Thayer ed., *Newton's Philosophy of Nature* (New York: Hafner Press, 1953), 4, 159-179.

⁴³ Rob Iliffe, *Priest of Nature: The Religious Worlds of Isaac Newton* (Oxford: Oxford University Press, 2017); Sarah Irving, *Natural Science and the Origins of the British Empire* (London: Pickering and Chatto, 2008).

⁴⁴ Steven Shapin, "Of Gods and Kings: Natural Philosophy and Politics in the Leibniz-Clarke Disputes," *Isis* 72:2 (1981), 187-215.

⁴⁵ Kim, *Affinity* (cit. n. 5), 17-36, esp. 22-23.

of plants, Du Clos pursued a program of “extreme resolution” to find the “true principles of mixts.”⁴⁶ Changing tides in analytic methods (from distillation to solution) and philosophical fashions (Aristotelian/Paracelsian to Cartesian) would create, however, an extraordinary strain on these academic chemists who conducted a long series of analyses in a shifting institutional context.

The ‘Cartesian’ moment in French chemistry reflects how the dual shift in analytic method and philosophical system destabilized the validity of philosophical-chemical principles and the identity of chemical substances.⁴⁷ Although Du Clos was critical of Boyle’s corpuscular language, mechanical philosophy was fashionable among the philosophically-oriented Academicians and their public. Nicolas Lemery (1645-1715), a master apothecary who offered private courses in Paris, began to employ in his lectures a corpuscular ontology of acid and alkali particles. His universal ontology worked to bridge the boundaries of different analytic methods and to present chemists’ laboratory reality to the fashionable public [*le monde*] as a part of an intelligible order of nature. With the reorganization of the Academy in 1699, its permanent secretary Bernard le Bovier de Fontelle (1657-1757) projected a vision of unified science based on rigorous experimentation and mathematical representation.⁴⁸ Fontenelle’s vision was colored by his literary-philosophical Cartesianism,⁴⁹ which provided an opportunity for the new generation of Academicians to develop a public discourse of corpuscular chemistry and helped them to cope with the royal administration’s mandate for useful knowledge. This ‘Cartesian’ rationalization of solution chemistry, which explained acid-alkali reactions in terms of pointed particles and holed receptacles, reflected the elite chemists’ effort to appropriate the promise of solution methods while dealing with the inadequacy of distillation methods in extracting medical virtues. Their effort yielded a methodical examination of what should count as the legitimate object of chemical inquiry and a symbiotic relationship between theory and experiment, which moved chemical theory away from the Aristotelian/Paracelsian discourse of chemical philosophy and prioritized the experimental system of displacement reactions.

⁴⁶ Kim, *Affinity* (cit. n. 5), 47-52; Victor D. Boantz, *Matter and Method in the Long Chemical Revolution: Laws of Another Order* (Farnham, Surrey: Ashgate, 2013).

⁴⁷ Kim, *Affinity* (cit. n. 5), 52-132; François Pépin, “Fontenelle, l’Académie et le devenir scientifique de la chimie,” *Methodos: Savoirs et textes* 12 (2012) [<https://journals.openedition.org/methodos/2898>]

⁴⁸ Bernard le Bovier de Fontenelle, “Preface to the History of the Academy of Sciences, from 1666 to 1699,” in Leonard M. Marsak ed., *The Achievement of Bernard le Bovier de Fontenelle* (New York: Johnson Reprint, 1970), IV:17-23; Daniel Garber, “Descartes and Experiment in the Discourse and Essays,” in Stephen Voss ed., *Essays on the Philosophy and Science of René Descartes* (Oxford: Oxford University Press, 2011), 85-110.

⁴⁹ Leonard M. Marsak, “Cartesianism in Fontenelle and French Science, 1686-1752,” *Isis* 50:1 (1959), 51-60; Herbert Dieckmann, “Philosophy and Literature in Eighteenth-Century France,” *Comparative Literature Studies* 8:1 (1971), 21-41.

The introduction of physical instruments also began to change chemists' laboratory reality. A critical figure in this regard was Wilhelm Homberg (1652-1715). Appointed to the Academy in 1691, he inherited Bourdelin's distillation analysis of medical plants and initiated a close scrutiny of chemical composition.⁵⁰ The infusion of solution methods into French pharmaceutical practice had created some intractable theoretical problems, which destabilized the standing alliance between distillation analysis and the Aristotelian/Paracelsian chemical philosophy, encapsulated in the doctrine of five principles.⁵¹ As an experimental philosopher looking into chemical practice, Homberg adapted physical instruments such as the air-pump and the aerometer to design new experiments meant to ascertain chemical composition. After the death of Bourdelin, the duc d'Orléans's patronage also allowed him to approach the problem with a "new key to enter the interior composition of bodies"—the Tschirnhaus burning glass—and a mode of reasoning akin to Boyle's, which engendered a complex laboratory reality that pushed the limits of chemical analysis and representation. Homberg hoped to resolve the five principles produced by distillation methods to their ultimate, corpuscular composition, which would end in the sulfur principle or the matter of light—presumably the only active principle in the world. Although he did not refute the chemical principles drawn from the distillation method or other substances stabilized through the solution method, he pursued the ultimate composition of all bodies down to the corpuscular level,⁵² which gave a prominent status to the hypothetical or alchemical sulfur principle.⁵³

Homberg's systematic effort to correlate chemical substances obtained from diverse analytic methods and to discern their hierarchical composition was broadly publicized as an effort to establish the principles of the "science" of chemistry via definitive experiments.⁵⁴ His decade-long effort did not result in the planned textbooks—*Cours de Chimie* and *Operations de Chimie*—to forge a secure theoretical foundation for chemical practice. Nevertheless, Homberg set up a creative context for chemical theorizing and broadened the scope of what could count as chemical experiment by introducing physical methods of analysis, an approach that would continue with Herman Boerhaave and Lavoisier. The nature and the function of

⁵⁰ Mi Gyung Kim, "Chemical Analysis and the Domains of Reality: Wilhelm Homberg's *Essais de Chimie*, 1702-1709," *Studies in History and Philosophy of Science* 31:1 (2000), 37-69; Rémi Franckowiak and Luc Peterschmitt, "La chimie de Homberg: Une vérité certaine dans une physique contestable," *Early Science and Medicine* 10:1 (2005), 65-90.

⁵¹ Mi Gyung Kim, "The Analytic Ideal of Chemical Elements: Robert Boyle and the French Didactic Tradition of Chemistry," *Science in Context* 14:3 (2001): 361-395; *idem*, *Affinity* (cit. n. 5), 17-36.

⁵² Kim, *Affinity* (cit. n. 5), 65-110.

⁵³ Lawrence Principe, "Wilhelm Homberg: Chymical Corpuscularism and Chrysopoeia in the Early Eighteenth Century," in H. Luthy, J.E. Murdoch, and W.R. Newman eds., *Late Medieval and Early Modern Corpuscular Matter Theories* (Leiden: Brill, 2001), 535-556.

⁵⁴ See the report of the Academy's public séance on April 22, 1705 in the *Journal de Trévoux* 5 (pub. 1751), 1414-1426.

chemical ‘theory’—as responsive to the laboratory practice and distinct from (chemical and natural) philosophy—became an abiding concern for French academic chemists. The emergent symbiosis between chemical theory and experiment would reify what should count as an object of chemical inquiry, or the chemical body.

The Emergence of Chemical Theory: The Affinity Table

Stabilizing the *chemical* body required a sharp turn from distillation to solution chemistry, which manifested as divergent efforts after the deaths of Wilhelm Homberg and Nicolas Lemery, both in 1715. On the one hand, Louis Lemery (1677-1743) refined the corpuscular language to develop a universal theory of solution chemistry. He established the displacement reactions of metals in acids as a model experimental system, conceptualized fire as a universal solvent, and scrutinized the differential solubility of salts in water. In addition to providing a detailed corpuscular modeling for chemical selectivity, he also designed specific experiments to support his theory. His corpuscular theory of chemical operations helped establish dissolution (in water or fire) as the primary analytic method of chemical composition and activity, which put an end to the doctrine of five principles based on distillation methods. Although Louis Lemery and his corpuscular modeling of solution chemistry are mostly forgotten in the historiography, they helped lay the conceptual groundwork for the affinity table which became the most successful theoretical scheme for the eighteenth-century chemistry of salts. His discourse on fire also set an important precedent for Herman Boerhaave’s which would become an integral part of French didactic discourse.⁵⁵

On the other hand, Etienne-François Geoffroy (1672-1731) turned chemical theorizing away from corpuscular imagination to a mode of representation more responsive to the laboratory practice and pedagogical needs. His affinity table [*Tables des rapports*], presented to the Academy in 1718, was meant to organize the frontier research on salts, especially the displacement reactions of acids and alkalis, as an empirical field of inquiry that would help laboratory instruction and the preparation of medicaments (see Figure 1). To this end, Geoffroy listed commonly used chemical substances on the top row and placed in each column below them other substances that react with the top substance in a decreasing order of “*rapports*”: “every time when two substances that have some disposition to join each other are found united, if there follows a third which has more *rapport* with one of the two, one is united with it by letting go of the other.”⁵⁶ Since the ‘order’ of these *rapports* was

⁵⁵ Kim, *Affinity* (cit. n. 5), 114-132.

⁵⁶ Etienne-François Geoffroy, “Table des différents Rapports observés en Chymie entre différentes substances,” *Mémoires de l’Académie royale des sciences* (1718), 202-212, on 203.

little known, Geoffroy had to gather the experiments and observations of other chemists, including German-speaking chemists such as Georg Ernst Stahl (1659-1734), and order them in a way that would allow chemical practitioners to quickly discern the affinities between the substances and predict their behavior. His training as a master apothecary and his position as the senior chemist of the Academy would have made it easier to discern the operations already accomplished and those that needed work. In emphasizing prediction in chemical experiments with the word '*rapport*' (rather than affinity), Geoffroy was following Fontenelle's ideal of controlled experiments and mathematical representation.⁵⁷

Mém. de l'Acad. 1718-29. E. pag. 212.

*TABLe DES DIFFERENTS RAPPORTS
observez entre différentes substances.*

							SM								

Figure 1. Etienne-François Geoffroy, “Table des différents Rapports observés en Chymie entre différentes substances,” *Mémoires de l’Académie royale des sciences* (1718), after p. 212.

⁵⁷ French word '*rapport*' can be translated either as relationship or as ratio. The ambiguity allowed Geoffroy to embrace both the anthropomorphic meaning of affinity, often used in chemistry, and the demand for mathematical representation Fontenelle advocated as the permanent secretary in the Academy.

For Geoffroy, a chemical ‘theory’ meant a reasonable explanation of a group of chemical operations, which could be applied across different analytic methods. If we recognize the affinity table as a comprehensive theoretical structure that organized the most salient (or profitable) chemical operations, we can configure French Enlightenment chemistry as an experimental science that fostered a productive symbiosis between concrete chemical operations and an interlocking set of theories that explained them in a consistent manner. Such synergistic process privileged certain experimental systems (displacement reactions) over others. It also promoted the theories that could coordinate the products of different analytic methods and identify chemical substances in a consistent manner. Phlogiston acquired its theoretical currency in this operational capacity, rather than in the Stahlian framework.⁵⁸

Born to a prosperous pharmaceutical dynasty, Geoffroy had spent a year in England where he became a Fellow of the Royal Society. Upon returning to France, he entered the Academy as Homberg’s protégé, but he always maintained an empirical approach to his master’s speculative project. He also mediated the Academy’s communication with the Royal Society.⁵⁹ Geoffroy gave up his hereditary rights to a prosperous pharmaceutical business and obtained a medical degree in 1702. He began to teach at the Jardin du roi in 1707 and at the Collège de France in 1712, while preparing a treatise on *materia medica* (1743). For this apothecary-turned-physician-teacher, the visually organized table could summarize “an entire course of chemistry” by presenting the relative affinities of substances to the beginners in a manner easy to learn.⁶⁰ It could also impart a method for deciphering complicated operations to the experienced practitioners. By enlisting common chemical agents and their salts in a form that predicted their behavior, the table organized chemists’ laboratory experience and fostered a growing field of inquiry on salts. In a loosely interactive context of systematic research and public teaching, as practiced at the Académie and the Jardin respectively, chemical theory moved away from chemical philosophy (Aristotelian, alchemical, Paracelsian, and Cartesian) to provide a clear operational identity for chemical substances and to explain their actions in a consistent manner without relying on speculative ontologies.

⁵⁸ Mi Gyung Kim, “The ‘Instrumental’ Reality of Phlogiston,” *Hyle* 14:1 (2008), 27-51; *idem*, “From Phlogiston to Caloric: Chemical Ontologies,” *Foundations of Chemistry* 13:3 (2011), 201-222. For the difficulties that have been caused largely by imposing our notion of theory on the eighteenth-century practice of chemistry, which is a common problem among the philosophers of science, see Geoffrey Blumenthal and James Ladyman, “The Development of Problems with the Phlogiston Theories, 1766-1791,” *Foundations of Chemistry* 19:3 (2017), 241-280.

⁵⁹ Anthony Turner, “An Interrupted Story: French Translations from *Philosophical Transactions* in the seventeenth and eighteenth centuries,” *Notes and Records of the Royal Society* 62:4 (2008), 341-54; Bernard Joly, “Etienne-François Geoffroy, entre la Royal Society et l’Académie royale des sciences: ni Newton, ni Descartes,” *Methodos: Savoirs et textes* 12 (2012) [<https://journals.openedition.org/methodos/2855>]; *idem*, “Etienne-François Geoffroy, a Chemist on the Frontiers,” *Osiris* 29:1 (2014), 117-131.

⁶⁰ Kim, *Affinity* (cit. n. 5), 132-146.

French academic chemistry of salts grew in a shifting intellectual and rhetorical context. The managerial ascent of René Antoine Ferchault de Réaumur (1683-1757) from 1715 turned the Academy’s attention away from mathematical-philosophical works toward useful sciences.⁶¹ By the 1720s, French chemistry stood at another crossroads with the eclipse (or rhetorical disavowal) of Cartesian philosophy, the full legitimation of solution chemistry, the thriving pharmaceutical enterprise, and the medical appropriation of chemical practice. Geoffroy’s offensive against the “fake Chemical Philosophers”—the imposters and cheats driven by “the insatiable avidity for profit” who claimed to possess the Philosopher’s Stone that would open a truly vast field of exploitation—was meant to protect the legitimate commerce of chemical remedies in this new environment.⁶² Medical utility provided significant impetus for the development of German chemistry as well. Stahl, previously a professor of medicine at Halle University, moved to Berlin in 1715 and campaigned vigorously for vitalist medicine and rational chemistry, sharply demarcated from alchemy.⁶³ His move consolidated a strong analytic school in Berlin with the addition of Johann Heinrich Pott and Johann Theodor Eller who helped demonstrate the utility of chemistry to a broad range of state industries such as metallurgy, brewing, dyeing, and glassmaking.⁶⁴

While Geoffroy shunned the discourse of natural philosophy (Cartesian or Newtonian) from chemical theorizing and did not justify his affinity table in terms of attraction, a notable push for ‘Newtonian’ chemistry in France came nearly a decade before Maupertuis’s or Voltaire’s well-known efforts to institute Newton’s authority in mathematics and public discourse. The effort fell in line with the traditional mode of legitimizing chemistry’s place within natural philosophy, which would have allowed the advocates to appropriate Newton’s authority as an alternative cultural icon to Descartes. Jean-Baptiste Sénac (1693-1770), who had studied in Leyden and London with the first generation of Newtonian physicians such as Archibald Pitcairne, John and James Keill, John Friend and George Cheyne,⁶⁵ published upon his return to Paris a new textbook, *Nouveau Cours de chymie, suivant les principes de Newton & de Stahl* (1723), to pitch for chemistry as an “experimental science.” He offered

⁶¹ J. B. Shank, *The Newtonian Wars and the Beginning of the French Enlightenment* (Chicago: University of Chicago Press, 2008), 47-104; Terrall, *The Man Who Flattened the Earth* (cit. n. 19)

⁶² Etienne-François Geoffroy, “Des supercheries concernant la pierre philosophale,” *Mémoires de l’Académie royale des sciences* (1722), 61-70.

⁶³ François Duchesneau and Justin E.H. Smith eds., *The Leibniz-Stahl Controversy* (New Haven, CT: Yale University Press, 2016).

⁶⁴ Karl Hufbauer, *The Formation of the German Chemical Community (1720-1795)* (Berkeley: University of California Press, 1982), 8-12; Andréa Bortolotto, “Johann Andreas Cramer and Chemical Mineral Assay in the Eighteenth Century,” *Ambix* 62:4 (2015), 312-332; Ursula Klein, *Nützliches Wissen: Die Erfindung der Technikwissenschaften* (Göttingen: Wallstein Verlag, 2016).

⁶⁵ Anita Guerrini, “The Tory Newtonians: Gregory, Pitcairne, and Their Circle,” *Journal of British Studies* 25:3 (1986), 288-311.

an erudite vision of a new chemistry based on Newton's philosophical and Stahl's chemical authority to address the literary public, which was designed to fill the noticeable gap in French didactic discourse. Although Nicolas Lemery's textbook was rather dated, no suitable replacement had appeared in the market. Sénac's combination of philosophical and chemical authorities was designed to dispel the Cartesian shadow of speculative philosophy and to shape an "experimental science" that was amenable to mathematical representation.⁶⁶ His textbook could not compete with the conventional operation manual for chemistry designed for apothecaries, but it formed an integral part of the public program of elite chemistry. In an effort to establish a predictive, useful science of chemistry for the public good, philosophical chemists condemned alchemy.⁶⁷

The evolution of chemistry as an experimental science depended, however, not on the Newtonian philosophical discourse but on a theoretical device that organized the complexifying field of salts. We must pay attention to the interlocking features of the affinity table and its use by the contemporary chemists to appreciate its unique capacity to embody *chemical* theories—reasonable hypotheses that could explain a variety of concrete chemical operations in a consistent manner—and thereby to present a uniform terrain of chemistry as an experimental science, as yet limited mostly to liquid and solid substances. Phlogiston, the infamous loser in Lavoisier's Chemical Revolution, was not a theory but a laboratory substance stabilized by its affinity relations until the 1770s when it emerged as the focus of a literary debate. Its evolutionary history can be read as a tell-tale sign of how French academic chemists transformed chemistry into an experimental science by coordinating a loose network of theories that could explain stable operations. Geoffroy included in his original table in 1718 "the sulfur principle" (different from Homberg's hypothetical principle), based on his experiments on the composition of sulfur and other metals, which was later identified with Stahl's phlogiston or the principle of inflammability.⁶⁸ In the operations Geoffroy cited, the sulfur principle or phlogiston was a substance contained in the inflammable bodies such as wood or charcoal that had the strongest affinity with vitriolic acid. In turn, Stahl discussed extensively different strengths of acids in his *Ausführliche Betrachtung und zulänglicher Beweiss von den Saltzen* (1723), which seems to have circulated in manuscript French translation well before its publication as *Traité des sels* (1771). This cross-fertilization of French pharmaceutical chemistry and German mining chemistry, accomplished through an exchange between prominent French and German physicians, gave rise to a productive

⁶⁶ Kim, *Affinity* (cit. n. 5), 174-177.

⁶⁷ Brian Vickers, "The 'New Historiography' and the Limits of Alchemy," *Annals of Science* 65:1 (2008), 127-156; Lawrence Principe, "The End of Alchemy? The Repudiation and Persistence of Chrysopoeia at the Académie Royale des Sciences in the Eighteenth Century," *Osiris* 29:1 (2014), 96-116.

⁶⁸ Kim, *Affinity* (cit. n. 5), 146-159.

period during which salts received a lion's share of theoretical and practical inquiry. The paradigmatic status of salts in eighteenth-century chemistry also made phlogiston an indispensable substance in chemical theorizing. Its composite identity—operational, theoretical, and philosophical—helped chemists to expand and to refine the chemistry of salts.⁶⁹ British chemists would develop a different understanding of phlogiston as their paths of investigation led to pneumatic studies.⁷⁰

Literary Public and Affinity Chemistry

Chemistry became a fashionable science during the High Enlightenment without explicit allegiance to Newtonianism. Guillaume-François Rouelle (1703-1770), a public lecturer at the Jardin du roi between 1743 and 1768, appropriated instead Stahl's chemical operations and Herman Boerhaave's experimental philosophy in the Boylean fashion for the native pharmaceutical tradition to project a perfect union between chemistry and medicine.⁷¹ Parisian elite chemists had been learning Stahl's chemistry of salts through concrete operations, as we have seen with Geoffroy, thereby appropriating German mining chemistry for French pharmaceutical chemistry.⁷² Although Stahl's reputation grew after moving to Berlin, French chemists did not appreciate his theoretical discourse as readily.⁷³ With a noticeable gap in the French textbook tradition, which was not effectively filled by Sénac's programmatic text, Boerhaave received strong approbation. Not only did his medical students include the baron d'Holbach who ran an influential Parisian salon, but also his didactic program for chemistry chimed closely with the French ideal of 'experimental science'—a systematic knowledge that combined positive experiments and basic axioms of natural philosophy in a manner akin to the Boylean experimental philosophy. To this end, Boerhaave incorporated physical instruments such as the thermometer and the air-pump into chemical practice. His discourse on fire indicates that he was familiar with the works of Wilhelm Homberg and Louis Lemery. In other words, Boerhaave

⁶⁹ Kim, "Instrumental Reality" (cit. n. 12); *idem*. "From Phlogiston to Caloric" (cit. n. 58).

⁷⁰ Frederic L. Holmes, "The Revolution in Chemistry and Physics: Overthrow of a Reigning Paradigm or Competition between Contemporary Research?" *Isis* 91:4 (2000), 735-753; Hasok Chang, *Is Water H₂O? Evidence, Realism and Pluralism* (Dordrecht: Springer Verlag, 2012).

⁷¹ Guillaume François Rouelle, "Cours de Chymie," Ms. NAF 4042 [Bibliothèque nationale de France, Richelieu], f. 4.

⁷² This learning process predated the so-called French Stahlism of the 1760s, outlined in Martin Fichman, "French Stahlism and Chemical Studies of Air, 1750-1770," *Ambix* 18:2 (1971), 94-122.

⁷³ Kim, *Affinity* (cit. n. 5), 168-174; Ku-Ming (Kevin) Chang, "Communications of Chemical Knowledge: Georg Ernst Stahl and the Chemists at the French Academy of Sciences in the First Half of the Eighteenth Century," *Osiris* 29:1 (2014), 135-157.

set an outstanding example for the French *savant-chimiste*, or the British philosophical chemist, who could scan a wide range of literature and shape the problem and theory domains of general significance that would elevate the cognitive and social status of chemistry. He utilized his scholastic training and disposition as a methodical reader and erudite teacher to forge a theoretical discourse that appealed to the more learned public of the early Enlightenment.⁷⁴

It is not surprising that Rouelle as a famous teacher at the Jardin du roi invoked Boerhaave's authority to present an intelligible discourse to the learned public. His lectures were attended not just by apothecaries and prospective medical students but also by the fashionable public [*le monde*] and the philosophes such as Jean Jacques Rousseau, Denis Diderot, Anne-Robert-Jacques Turgot, and the baron de Laune. Rousseau composed his own chemical work, *Les Institutions chymiques*, while Diderot opened his *Encyclopédie* to Rouelle's students who socialized at the baron d'Holbach's salon.⁷⁵ A new generation of chemists—Jean Darcet, Pierre Bayen, Antoine-Louis Brongniart, Jean-Baptiste-Marie Bucquet, Jacques-François Demachy, Jean-Philippe de Limbourg, Pierre-Joseph Macquer, and Guillaume-François Venel—also came out of Rouelle's lectures which relied on Geoffroy's affinity table.⁷⁶ In preparing for an 'analytic' table that contained a series of interrelated facts, for example, Brongniart sought to complete Rouelle's lectures in the way others sought to expand Geoffroy's table.⁷⁷ The case of Madame d'Arconville, a Tax Farmer's daughter and magistrate's wife, indicates that the utility of chemistry was broadly acknowledged among the enlightened public to attract elite patronage.⁷⁸ Teaching practice at the Jardin helped cultivate a public culture of French Enlightenment chemistry somewhat similar to the British.⁷⁹

The affinity table continued to foster a close interaction between chemical theory

⁷⁴ Kim, *Affinity* (cit. n. 5), 177-188; John Powers, *Inventing Chemistry: Herman Boerhaave and the Reform of the Chemical Arts* (Chicago: University of Chicago Press, 2012).

⁷⁵ Rousseau's *Institutions* remained as a manuscript until 1919. On Diderot and chemistry, see François Pépin, *La philosophie expérimentale de Diderot et la chimie* (Paris: Garnier, 2012); Fumie Kawamura, *Diderot et la chimie: science, pensée et écriture* (Paris: Garnier, 2014).

⁷⁶ Kim, *Affinity* (cit. n. 5), 161-168 and 188-201; Christine L. Lehman, "Gabriel-François Venel, sa place dans la chimie française du XVIII^e siècle" (Thèse, Université Paris X, 2006).

⁷⁷ A.L. Brongniart, *Tableau analytique des combinaisons et des décompositions de différentes substances ou procédés de chimie pour servir à l'intelligence de cette science* (Paris: P.F. Gueffier, 1778), "Avertissement."

⁷⁸ Mi Gyung Kim, Essay Review of Marc André Bernier and Marie-Laure Girou Swiderski eds., *Madame d'Arconville, moraliste et chimiste au siècle des Lumières: Etudes et texts inédit*, Oxford University Studies in the Enlightenment (Liverpool University Press, 2016), in *H-France* 16 (2016), No. 212.

⁷⁹ Jan Golinski, *Science as Public Culture: Chemistry and Enlightenment in Britain, 1760-1820* (Cambridge: Cambridge University Press, 1992); Larry Stewart, *The Rise of Public Science: Rhetoric, Technology, and Natural Philosophy in Newtonian Britain, 1660-1750* (Cambridge: Cambridge University Press, 1992).

and laboratory practice. In the 1760s, Pierre-Joseph Macquer (1718-1784) as the representative French chemist in charge of royal manufactories⁸⁰ and his associate Antoine Baumé (1728-1804) as a leading Parisian apothecary set the tone in the vogue of the affinity table, as seen in their constructive criticisms. Baumé complained about its limitation in accommodating the infinite number of circumstances that could change the outcome of chemical action and proposed a double table composed for the humid and the dry analysis. Macquer also called for its further elaboration that would match the progress of chemistry. Rouelle used the table in his lectures and modified it as needed. Jean Philippe Limbourg, Christlieb Ehregott Gellert and Jacques François Demachy composed their own tables to cope with this imperfect state of theory.⁸¹ A surviving wall-size "Tabula affinitatum" in the Galileo museum (oil on canvas, 1.54 m x 1.3 m), apparently commissioned (ca. 1766) by Franz Huber Hoefer for the apothecary's shop of the Grand Duke of Tuscany, attests to its usage in the pharmaceutical laboratory.⁸² Much work remains to discern exactly how the table was used and whether it facilitated pharmaceutical or industrial discoveries, although Guyton's example from a later period sheds some light (see below).

A noticeable change in French public opinion after the humiliating defeat in the Seven Years' War (1757-1763) was the feverish pitch for useful sciences, which would presumably restore France's economic and geopolitical power.⁸³ Chemistry as a necessary component of public medicine received a notable boost. The literary public's interest in chemistry can be discerned, for example, from the debate over the 'negative weight' of phlogiston. Jean-Pierre Chardenon (1714-1769), a physician member of the Dijon Academy, turned the well-known fact of the weight gain in the combustion of metals into an urgent puzzle. In the memoirs he presented to the Dijon Academy on July 15, 1763 and December 9, 1764, Chardenon criticized two existing hypotheses concerning the weight gain—the accumulation of fire or the deposit of foreign particles—and attributed it to the loss of phlogiston. Since phlogiston seemed to provide "wings" to the bodies that contained it to lessen their weights, he deemed it as "nothing other than fire itself." He called for an experiment that would establish a causal correspondence between the quantity of phlogiston and the

⁸⁰ Kim, *Affinity* (cit. n. 5), 201-212; Christine Lehman, "Pierre-Joseph Macquer: Chemistry in the French Enlightenment," *Osiris* 29:1 (2014), 245-261.

⁸¹ Kim, *Affinity* (cit. n. 5), 222-229.

⁸² <https://catalogue.museogalileo.it/object/TabulaAffinitatum.html>. Thanks to Mary Terrall for bringing this artifact to my attention.

⁸³ Seymour Mauskopf, "Chemistry in the Arsenal: State Regulation and Scientific Methodology of Gunpowder in Eighteenth-Century England and France," in Brett D. Steele and Tamera Dorland eds., *The Heirs of Archimedes: Technology, Science and Warfare through the Age of Enlightenment* (Cambridge, MA: MIT Press, 2005), 293-330; Kenneth Margerison, "Commercial Liberty, French National Power, and the Indies Trade after the Seven Years War," *Historical Reflections* 35:3 (2009), 52-73; Hamish Scott, "The Seven Years War and Europe's Ancien Régime," *War in History* 18:4 (2011), 419-455.

diminution of weight.⁸⁴ In other words, a physician's systematic reflection on the well-known facts of combustion suddenly transformed the material identity and the quantitative control of phlogiston into a critical puzzle in understanding chemical composition. A sharp rebuttal from an obscure figure, M. Ribaptome, who characterized the weight loss of bodies after gaining phlogiston as a "strange paradox," fared no better on experimental grounds.⁸⁵ This literary debate consolidated a new problem domain in chemistry—the nature of phlogiston/fire and its role in chemical composition—which made it necessary for chemists to invent new analytic methods and concepts that would work across instrumental and disciplinary boundaries.

Louis Bernard Guyton de Morveau (1737-1816) would take up the problem and produce a more systematic treatment in his "Dissertation sur le phlogistique (1772)," which made the weight of phlogiston a frontier issue in chemical theorizing and forced Parisian Academicians to take it up. As a methodical reader, he also scrutinized the basic tenets of solution chemistry to shore up the theory domain of affinity. He first scanned the literature to construct a comprehensive "chemical world map"—the "table halotechnique." It listed on the top row the category of base, four 'simple acids' and eight 'compound acids' and on the left column twenty-four different kinds of base including phlogiston to identify their compounds at each intersection. The table visualized the composition of the middle salts then known, pointing to the possible compounds not yet discovered in empty slots. In the "Essai physico-chymique sur la dissolution et la cristallization et les précipitation (1772)," Guyton sought a "mechanical explication of affinities" and a "determination of the law of attraction between constituent parts of bodies." Phlogiston occupied an important place in this scheme as the pervasive solvent of nature. He hoped to measure the quantity of phlogiston fixed in the bodies by measuring the attractive force of dissolution.⁸⁶

The Quantitative Frontier of Affinity Chemistry

As a literary chemist, Guyton sought to shape the research frontier of chemistry by synthesizing the existing literature and by injecting the Newtonian language into chemical discourse. His call for the quantitative determination of affinities was a timely one, given the rapidly increasing number of salts and the complexifying table of affinities. Torbern Bergman in Sweden tackled the problem by assuming the enormous task of updating the affinity table, which garnered admiration from Macquer

⁸⁴ *Mercure de France* (1765), 127-134.

⁸⁵ *Journal des Sçavans* (1767), 889-894.

⁸⁶ Guyton de Morveau, *Digressions académiques* (Dijon: L.N. Frantin, 1772); discussed in Kim, *Affinity* (cit. n. 5), 233-252.

and his long-distance student Guyton. Bergman's *Dissertation on Elective Attractions* listed fifty columns in the 1775 version and fifty-nine columns in the 1783 version, which required a long series of *designed* experiments to fill them. Still, the number of new acids was quickly rising and the measurements in dry and wet methods could not accommodate all of the changing laboratory conditions to afford accurate prediction. In the end, Bergman's heroic effort only made it more obvious that the affinity table could no longer function as an effective tool of prediction in the laboratory.⁸⁷ A different approach came from Richard Kirwan, an Irish lawyer who resided in London amongst a group of active chemists.⁸⁸ He proposed the saturation capacity of acids and bases as a measure of their respective affinities. Although his premise—that a given quantity of fixed alkali combined with the same quantity of all acids to produce neutral salts—was a variation of Homberg's approach in 1699, Kirwan had a distinct advantage in using the marine acid air as the analytic standard of acid-base neutralization reactions since gases could be isolated in a much purer form than other liquid acids. By utilizing the full analytic potential of pneumatic chemistry, his effort to provide the true measure of affinities opened a new analytic frontier on which was built the practice of stoichiometry and chemical atomism that would dominate early nineteenth century chemistry.⁸⁹ In short, the composition of salts became a main theoretical domain for which generations of chemists would design specific experiments. The correspondence between Kirwan and Guyton, which began in 1782, indicates how they charted the frontier research on pneumatic chemistry and its relevance to affinity studies.⁹⁰ Kirwan was working on determining numerical values for the affinities of three mineral acids. Guyton continued his effort to quantify affinities for an updated table that could help predict chemical action.

A remarkable artifact hitherto unknown, which provides a significant insight to how the affinity table was used in the laboratory, is Guyton's "Tableau physico-chimique" preserved in the archive of the Dijon Academy (see Figure 2).⁹¹ It is made of a large piece of linen (about six feet wide and five feet tall) that folds neatly into the size of a piece of paper, a material technology probably developed in portable map-making, each about six inches wide and nine and a half inches long. There are seventy-two pieces of paper pasted on it, twelve in each row. The table was meant to display the "actual knowledge of the results of the combination of bodies." The

⁸⁷ Kim, *Affinity* (cit. n. 5), 258-268.

⁸⁸ Gerard L'Estrange Turner and Trevor Levere eds., *Discussing Chemistry and Steam: The Minutes of a Coffee House Philosophical Society, 1780-1787* (Oxford: Oxford University Press, 2002).

⁸⁹ Kim, *Affinity* (cit. n. 5), 268-277; Georgette Taylor, "Tracing Influence in Small Steps: Richard Kirwan's Quantified Affinity Theory," *Ambix* 55:3 (2008), 209-231.

⁹⁰ E. Grison, M. Goupil and P. Bret eds., *A Scientific Correspondence during the Chemical Revolution* (Office for History of Science and Technology: University of California Press, 1994).

⁹¹ Archives départementales de la Côte d'Or, Ms. 128J, #202.

conventional affinity table following Geoffroy’s example only listed the components of combined salts. In contrast, Guyton’s table lists the same fifty-three substances vertically (on the left), horizontally (at the bottom) and diametrically (top left to bottom right), divided into four classes which are subdivided into several groups, to indicate their products at the intersection. The first class comprises fifteen acids—seven mineral acids (vitriolic, nitric, marine, regal, spathic, arsenic and boracic), four vegetable acids (saccharin, tartaric, oxalic and acetous) and four animal acids (Fluoric, sebaceous, phosphoric and aerial). The second class lists four alkalis—vegetable, mineral, volatile, and Prussian. The third class contains eight or nine elements—five earths (heavy, calcareous, magnesia, clayey, siliceous) and three or four fluids (water, air, fire, and phlogiston). Guyton seems to have regarded phlogiston as a fluid element and an inflammable substance, which blurs the classification. The fourth class contains twenty-six inflammable substances—three related to sulfur (phlogiston, sulfur, and foie de soufre), eight oils (spirit of wine, ether, essential oil, resin, fatty oil, bitumen, astringent principle and gum), eight metals (gold, platinum, silver, mercury, lead, copper, iron and tin) and seven semi-metals (bismuth, nickel, arsenic, cobalt, zinc, antimony and manganese).

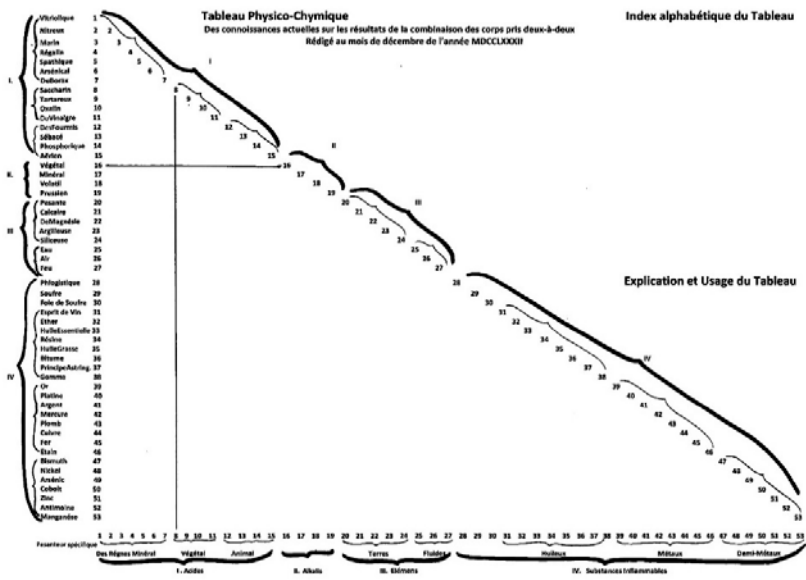


Figure 2. An overview of Guyton’s physico-chemical table made in 1782. Archives départementales de la Côte d’Or, Ms. 128J, #202.

Apparently fashioned in the manner of Pythagoras’s table according to the explanation at the right bottom corner, the arrangement produces 1,378 boxes. Each box

at the intersection of a substance listed on the left vertical column and another listed on the horizontal column contains their compound or mixture with its specific weight, written in red color. The first column headed by vitriolic acid thus contains its mixture or combination (some unknown)—mixed acids, vitriols (vitriolic acid plus alkali or inflammable substances), etc. Each substance, having combined with the substance that precedes it in the same column on the horizontal line, will combine with those that come after it. The alphabetical index (see Figure 3) on the right side of the table contains the summary of analysis and synthesis. To find a combination of two substances (e.g. nitric acid and vegetable alkali, which produces niter), one finds each on the Index—2 and 0 for nitric acid, and 16 and 0 for vegetable alkali. Since the table is diagonally cut, the substance with smaller number should always be used to locate the vertical column (nitric acid heads the second column) and the substance with the larger number, for the place in that column (vegetable alkali is 16th). One can also find out what a substance is made of. Sublimated corrosive has numbers 3 and 42 in the Index, which points the reader to the box located at the third column (headed by marine acid) and 42nd row (mercury).

INDEX ALPHA	
A	E
Acide Aërien	Eau Régale
Arténical	Vernisfuge
Borax	de Vie
des Fourmis	Email
Marin	Emplâtre
Marin Déphlogistique	Emulsion
Nitreux	
Oxalin	Kuere
Phosphorique	de Sympathie
Phosphorique Dulcifié	Enduit de Vernier
Régalin	Espirit de Minderefus
Saccharin	de Nitre dulcifié
	Sulfureux volatil de Sagesse
	de vin
	de Vitriol dulcifié
	Volatils Aromatiques
	Etain
	Etamage
	Ether
	Acetueux
	Animal
	Fixé
	Marin
	Nitreux
	Oxalin
	Succine
	Vitriolique
	Extrait de Saturne

Figure 3. Index of Guyton's physico-chemical table

A sign of active use can be found in each box. In addition to the specific weight (in comparison to pure water at average temperature) where available, it often contains other substances (noted in symbols) and their affinities (expressed in numbers). In the box that contains niter (see Figure 4), its specific weight is given as 1,900. The sign of water (left top) with the number 4 underneath indicates that it takes four times of water in weight to completely dissolve niter at room temperature (12-15 degrees of the thermometer). Other elements (in symbols) are also written in with corresponding numbers (in red) to indicate the combining proportions of the elements or proximate principles [*les principes prochains*] of niter. The word clay [*aigilles*] indicates that niter congeals in clayish form.

	1. Acide Vitriolique	2. Acide Nitreux	3. Acide Marin
16. Alkali Végétal	Tartre Vitriolé décrepité	Nitre	Sel de Sylvius
17. Alkali Minéral	Sel de Glauber	Nitre Cubique	Sel Commun décrepité
18. Alkali Volatil	Vol. Ammoniacal Décrepité	Nitre Ammoniacal	Sel Ammoniac

16 ³ 16 2,298 Tarte Vitriolé décrépité 32. Pril 6. gones. 2. à Ry. 6. Edres. 40.	¹ 4 1,900 Nitre 56. 18. 40. Aiguilles	³ 8 Sel de Sylvius décrépité 31. 8. 61. cubes
17 ² 24 2,246 Sel de Glauber 27. 38. Pril 6. gones. 12. Irreguliers	¹ 4 Nitre Cubique	² 12 2,143 Sel Commun décrépité 32. 42. cubes trémies
18 ² Vol. Ammoniacal décrépité un pendetiq Pril. 6. Edres	¹ 4 Nitre Ammoniacal Delia Tabl 6. g. Edres à l'omniery, Edres	³ 12 1,488 Sel Ammoniac en barbes de Plume

Figure 4. Combination of common acids and alkalis

Given the date (December 1782), the table must have been a part of Guyton's writing process for the articles in the first chemistry volume of the *Encyclopédie méthodique* (pub. 1786) on acid, adhesion, affinity, and air—the subjects that constituted the contemporary frontier of chemical research and reform efforts. Fully aware of the interrelated developments in these subjects, Guyton wished to unite all knowledge of ancient and modern chemistry to establish a *theoretical order that*

would be independent of particular hypotheses. As the most common instrument of chemical operation, acids shaped the contour of the science. They should therefore serve as the foundation for a general system of chemistry. Guyton apparently suspected that vital air entered into the composition of all acids as a constituent part, or that it was the "true universal acid" of all twenty-eight acids then known—a point of view Lavoisier shared, judging from his emergent oxygen theory of acids for which Guyton claimed partial priority. The affinity table had opened in his view "the first age of science" for chemistry, setting it apart from the art consisting of trial-and-error recipes. By placing all accumulated knowledge at the chemist's fingertip, the table made chemistry into a "science" that could explain its procedures and predict their results. In order to predict complicated reactions, however, it was necessary to determine the affinities in numbers. Whenever there came into contention more than three bodies, he had to consider all competing affinities to determine the outcome rather than the simple affinity of one body to another. Lacking reliable numbers or methods of determining them independent of one another, Guyton approximated them to provide a reasonable set of starting numbers that did not contradict the known affinity relations. The saturation point of two bodies, the thread picked up by Kirwan, was a recurrent point of reflection since it could fix the composition of compounds.⁹²

Epilogue

European theoretical chemistry was fundamentally transformed in the late 1770s by the three literary chemists—Guyton de Morveau in France, Richard Kirwan in Britain, and Torbern Bergman in Sweden—who represented the analytic frontier of affinity chemistry. Once we recognize the importance of affinity in their shared vision, Lavoisier's revolution can be assessed in a different light, perhaps as a 'rhetorical moment' when the master Academician sought to consolidate his leadership and set a new direction for research within the Academy.⁹³ Although his trajectory to the Chemical Revolution has been minutely studied,⁹⁴ his interaction with Guyton and other chemists of his generation has not been prominently featured in the conventional stories. If we soften the spotlight on Lavoisier, Guyton's case illustrates particularly well how chemistry became an experimental science that could serve the

⁹² Kim, *Affinity* (cit. n. 5), 356-370.

⁹³ Mi Gyung Kim, "Constructing Symbolic Spaces: Chemical Molecules in the Académie des Sciences," *Ambix* 43:1 (1996), 1-31; *idem*. "Lavoisier, the Father of Modern Chemistry?" In Marco Beretta ed., *Lavoisier in Perspective* (München: Deutsches Museum, 2005), 167-191.

⁹⁴ Henry Guerlac, *Lavoisier – The Crucial Year: The Background and Origin of the First Experiments on Combustion in 1772* (Ithaca, NY: Cornell University Press, 1961); Frederic L. Holmes, *Antoine Lavoisier – The Next Crucial Year*. (Princeton: Princeton University Press, 1998).

state and the public through a set of literary, didactic and laboratory practices, which created a symbiotic relationship between theory and experiment.⁹⁵

In order to become an experimental science, chemistry had to develop the capacity to define its own objects of inquiry, to predict their behavior, and to represent them in a systematic fashion to the public and the state. Medical utility provided the institutional matrix and a path of social legitimation for chemical expertise. While the Académie royale des sciences promoted research in the three medical sciences of botany, chemistry and anatomy, the Jardin du roi maintained prestigious public lectures in these fields.⁹⁶ Chemistry and medicine were supposed to form a perfect union, as Rouelle declared in his lectures at the Jardin. Less well known, but no less important, was the development of the pharmaceutical and related businesses which supplied starting materials for a sustained theoretical inquiry. Guyton's and other literary chemists' capacity to engage in a theoretical debate involving Parisian chemists depended on the chemical substances distributed by Parisian master apothecaries, especially by Antoine Baumé. Correlating a literary debate with the laboratory reality required a reliable supply of starting materials for those conducting experiments at a distance from the acknowledged 'center of calculation', notwithstanding Bruno Latour's focus on inscriptions.⁹⁷ In the nineteenth century, Justus Liebig would carry on his theoretical dispute with the representative Parisian chemists such as Jean-Baptiste Dumas by starting with the chemicals supplied by Parisian apothecaries. It was less an extraordinary vision than his immediate need as a Paris-trained chemist that turned Liebig's attention to domesticating the supply of pharmaceuticals.⁹⁸

The transformation of a pharmaceutical art into a state-sponsored experimental science in France involved not just laboratory practices but also teaching and literary practices which organized an extensive array of practical operations into a set of facts that could support an intelligible order of nature. The elite chemists' effort to systematize their laboratory practices and represent them in an intelligent fashion made chemistry an autonomous field of inquiry with a degree of institutional prestige and public patronage, free from the metaphysical concerns of natural philosophy and the exclusive instrumental practice of experimental philosophy. In other words, the symbiosis between theory and experiment that privileged a model system (displacement reactions) and a representative theoretical scheme (the affinity table) was engendered by a set of laboratory, literary and teaching practices which shaped chemistry's identity and social status and laid the groundwork for modern chemistry.

⁹⁵ Kim, *Affinity* (cit. n. 5), 300-455.

⁹⁶ Stroup, *Company of Scientists* (cit. n. 4); Guerrini, *Courtiers' Anatomists* (cit. n. 4).

⁹⁷ Bruno Latour, *Science in Action: How to follow scientists and engineers through society* (Cambridge, MA: Harvard University Press, 1987).

⁹⁸ Kim, "Constructing Symbolic Spaces" (cit. n. 94); William H. Brock, *Justus von Liebig: The Chemical Gatekeeper* (Cambridge: Cambridge University Press, 1997).

Enlightenment chemistry set a significant precedent for modern experimental sciences by cultivating a symbiosis between practice-oriented theories and theory-oriented experiments, by endorsing the utilitarian purpose of 'science' and state sponsorship, and by developing a literary public for its esoteric practice. In the 1780s, pneumatic chemistry engendered a mass public through the balloon ascents, which also helped Lavoisier's maneuvers to legitimize his new system of chemistry.⁹⁹ With the articulation of stoichiometric laws and the advent of organic classification, Jean-Baptiste Dumas could declare the end of traditional chemical philosophy by the 1830s and characterize the investigative process of chemistry as a methodical one proceeding from a hypothesis to a theory, then to a law with increasing breadth and certainty of application.¹⁰⁰ Few would have doubted by then chemistry's pre-eminence as a model experimental science whose methods could transform the practice of other aspiring scientific fields, especially pharmacy and medicine.¹⁰¹ The conception of physiology as an 'experimental science' had already emerged by the turn of the nineteenth century.¹⁰² Claude Bernard staged a full-scale public campaign in the 1870s to subject living beings to an experimental method comparable to that of physico-chemical sciences with "absolute and necessary determinism."¹⁰³ In the way Robert Boyle had insulated experimental philosophy from metaphysical questions, Bernard dissociated experimental physiology from the questions regarding the first cause of life. In his opinion, an 'experimental science' only sought to attain the physico-chemical conditions that determine vital activity, not to answer the question of why such activity commenced. Chemistry (and later physics) set the standards for modern experimental sciences, although the pattern of centralized state patronage cultivated in absolutist France lost its efficacy to that of multi-centered German universities in the nineteenth century.¹⁰⁴

⁹⁹ Mi Gyung Kim, "'Public' Science: Hydrogen Balloons and Lavoisier's Decomposition of Water," *Annals of Science* 63:3 (2006), 291-318.

¹⁰⁰ Jean-Baptiste Dumas, *Leçons sur la philosophie chimique* (Paris: Ébrard, 1837).

¹⁰¹ Jonathan Simon, *Chemistry, Pharmacy and Revolution in France, 1777-1809* (Aldershot: Ashgate, 2005).

¹⁰² Charles Louis Dumas, *Principe de physiologie, ou introduction à la science expérimentale, philosophique et médicale de l'homme vivant* (Paris: Deterville, 1800-1803).

¹⁰³ Claude Bernard, *La science expérimentale* (Paris: J.B. Baillière & fils, 1878), 40; Mirko Grmek, *Claude Bernard et la méthode expérimentale* (Paris: Payot, 1991).

¹⁰⁴ Alan Rocke, *The Quiet Revolution: Herman Kolbe and the Science of Organic Chemistry* (Berkeley: University of California Press, 1993).

Abstract

This article argues that French royal institutions such as the Jardin du roi and the Académie royal des sciences helped transform chemistry into an ‘experimental science’ during the French Enlightenment. By establishing a loose coordination between public teaching and systematic research, French elite chemists cultivated a symbiotic relationship between chemical theory (the affinity table) and model experiments (displacement reactions) to transform chemistry into a ‘science’—a genre of systematic knowledge that could be codified and communicated to the literary public and contribute to the maintenance of the state. This development under the most advanced absolutist regime calls for a different understanding of the relationship between science and the Enlightenment.

Keywords: Chemical philosophy, Experimental science, theory, affinity table, experiment, phlogiston, Chemical Revolution, Guyton de Morveau, Lavoisier