To Affinity and Beyond: Tables, Textbooks, and the Disciplinary Development of Chemistry in Eighteenth-Century Europe

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1 April 2019

TABLE OF CONTENTS: OR, THAT THROUGH WHICH WE SHALL EXPLORE THE CONTENT OF THE TABLE:

AKNOWLEDGEMENTS

To all of those who have helped me along the way, I would like to express my sincere gratitude. When I first began this project, I never imagined it coming so far, and I would like to take this space to recognize that this was only made possible through the help of countless colleagues, mentors, and friends. First and foremost, I would like to thank the Yale Department of the History of Science, Medicine, and Public Health for continually reminding me why I love to study these messy, challenging, and vital topics. The freedom I have been afforded over the years has introduced me to so many new perspectives and new areas of interest, all of which has helped me to grow into not only a better student, but also a better individual.

No other time has perhaps been as transformative for me as this year, and I owe many of these positive changes to my infinitely patient advisor, Professor Chitra Ramalingam. I cannot thank Professor Ramalingam enough for her continual support and understanding, especially at the times when I felt I was undeserving of such kindness. While the guidance and resources she provided during this project were instrumental to its completion, I will always be thankful to Professor Ramalingam for her unwavering yet gentle compassion.

To B&M, thank you for providing me with a common room where I could go to avoid my problems, or, more often than not, to make different, but even more significant, ones. To Alison, thank you for indulging my requests to go on late night walks to help me clear my head. You are some of the most remarkable people that I know, and I appreciate every day I get to call you my friends. To my family, thank you for being the home I can always go back to when life starts to become too much. Finally, to affinity and…well, you know the rest.

"The doctrine of chemical affinity is unquestionably
the great and distinguishing principle of the science of
chemistry as the laws of motion are of mechanical philosophy"
–Joseph Black, 1803

INTRODUCTION

A fuming mixture of rust-colored compounds bubbles at the front of a crowded Glasgow University lecture hall in 1749. Standing beside his concoction, the lecturer, a poised and bewigged gentleman by the name of William Cullen, explains how introducing a liquid sample of aqua fortis to a solid sample of brown potash instantly sets this reaction in motion. The production of fumes, Cullen emphasizes, is evidence of the sensible heat that this reaction generates, and indicates the successful combination of its substituents. The mixture soon stops bubbling and a new, solid white substance, which Cullen identifies as saltpeter, is left behind. He lifts this sample into the air to show all of his students the change the original solid has undergone. Continuing his demonstration, Cullen introduces another liquid to this solid; in this instance, it is the acidic oil of vitriol which suddenly causes the saltpeter to effervesce and evolve even more significant fumes. With the attention of every student focused on him and his lively display of frothing materials, Cullen utilizes this moment to explain how qualities of substances can be changed by combination and separation, transformative properties which, he declares, are reflective of the natural tendency of all substances to approach or depart one another through elective attraction.[1]

For the next twenty years, William Cullen would continue to use this demonstration and its accompanying lecture to introduce his students to the concept of chemical affinity and its role in the behavior of chemical reactions.[2] Indeed, the life and lectureship of William Cullen span a highly transformative time for the development of chemistry as an academic field, and this demonstration that he presented before his students at Glasgow University represents one of the

[1] Fragment of a lecture given by William Cullen on Saltpetre, Aquafortis, and Elective Attractions, Separating and Combining, 1749, MS 1060, Cullen Papers, Glasgow University Library, Glasgow.
[2] Notes taken by Sir Charles Blagden from Lectures on Chemistry, 1766, MS 1922, Blagden Collection, Wellcome Library for the History and Understanding of Medicine, London.

earliest instances of institutionally organized chemical education in Europe.[3] Over the course of the eighteenth-century, chemistry transitioned from a publicly-defined art to a recognized, academic science.[4] Much like the messy and multilayered chemical reactions put on display by William Cullen, however, this disciplinary transition was neither a simple nor a linear progression. Analyzing this specific period in history, therefore, requires careful attention to and consideration of confounding, and often convoluted, developments. These linguistic, technological, and practical developments occurred not only within the physical spaces of the laboratories, classrooms, and businesses where chemistry was used, but also in the complex social networks of those who were practicing, teaching, and learning the chemical arts.

One of the most significant forms of expression capable of reproducing and representing the complicated social and practical aspects of this emerging field was the chemical affinity table. First compiled by the French chemist Etienne-François Geoffroy in 1718, this literary technology sought to symbolically and structurally organize experimentally derived information regarding the reactive relationships between several different chemical substrates.[5] While this initial organizational goal was readily achieved by Geoffroy's table, its creation had the secondary effect of establishing a specifically structured space that influenced how chemical knowledge was generated, organized, and expressed. This enabled these diagrammatic tables to

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[3] Georgette Taylor, "Variations on a theme: patterns of congruence and divergence among 18th century chemical affinity theories," (PhD diss., University College London, London, 2006), 67.
[4] Lissa Roberts, "Setting the Table: The Disciplinary Development of Eighteenth-Century Chemistry as Read Through the Changing Structure of Its Tables" in *Literary Structure of Scientific Argument*, Peter Dear, ed., (Philadelphia: University of Pennsylvania Press, 1990), 99.
[5] Several scholars have identified this initial purpose of chemical affinity tables as devised by Geoffroy. See: Alistair Duncan, *Laws and order in eighteenth-century chemistry* (New York: Clarendon Press, 1996), 201-210; idem, "Some Theoretical Aspects of Eighteenth-Century Tables of Affinity," *Annals of Science*, 18, (1962): 177–194; Benjamin R. Cohen, "The Element of the Table: Visual Discourse and the Preperiodic Representation of Chemical Classification," *Configurations*, 12, no. [1] (Winter 2004): 47.

popularize the theory of chemical affinity as chemistry expanded its reach geographically, intellectually, and academically.

In this essay, I seek to trace historically the emergence and use of chemical affinity tables from their first appearance in 1718 until their fall from favor during the 1860s with the rise of theories of periodicity. The extensive use of chemical affinity tables across Europe during this time period directly coincides with the development of chemistry as a distinct academic discipline, signaling a potentially meaningful correlation. Unfortunately, however, discussions of the history of chemistry rarely acknowledge the complicated and dynamic relationship between the physical construction of these tables and the abstract, intellectual construction of chemistry.[6] Current scholarship on visual anthropology has reflected these ideas to show that the designers of research and teaching diagrams do not see their creations as timeless abstractions, but that these designers instead imbue their diagrams with influences from both natural knowledge and visual culture.[7] Accordingly, when such tables are reproduced in media, including textbooks and lecture notes, the beliefs of both their creators and users, in addition to the initial purpose for their creation, are also perpetuated. As the historian Christopher Ritter explains,

> Paper is not a two-dimensional window that vanishes as chemists view the micro-world that lies beyond its surface. What is inscribed upon the page compels chemists' engagement in an increasingly visual practice of chemistry, and a historical logic of practices that extend in space and time well beyond the page.[8]

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[6] Though several scholars have produced works tracing the relationship between the emergence of chemical affinity tables and chemistry as a disciplined form of study, I have not found any which acknowledge the specific expansions and contractions of the discipline in relation to this tabulated instrumentation that I discuss. Lissa Roberts explores how chemists practiced manipulation and rearrangement to establish discipline within chemistry, while Alistair Duncan has elucidated how chemical tables were useful for chemists in the creation of unique objects of study. See: Cohen, "The Element of the Table," 47; Roberts "Setting the Table," 99-132; idem, "Filling the Space of Possibilities: Chemistry's Transition from Art to Science in the Eighteenth Century," *Science in Context,* 6, (1993): 511–553; Duncan, *Laws and Order,* 1-253.

[7] Matthew Eddy, "How to See a Diagram: A Visual Anthropology of Chemical Affinity," *Osiris*, 29, no. [1] (2014): 179.

[8] Christopher Ritter, "An Early History of Alexander Crum Brown's Graphical Formulas," in *Tools and Modes of Representation in the Laboratory Sciences,* Ursula Klein, ed., (Dordrecht: Springer Science and Media, 2001), 43.

Understanding chemical affinity tables in this manner suggests that these repositories for experimental knowledge served complex roles in the recording of experimental observations, the perpetuation of chemical theories, and the creation of new methods of scientific inquiry for chemistry as a discipline in the eighteenth-century. Within this essay, I intend to show how affinity tables had the unique ability to facilitate a discourse not only between teachers and students, but also between competing international approaches to chemistry over time. These tables thus became the communicative and predictive frameworks that bridged the practical nature of chemistry as an art with the contemporary demands of a science based on theory.

It is unsurprising that previous research in the history of chemistry has traced extensively the emergence of chemistry as a scientific discipline. Through their main focus on the historical divergence of chemistry, on the one hand, from the artisanal practices of alchemy, and, on the other, from the dominant contemporary theories of the mechanical arts, several scholars have characterized various pillars of, as it is often termed, an eighteenth-century chemical "revolution."[9] My analysis seeks to refine this collection of scholarship through the assertion that narratives of revolution often fail to recognize the value of persistent and pervasive tools exemplified by these affinity tables. Furthermore, when considering this question of disciplinary emergence, I have chosen to evoke the notion of "boundary-work," that, as defined by sociologist Thomas Gieryn, describes the practical efforts made by scientists to distinguish their

[9] For general discussions of the historical emergence of chemistry, see: Duncan, *Laws and Order*, 1-253; A. J. Berry, *From Classical to Modern Chemistry*: *Some Historical Sketches* (Cambridge: Cambridge University Press, 1954), 1- 250; Joseph S. Fruton, *Methods and styles in the development of chemistry* (Philadelphia: American Philosophical Society, 2002), xviii-332. For discussions that invoke the narrative of a revolution, see: Catherine Jackson, "The 'Wonderful Properties of Glass:' Liebig's *Kaliapparat* and the Practice of Chemistry in Glass," *Isis*, 106, no. [1] (March 2015), 43; Robert Siegfried, "The Chemical Revolution in the History of Chemistry," *Osiris*, 4 (1988), 34-50; Hasok Chang, "Water and the Chemical Revolution," in *Is Water H_2O?* Boston Studies in the Philosophy and History of Science, vol. 293, (Dordrecht: Springer, 2012), 1-70; Maurice Crosland, "Chemistry and the Chemical Revolution," in *The Ferment of Knowledge: Studies in the Historiography of Eighteenth-Century Science*, George Sebastian Rousseau and Roy Porter, eds., (Cambridge: Cambridge University Press, 1980), 389-416.

field from other intellectual pursuits.[10] The creation of these chemical affinity tables, then, offers a highly interesting example of both literal and figurative boundary-work: in their continual revisions of the boundaries of the table and the substances it included, chemists were also establishing new boundaries for chemistry as a profession. The divergence of chemistry from similar academic and artisanal disciplines only occurred through the careful combination of practical, demonstrative qualities with predictive theoretical elements made possible by the gradual *evolution* of chemical affinity tables during the eighteenth-century.

Understanding how chemical affinity tables change over time, however, is not as simple as drawing comparisons between the differing appearances of these charts during the course of the eighteenth-century. The theoretical framework of "paper tools," first introduced by Ursula Klein to discuss the significance of chemical formulas in the nineteenth-century, proves to be an especially productive method for a more nuanced conceptualization of chemical affinity tables.[11] As "resources whose possibilities are not exhausted by scientists' attempts to achieve existing goals, but rather whose applications generate new goals," paper tools reflect the simultaneous material, performative, and generative culture that is present in each iterative appearance of the chemical affinity table over time.[12] Literature that is focused on the analysis of diagrams, nomenclature, tables, and charts with respect to how these techniques of categorization and visual organization affect the individual phenomena that they describe, however, have rarely considered the chemical affinity table.[13] Accordingly, I plan to apply these theoretical

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[10] Thomas F. Gieryn, "Boundary-Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists," *American Sociological Review* 48, no. [6] (1983), 781.
[11] Ursula Klein, "The Creative Power of Paper Tools in Early Nineteenth-Century Chemistry," in *Tools and Modes of Representation in the Laboratory Sciences*, Ursula Klein, ed., (Dordrecht: Springer Science and Media, 2001), 13.
[12] Ritter, "An Early History," 42.
[13] Much work has instead been completed on molecular formulas and the Periodic Table and periodic system. See Klein et al., *Tools and Modes of Representation in the Laboratory Sciences*, ed. Ursula Klein (Dordrecht: Springer Science and Media, 2001), 1-237; Ursula Klein and Carsten Reinhardt, eds. *Objects of Chemical Inquiry* (Sagamore

frameworks to show that chemical affinity tables were more than simple pictorial representations of information that could be communicated orally. Instead, they were sites for forms of experiment and prediction that intangibly combined the practical and theoretical natures of chemistry in order to allow it to continually redefine and refine its boundaries as a scientific field.

It is necessary to highlight that the development of chemical affinity tables, as this paper will show, is not a linear path from an initial imperfect representation to an ideal, universally accepted one. The implication of a paper tool additionally, "Rejects expectations that laboratory scientists might over time select those particular modes of representation which are generally regarded to be 'rational,' i.e. belonging to the logical type of sign systems," making this framework an incredibly robust option for the analysis of these diagrammatic tables.[14] As this paper follows the expansion, contraction, revision, and redesign of chemical affinity tables in their movement from France to Great Britain and the Baltic region, I intend to highlight how affinity tables transitioned from mere repository sites to tools for discussion, education, and, eventually, experimentation. Along the way, several actors will be identified in order to examine how their individual goals influenced their uses of chemical affinity tables, and how these differences came to shape the tables themselves as well as the disciplinary boundaries of chemistry.

Indeed, because this paper explores a time period before chemistry was an established field with explicit and consistent disciplinary borders, the appearance, practice, and influence of

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Beach, MA: Watson Publishing International LLC, 2014) 1-382; Mary-Jo Nye, "Paper Tools from the 1780s to the 1960s: Nomenclature, Classification, and Representations," *Ambix*, 65, no. [1] (2018), 1-8.

[14] Ursula Klein, "Introduction," in *Tools and Modes of Representation in the Laboratory Sciences*, Ursula Klein, ed., (Dordrecht: Springer Science and Media, 2001), ix.

chemistry in various geographic locations had subtle differences. Throughout this paper, I will make use of the term "chemist" to describe those who practiced or taught these organized scientific activities. Some historians find this usage to be anachronistic, since the individuals carrying out chemical work at this time would have hardly applied this term to themselves, while the field of chemistry itself was not clearly demarcated from other practices.[15] However, my application of the term "chemist" has the dual function of providing expediency while also highlighting that I am principally concerned with understanding the *chemical* activities of the actors I introduce. In a similar manner, the term "chemistry" will also be employed as a broad encompassing term to allow for expediency and to continually reinforce the trend toward the emergence of chemistry as a distinct, autonomous scientific field.

Before examining how chemical affinity tables impacted the practice of chemistry, it is useful to provide context for the various geographic approaches to the discipline as well as the major actors present in these areas. This essay will travel to three major regions: Great Britain, the Baltic region, and France. In Great Britain, chemistry was most readily and often *practiced*, rather than considered on a simple theoretical basis. Chemical texts of the time are notable for their reproductions of chemical experiments, which provided instructions for the reader to carry them out in the form of direct descriptions of experiments from a public witness.[16] Even in an academic setting, lecturers, most significantly William Cullen and Joseph Black, both of

[15] For commentary on anachronisms in historical discussions of science, see: Nick Jardine, "Uses and Abuses of Anachronism in the History of the Sciences," *History of Science*, xxxviii, (September 2000), 252-270. I have modelled my use of the term "chemist" after that outlined by Georgette Taylor, found in: Taylor, "Variations on a theme" 10.

[16] Brian Dolan, "The Language of Experiment in Chemical Textbooks: Some Examples from Early Nineteenth-Century Britain," in *Communicating Chemistry: Textbooks and Their Audiences, 1789-1939*, vol. 3, Anders Lundgren and Bernadette Bensaude-Vincent, eds., (Canton, MA: Science History Publications, 2000), 141-165.

Scotland, would engage their students by performing demonstrative experiments, or representations of experiments, in their classrooms.[17]

At this same time in Sweden and Germany, however, scientists approached chemistry with much more conscious attention to both theoretical and practical perspectives. Torbern Bergman, writing in his chemical textbook of 1775, reproduced diagrams found in the lecture notes of Cullen and Black to popularize these demonstrative techniques within a more theoretical context.[18] His textbook is also notable for its inclusion of updated versions of affinity tables in successive publications, showing how theory was continually adapted as new experiments were completed.[19] J.J. Berzelius, another Swedish author writing at this time, took this method of reproduction a step further and expanded on the framework provided by chemical affinity tables to suggest reaction ratios that were governed by proportions.[20] These two prominent scientists produced several landmark texts which, as I will later elaborate, are representative of the theoretical and practical approach that was characteristic of general Baltic understandings of chemistry.

Finally, in France, scientists adopted an approach that placed an even greater emphasis on theory than either of the two previously described regions. Here, Geoffroy created tables that, although experimentally derived, suggested predictions for future reactions and initiated a new

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[17] See, for example: Joseph Black, *Notes from Dr. Black's Lectures on Chemistry 1767/8 Thomas Cochrane*, ed. Douglas McKie (Imperial Chemical Industries Limited, Pharmaceuticals Division: Cheshire, 1966), 43; Cullen, "Lecture on Saltpetre;" idem "The Plan of a Course of Chemical Lectures and Experiments to be Given in the College of Glasgow during the Session MDCCXLVIII," 1748, MS 1069, Cullen Papers, Glasgow University Library, Glasgow.

[18] Torbern Bergman, "A Dissertation on Elective Attractions. By Torbern Bergman. Late Professor of Chemistry at Upsal, and Knight of the Royal Order of Vasa. Translated from the Latin by the Translator of Spallanzani's Dissertations. London, Printed for J. Murray, No. 32, Fleet Street; and Charles Elliot," in *A Source Book in Chemistry: 1400-1900*, Henry Leicester and Herbert Klickstein, eds., (Cambridge, Mass.: Harvard University Press, 1952), 95.

[19] Henry Leicester and Herbert Klickstein, eds., *A Source Book in Chemistry: 1400-1900* (Cambridge, Mass.: Harvard University Press, 1952), 92.

[20] J.J. Berzelius, "On the Chemical Signs, and the Method of Employing Them to Express Chemical Proportions." *Annals of Philosophy*, *3*, (1814): 51-52.

visual culture of chemistry, while Claude-Louis Berthollet built upon the theory of chemical affinities to suggest and then experimentally demonstrate the directionality of chemical reactions, their dependence on substrate masses, and the existence of chemical equilibria.[21] Guyton de Morveau and Antoine Lavoisier, working at the end of the eighteenth-century, transformed the original appearance of Geoffroy's chemical affinity table in order reconfigure the information that could be presented.[22] The differences in the state of chemistry in each of these regions suggests the heterogeneous appearance of the field during the eighteenth-century. This provides the foundation upon which these various actors and their contemporaries constructed chemistry as a scientific discipline through the international and intergenerational communication fostered by chemical affinity tables.

In order to trace how these affinity tables travelled over time and overseas, I have decided to designate the chemistry textbooks that contained them as my final area of interest. Significant work has been completed regarding the development of chemistry textbooks in the eighteenth-century to suggest that they were novel forms of chemical communication that were different from scientific papers, journal publications, and alchemical writing.[23] Moreover, a broad range of analysis has previously been completed on scientific textbooks as a form of communication and knowledge reproduction.[24] I intend to introduce and modify these dominant theories within my

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[21] Etienne-François Geoffroy, "Table des différents rapports observés en Chimie entre différentes substances" in *Mémoires de l'Académie royale des sciences* (1718): 202-212; Claude-Louis Berthollet, "Essay on Chemical Statics, with copious explanatory Notes and Appendix on Vegetable and Animal Substances," R. Lambert, trans., in *A Source Book in Chemistry: 1400-1900*, Henry Leicester and Herbert Klickstein, eds., (Cambridge, Mass.: Harvard University Press, 1952), 193-205.

[22] Louis Bernard Guyton de Morveau et al., "Méthode de Nomenclature Chimique, Purposée par MM. de Morveau, Lavoisier, Bertholet, & de Fourcroy. On y a joint Un noveau Systême de Caractéres Chimiques, adaptés á cette Nomenclature, par MM. Hassenfratz & Adet," (Paris, 1787), 1-69; Antoine Laurent Lavoisier, "*Traité élémentaire de chimie*," (Paris, 1789): 208, 212, 216.

[23] John Hedley Brooke, "Introduction: The Study of Chemical Textbooks" in *Communicating Chemistry: Textbooks and Their Audiences, 1789-1939*, vol. 3, Anders Lundgren and Bernadette Bensaude-Vincent, eds., (Canton, MA: Science History Publications, 2000), 1-17.

[24] Thomas Kuhn, *The Structure of Scientific Revolutions*, (Chicago: University of Chicago Press, 1962), 136-138; Marga Vicedo, "Introduction: The Secret Lives of Textbooks," *Isis*, 103, no. [1], (March 2012): 83.

narrative by suggesting that the chemical textbook at this time was a dynamic space that challenged students and teachers to actively engage with and critically analyze its contents. This, in turn, established an environment where chemical affinity tables were continually reproduced, discussed, and revised, thereby promoting the active boundary-work required to demarcate chemistry as an autonomous science.

This essay thus follows the complex narrative of chemical affinity tables through their use in chemistry textbooks and classrooms across Europe in the eighteenth-century. Beginning by explaining the historical emergence of the chemical affinity table and its early uses, I will analyze the representational structure of Geoffroy's first published table. Having shown that the presentation of information in this form explicitly encouraged the use of chemical affinity tables as educational and practical tools for chemists, I will revisit the aforementioned international regions to highlight their differing concepts of chemistry and more critically analyze how chemistry was practiced, taught, and valued in the representative regions of Great Britain, France, and the Baltic states. I will then proceed to examine how the tables themselves began to appear in textbooks and, in turn, popularize theories of chemical affinities. By following the movement of chemical affinity tables within textbooks, I will show how networks of communication between scientists themselves and, more subtly, within translations of scientific textbooks were established. From there I will then examine how these scientific texts were used as dynamic instruments within classrooms, as popularizers of theories throughout the world, and as sites of evolution for chemical affinity tables themselves. Bringing all of this together, I will finally demonstrate how chemistry emerged as a unified discipline through the relationship between the visual organization of information and its active use. Chemical affinity tables effectively exploited this relationship to become sites of both experiment and communication.

This essay aims to combine historical analyses with visual anthropological studies in order to examine the role of chemical affinity tables in the development of chemistry as an autonomous discipline in Europe during the eighteenth-century. These tables are usefully understood as participating in the active daily practice of chemistry; in much the same way that a chemist would use a balance or reaction flask, these tables became valuable instruments for teachers and students alike to generate new forms of chemical knowledge. Invoking the words of Ritter once again:

> Representation has no existence in the absolute, nor in a void. Any representation is both utilitarian and self-referential. Since any representation is purposeful, to detach it from its original practical use is a methodological bias as reprehensible as removing it from its historical context.[25]

I thus aim to evaluate the changing purposes of chemical affinity tables with careful attention to the various contexts from which they emerged. Within the history of chemistry, these tables initiated the legacy of ordering chemical information on paper and, for the first time, organized teaching and learning chemistry from these two-dimensional surfaces. They drove investigative practices arising out of representation, and in turn, served as a fundamental component of the disciplinary structure of the chemical science.

I. SETTING THE TABLE

While it would be beyond the scope of this essay to characterize fully the states of the mechanical arts and alchemy, the intellectual predecessors to chemistry leading up to the eighteenth-century, it is valuable to describe the general practices associated with these fields in order to establish the context from which chemistry as a science emerged. Between the twelfth- and sixteenth-centuries, alchemy was practiced as an art that sought the transmutation of metals

[25] Ritter, "An Early History," 43.

while simultaneously proposing a series of theories based on philosophical and cosmological suppositions.[26] This tension between artisanal practice and theoretical foundations caused the status of alchemy to be highly problematic. In an effort to alleviate this tension and raise the status of alchemy to that of *scientia*, scholars during the Renaissance delineated three different kinds of alchemy: the true, the sophistical, and the false.[27] By the sixteenth-century, true alchemy had transformed into practical chemistry in the form of metallurgy, while Paracelsus simultaneously attempted to establish alchemy as the foundation of modern medical practice. Unlike the alchemy of the past, these forms of the art encouraged the publication of recipes and theories in scientific literature, effectively eliminating one of the barriers of secrecy which had previously been characteristic of alchemical practices.

Subsequent texts that followed, notably those of Libavius, sought to impose method and order as a way to transform this new chemistry into a teaching discipline.[28] Many of these sentiments were echoed by Marin Mersenne, who rebuked alchemists for their secrecy and exclusive terminology and urged alchemists to undertake a significant reform of their language and to form an academy which would coordinate their experiments.[29] These early examples of texts and attitudes are indicative of the growing atmosphere of openness and organization that catalyzed the appearance of chemistry in German universities by the mid-seventeenth centuries. Chemical teaching in other regions, however, faced much greater opposition, as the medical establishment maintained that chemistry could not exist without the study of medicine and that traditional medicine held complete intellectual authority.[30] Appearing alongside a new definition

[26] Antonio Clericuzio, "'Sooty Empiricks' and Natural Philosophers: The Status of Chemistry in the Seventeenth Century," *Science in Context,* 23, no. [3], (2010): 330.
[27] Ibid., 331.
[28] Ibid., 332.
[29] Ibid., 333.
[30] Ibid., 332; Berry, *From Classical to Modern Chemistry,* 112.

in nearly every textbook published at this time, chemistry began to distance itself from alchemy and enter into the realm of academic science, but still struggled to find a consistent, independent identity.

By the seventeenth- and eighteenth-centuries, the struggles of chemistry as an autonomous and consistent field shifted slightly as the discipline now also needed to navigate a tenuous relationship with mechanical philosophy. Nicolas Lemery, a French author who published the foundational *Cours de Chymie* in 1675, asserted that most of his contemporary authors wrote on chemistry with a certain obscurity reflective of their purposeful intention *not* to be understood. In opposition to this tendency, Lemery uses his text to define chemistry explicitly as, "an art that teaches how to separate the various substances that are found in mixtures," these mixtures primarily being composed of "les choses qui croissant naturellement," or substances that occur naturally, namely minerals, plants, and animals.[31] With this clear definition, Lemery's landmark text remained a standard in France until 1730, and influenced the public practice of chemists during its half-century of prominence.

Indeed, the primary goal of chemists at this time transitioned from a focus on synthesis of metals and inorganic compounds to the analysis of the composition of every possible sample of matter.[32] French attitudes toward the utility and purpose of chemistry thus maintained that, although chemists could perform experiments, only mechanical theories could be used to explain the natural phenomena these experiments uncovered. Accordingly, as chemistry started to emerge as an autonomous discipline, it invited scrutiny and manipulation of the natural world but made "no claim to possessing a fully systematic understanding of nature," in the form of a single

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[31] Nicolas Lemery, *Cours de Chymie*, (Paris, 1675), 2.
[32] Berry, *From Classical to Modern Chemistry*, 45-47; Clericuzio, "'Sooty Empiricks,'" 334; Klein, "The Creative Power of Paper Tools," 13.

interpretive structure.[33] Richard Russell, an English chemist writing in 1678, continued to argue that, “Chemistry is a true and real Art, and (when handled by prudent Artists) produceth true and real effects.”[34] At the turn of the century, John Freind, the first professor of chemistry at Oxford University, still continued to echo the sentiments of his contemporaries, noting that “chemistry is the art of conjoining separate parts of natural bodies and of dividing them when conjoined.”[35] Over these decades, it is thus demonstrated that, internationally, chemistry remained an art, which although widely accepted in the utilitarian service of physics, physick, industry, and natural theology, fundamentally lacked a clear definition based upon an internal scheme of organization.

In this context, Etienne-François Geoffroy first published his “Table des différents rapports observés en Chimie entre différentes substances” in 1718 to initiate a new style of experimental reporting and organization in the chemical discipline.[36] Geoffroy’s first table systematically displayed a variety of chemical substances organized by their relative attraction to one another. The top row of his table shows symbolic representations of sixteen different chemical reagents (or types of reagents), below which different substances (or types of substances) are arranged in descending order of their attraction to the reagent at the top of their column. The accompanying title of this table, in keeping with the conventions of textbooks and chemical practice at this time, did not denote any causal implication for the order of the table, but instead signified that the relations listed had simply been observed as such.

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[33] Roberts, “Setting the Table,” 101.
[34] Robert Russell, quoted in: Maurice Crosland, *Historical Studies in the Language of Chemistry* (Mineola, New York: Dover Publications, Inc., 1962), 60.
[35] John Freind *Chymical Lectures: In Which Almost All the Operations of Chymistry Are Reduced to Their True Principles, and the Laws of Nature* (London, 1712), 175.
[36] Geoffroy, “Table des différents rapports,” 204.

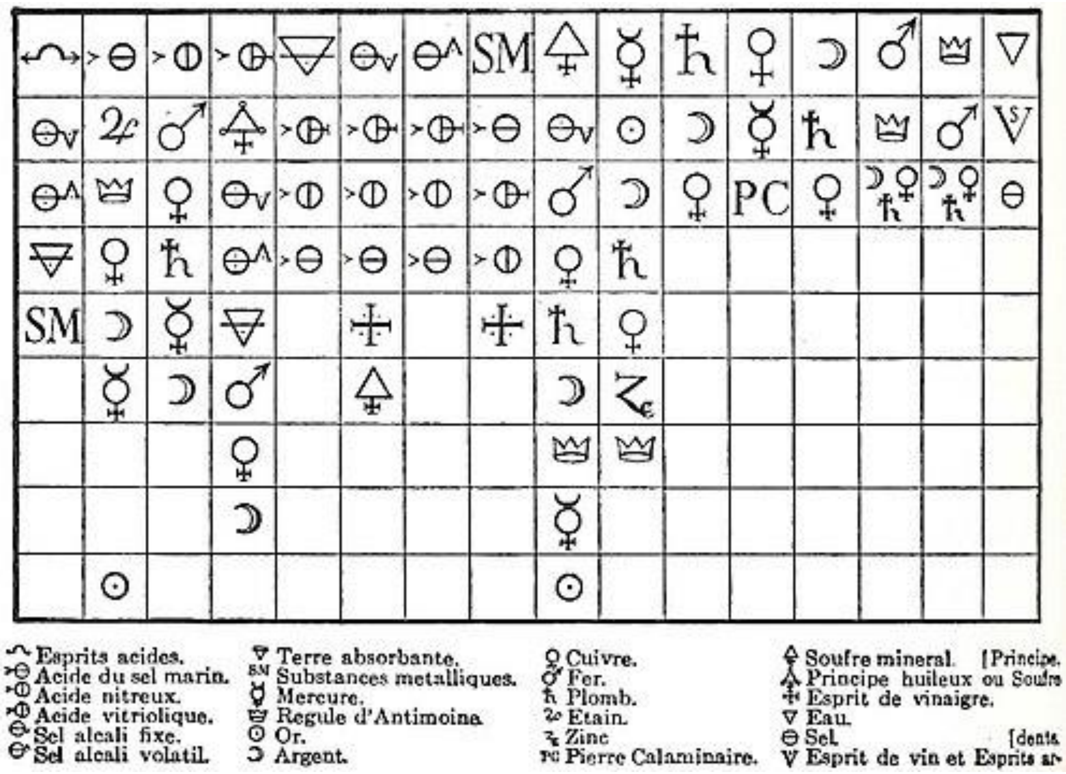

Figure 1: "Table des différents rapports observés en Chimie entre différentes substances" as shown in *Mémoires de l'Académie royale des sciences,* 1718. [37]

Here, Geoffroy continued to distinguish between the natural mechanical forces responsible for determining chemical behaviors and the effects that chemists observed through the manipulation and recording of natural substances. The accompanying *Mémoire* with which Geoffroy published his table also did not discuss the causal properties of the displayed reactivities or the composition of the elemental substances.[38] Geoffroy instead chose to highlight the practical applications of his table, explaining:

> Par cette Table, ceux qui commencent à apprendre la Chimie se formeront en peu de temps une juste idée du rapport que les differentes substances ont les unes avec les autres, & les Chimistes y trouveront une methode aisée pour découvrir, ce qui se passe dans

[37] Geoffroy, "Table des différents rapports," 204.
[38] Indeed, the accompanying text is rather short, and can be extensively reviewed in full to determine that theoretical discussions were not included. See: Geoffroy, "Table des différents rapports," 202-212.

> plusieurs de leurs operations difficiles à démêler, & ce qui doit resulter des melanges qu'ils sont de differents corps mixtes.[39]

From this initial description, Geoffroy makes it apparent that his table had a twofold functionality: it was for students of chemistry (apprendre la Chimie) to form an idea of how chemical substances relate to one another, and for chemists themselves (Chimistes) to see the results of different reactions they typically encountered. His demarcation of students and professionals not only establishes an important dynamic which I will show pervaded the applications of his tables for decades to come, but also suggests the primary importance Geoffroy placed on the utility of his table.

Geoffroy further demonstrates his commitment to the use of his table as a method to organize observations through his own internal rebuff of the single analysis appearing in his *Mémoire* for one of the specific solvent reactions shown in his table. Although he suggests "a subtle sulfurous principle" that could be responsible for this reaction, he immediately dismisses this notion in stating that "this is not the place to examine this subject in depth."[40] Any form of explanation, even one as vague and as brief as this, was found to have no place next to Geoffroy's table. In his dismissal of these causal relations, Geoffroy suggests that manipulative understanding and practical recordkeeping took priority over quantitative precision and theoretical explanation. His first chemical affinity table, although expansive in its collection of data and its organization, thus provided little certainty, and Geoffroy even cautioned that his table should not be generalized until all proposed combinations had been tested to determine the presence of any counterevidence.[41] This proposition now uniquely positioned chemical affinity tables within this time-period not only as tools that could be used for understanding and learning

[39] Ibid., 202.
[40] Ibid., 210. My translations.
[41] Ibid., 211.

about historical chemical reactions, but also as spaces that invited future studies and development from those who were practicing chemistry. Chemical affinity tables, since their earliest appearance, embodied several dualities: they were simultaneously reportative and predictive, educational and practical, as well as precise and non-explanatory.

II. DRAWING THE BORDERS

In order to further contextualize the setting that catalyzed the precipitation of Geoffroy's table and the subsequent evolution of the chemical discipline, it is important to recognize the variety of discourses occurring across Europe in the eighteenth-century. The ways in which chemistry was practiced, taught, and discussed was partly dependent on the national identities of the chemists themselves. Moreover, the function of chemistry as an intellectual and practical pursuit also differed across national borders. This section thus seeks to analyze the status of chemistry in three representative regions: Great Britain, France, and the Baltic states of Sweden and Germany, over the course of the eighteenth and early nineteenth-centuries in order to examine how chemical affinity tables were uniquely positioned to influence the communication that occurred between these nations. Here, I will trace the simultaneous changes in the frontiers of chemical textbooks and the disciplinary standards of chemistry in relation to the distinct, but permeable, borders of European nations: Boundary-work, in three short acts.

In the United Kingdom, the chemistry of the early nineteenth-century remained characterized by a focus on experimentation and practicality, indicating a sustained commitment to the original artisans of the field. Although a consistent theoretical basis had not yet been established, the discipline was dynamical, functional, and, most importantly, accessible.[42]

[42] Dolan, "The Language of Experiment," 145.

Indeed, the Royal Institution in London would soon become not only England's most prominent center for research and lectures on chemistry, but also a cultural hub.[43] Owing in great part to its utility, chemistry was viewed as one of the first sciences which could translate current knowledge and observations directly to the improvement of human conditions.[44] In a period when "the improvement of individual character as well as social benefits of science instruction were considerations," leveraging these practical applications of chemistry became a vital strategy chemists used to establish the academic validity of their practices.[45] The manipulation of these attitudes is continually reflected by the chemical publications of this time. Notably, the distinction between textbooks and more popular works was relatively ill-defined, which signals the ease of accessibility intended for these English didactic works. Indeed, it is at this time that children's publications such as *The Newtonian system of philosophy, adapted to the capacities of young gentlemen and ladies* began to appear across the United Kingdom.[46] This sweeping volume surveyed the whole of contemporary natural philosophy, introducing concepts of chemistry alongside those of cosmology and biology. This entry of science into the domain of children's literature shows how the concepts of natural philosophy, like Aesop's fables, "could be employed in teaching moral codes and good manners."[47] For the young and the old, the educated and the uneducated, chemistry was a practical and understandable discipline with increasing social value.

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[43] Ibid., 146.
[44] Ibid., 148.
[45] Ibid., 145.
[46] David Knight, "Communicating Chemistry: The Frontier between Popular Books and Textbooks in Britain during the First Half of the Nineteenth Century," in *Communicating Chemistry: Textbooks and Their Audiences, 1789-1939*, vol. 3, Anders Lundgren and Bernadette Bensaude-Vincent, eds., (Canton, MA: Science History Publications, 2000), 188.
[47] James A. Secord, "Newton in the Nursery: Tom Telescope and the Philosophy of Tops and Balls, 1761-1838," *History of Science*, xxiii, (1985): 128.

To bolster these social developments, chemistry achieved a prominent professional status in the United Kingdom, as in other regions, by adjoining itself to a medical education. Traditionally, pharmacists, apothecaries, and surgeons learned their trade by apprenticeship, but as the century marched on, more and more aspiring medical practitioners began seeking training in private medical schools, primarily those found in Edinburgh.[48] Accordingly, examinations started to be required for entrance into the medical profession, and with these examinations came a rise in formal education and textbook use. One of the first landmark texts, William Nicholson's *First Principles of Chemistry*, was published in 1790 and is characterized by its highly empirical tone, in which theory, if any, is presented at the end of chapters, separate from other initial descriptions.[49] In his preface, Nicholson explains that his work condenses a great deal of information because of his judicious selection of topics, and his avoidance of "systematizing" nomenclature and theory.[50] Despite this focus on selectivity, the back of Nicholson's volume features several different chemical affinity tables, indicating their great importance and empirical conception.[51] Instruction in pure chemistry, however, remained relatively limited, and courses in chemistry tended to be taught only as part of a medical education.

Similar to the *First Principles*, later textbooks built upon the focus of empiricism in order to gain prominence in classrooms across England. Frederick Accum's *A Manual of Analytical Minerology Intended to Facilitate the Practical Analysis of Minerals* provided a series of detailed experimental procedures that were intended to be carried out by everyone reading the book, student or otherwise.[52] In a similar manner, Jane Marcet's *Conversations on Chemistry; in*

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[48] Clericuzio, "'Sooty Empiricks,'" 335; Dolan, "The Language of Experiment," 150.
[49] William Nicholson, *The First Principles of Chemistry*, (London: Printed for G. G. J and J. Robinson, Paternoster-Row, 1790), 58, 236-239, 258, 267, 293-295, 370.
[50] Ibid., vii.
[51] Ibid., 523-529.
[52] Frederick Accum, *A Manual of Analytical Mineralogy Intended to Facilitate the Practical Analysis of Minerals*, 2nd ed, (London, 1808), ix-xii.

which the Elements of that Science are Familiarly Explained and Illustrated by Experiments recounted observed experimental demonstrations written in easily digestible prose.[53] Both of these texts exemplify how popular literature and chemistry textbooks remained highly similar in their tones and styles, for many chemistry texts were simply stories explaining the results of chemical reactions. Moreover, textbooks were not only written in an accessible manner, but they also invited the reader to be an active participant. In their style and their content, these English chemical texts helped to popularize chemical theory outside the walls of a classroom or the operating table of a physician. The practical nature of these experiments, coupled with their ease of understandability, established chemistry in Great Britain as a topic that could be readily discussed, practiced, and performed by anyone.

In France, chemistry textbooks had become an essential part of the national educational system by the start of nineteenth-century.[54] Analyzing this group of texts, therefore, provides insight into the characteristics of the science as it was taught in schools and universities. However, the chemical textbook was by no means a clearly defined genre of chemical literature at this time, as new contents and formats, in addition to new social relationships between authors, readers, and publishers, were continually being navigated.[55] In these instances of competing ideologies and goals, the methods undertaken by chemists to define the category of the chemical textbook, and the discipline of chemistry as a whole, become apparent.

Like in the United Kingdom, chemistry textbooks and the instruction of chemistry in France were tied initially to practical medical applications.[56] Increasingly over the years,

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[53] Knight, "Communicating Chemistry," 195.
[54] Antonio Garcia Belmar and Jose Ramon Bertomeu Sanchez, "French Chemistry Textbooks, 1802-1852: New Books for New Readers and New Teaching Institutions," in *Communicating Chemistry: Textbooks and Their Audiences, 1789-1939*, vol. 3, Anders Lundgren and Bernadette Bensaude-Vincent, eds., (Canton, MA: Science History Publications, 2000), 20.
[55] Ibid., 35.
[56] Ibid., 27; Clericuzio, "'Sooty Empiricks,'" 335-340.

however, French texts began to show an increased commitment to elucidating both the practice and theory of the chemistry they described. Jean-Antoine Chaptal's *Chimie appliquee aux arts* and Louis Jacques Thénard's *Traite de chimie elementaire, theorique et pratique,* published in 1807 and 1813, respectively, each explicitly declared a committed focus on chemistry as an active practice.[57] Thénard's work took this a step further, as it also introduced the importance of theory in order to help distinguish chemistry from the medical and pharmaceutical practices. Moreover, in successive editions of Thénard's *Traite*, developments in atomic theory, and French conceptions of it, can be continually traced. This indicates how chemistry, through its appearance in French literature, became increasingly reliant on theoretical frameworks and effective explanations of abstract concepts.[58] Indeed, French textbooks are notable for the frequency at which they were re-issued across various disciplines and levels of education. Most chemistry textbooks for general, primary, and secondary education we re-issued as frequently as every year in order to update their theoretical content and better reflect the unique educational goals of the various programs within which they were incorporated.[59] The regularity of these updates allowed for the gradual introduction of complex theoretical concepts and the evolution of theory over time, suggesting that chemists in France sought to distinguish their discipline based on its theory, rather than its utilities.

Moving further east to the Baltic states of Sweden and Germany, it is found that chemistry was performed and studied with an interesting commitment to theoretical and practical properties, which caused the discipline to emerge here through a process similar to the paths it

[57] Jean-Antoine Chaptal, *Chimie appliquee aux arts*, vol. 3, (Paris: Deterville, 1807), iii-xvi. This table of contents demonstrates chapter titles which consistently imply chemical reactivity and, often, experimentation. Upon reviewing their contents, these titles are found to be representative of the activity discussed throughout the text. Louis Jacques Thénard, *Traite de chimie elementaire, theorique et pratique,* (Paris: Crochard, 1813), ij-iv.
[58] Belmar and Sanchez, "French Chemistry Textbooks," 24.
[59] Ibid., 30.

followed in Great Britain and France. Once again, the genre of a chemical textbook remained imprecisely defined, as the handbooks, texts for beginner and advanced students, and popular science books all shared a high degree of similarity in this region.[60] Here again, it was apparent that by the nineteenth-century, chemical theory was beginning to permeate popular culture separate from discussions of its practical applications. Mimicking the tone of English textbooks, German and Swedish chemical texts also tended to maintain a descriptive focus which made them more accessible and, accordingly, encouraged the general public to accept them and the theories contained within.[61] Chemical texts in Sweden, however, differed from those of Great Britain and France due in large part to the influence of Swedish chemist J.J. Berzelius, who published several of the region's most famous texts. Indeed, the textbooks of Berzelius inspired a Swedish chemical dogma that would last for years following their publication.

Over the course of 22 years, from 1808 to 1830, Berzelius compiled and continually revised his *Lärbok i kemien*, an ambitious publication which consisted of six volumes meant to encompass the whole of chemistry.[62] Throughout these textbooks, Berzelius explicitly emphasized the differences between practice and theory. He acknowledged that practice was characterized by precise lab work that yields descriptive results, and although these results themselves would never be completely accurate, he suggested that there was a significant need for this kind of work in order to generate empirical data. Conversely, to Berzelius, theory was a way to connect and systematize that which had been determined empirically.[63] This philosophy

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[60] Anders Lundgren, "Theory and Practice in Swedish Chemical Textbooks during the Nineteenth Century: Some Thoughts from a Bibliographic Survey," in *Communicating Chemistry: Textbooks and Their Audiences, 1789-1939*, vol. 3, Anders Lundgren and Bernadette Bensaude-Vincent, eds., (Canton, MA: Science History Publications, 2000), 94.
[61] Ibid., 95.
[62] J.J. Berzelius, *Lärbok i kemien*, (Stockholm: 1808), 1-483.
[63] Ibid., 1-6, 36-40, 98. Berzelius begins by defining chemistry in reference to doctrines of affinity with a focus on its empirical foundations. His later discussions on artificial cold (36-40) and phlogiston (98) are similarly useful for showing his combination of an experimental basis giving rise to chemical theory.

is continually reproduced by Swedish and German authors, establishing that in the chemical practices of these two nations, theories followed from observable evidence, and the primary purpose of the chemist was to search experimentally for this evidence.[64] Accordingly, the state of chemistry in this region was best defined through the chemists' desire to combine theory and practice in a dynamic, reflective manner.

III. HITTING THE BOOKS

Although Geoffroy's chemical affinity table was the first of its kind to be published in literature, it was met with neither fanfare nor harsh criticism. Perhaps, as a historian, I have overstated the importance of these tables by retroactively assigning them a significance that chemists of the time never found them to have. After all, I have just discussed at length some of the literary strategies employed by chemists to demarcate their field during the eighteenth-century with nary a reference to chemical affinity tables. This contextualization which I provided, however, is of primary importance for this story because it establishes a foundation of competing national conceptualizations of chemistry which, as I will show, chemical affinity tables were uniquely able to permeate. This section will discuss how chemical affinity tables were perpetuated and revised over time, enabling them to continually impact the disciplinary establishment of chemistry, even when their value was not explicitly recognized.

After the initial presentation of Geoffroy's table in 1718, only three issues regarding its content were brought to the attention of the *Académie des Sciences*. Each of these issues received a prompt response and explanation from Geoffroy, thereby confirming the accuracy of the table

[64] Lundgren, "Theory and Practice," 100-102.

shortly after its introduction.[65] Despite the fact that his table was a novel and accurate organization of observed chemical behavior, it is not until decades later that any sign of the table reappears in publication or recorded discussion. The reasons for this slow response to Geoffroy's chemical affinity table remain unclear. Some historians acknowledge that, because Geoffroy presented his table without an accompanying theory and because he tabulated reactions that were already familiar to many chemists, the table may have been seen as a mere summary of established knowledge.[66] Though Geoffroy presented his table without reference to theory, he clearly outlined its purpose as a tool for students and practiced chemists alike. The words of historian Christopher Ritter once again become valuable here, as he explains, "Tools are made, over time, not born with all their capabilities and uses immediately obvious or ready to be held."[67] It is thus precisely through the persistence and adaptation of chemical affinity tables throughout the eighteenth-century that they transformed into the significant devices which Geoffroy envisioned.

[65] Etienne Roth, "Etienne Francois-Geoffroy's table of relations and the concept of affinity," *Fresenius' Journal of Analytical Chemistry*, 337, (1990): 190.
[66] Taylor, "Variations on a theme," 53.
[67] Ritter, "An Early History," 43.

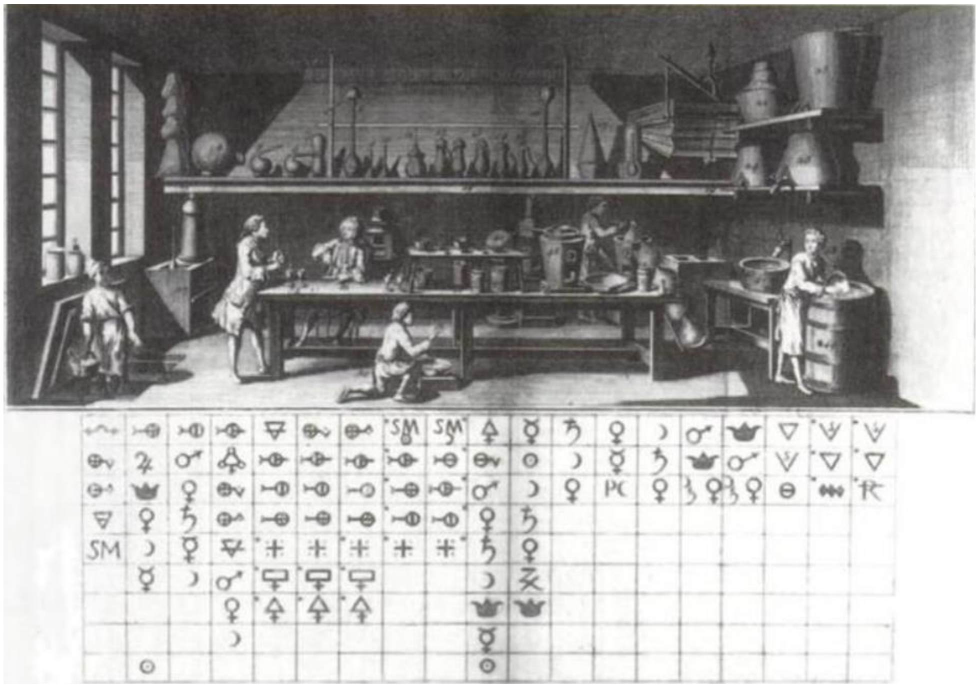

Figure 2: French Encyclopedic Depiction of an Expanded Affinity Table with a Laboratory. Present under the definition for "Chymie," 1753.

In 1753, the entry for "Chymie" in the "Encyclopédie, ou dictionnaire raisonné des sciences, des arts, et des métiers" became one of the first major French publications to feature Geoffroy's table. The depiction, however, did include some minor edits and was presented in conjunction with a picture of a chemical laboratory.[68] The incorporation of this table within the French encyclopedic definition of chemistry suggests the fundamental role that these tables were seen to serve for the discipline, while the decision to pair the table with the visual of an iconic chemical laboratory further emphasizes the importance of experimentation completed in conjunction with the data of the chemical affinity tables. As the presence of the minor edits within this depiction of the table exemplifies, however, the chemical affinity table of Geoffroy found its greatest success outside of the initial boundaries drawn by Geoffroy. As his table was reproduced and edited across Europe over the following decades, the table became increasingly vital to the discipline of chemistry.

[68] Image cited in: Roth, "table of relations," 193. See Fig. 2.

Figure 3: The Nineteen Column Affinity Table of Jean Grosse. Grosse's table shows high correlation to the original table of Geoffroy, but has expanded to include more experimental data, 1730.

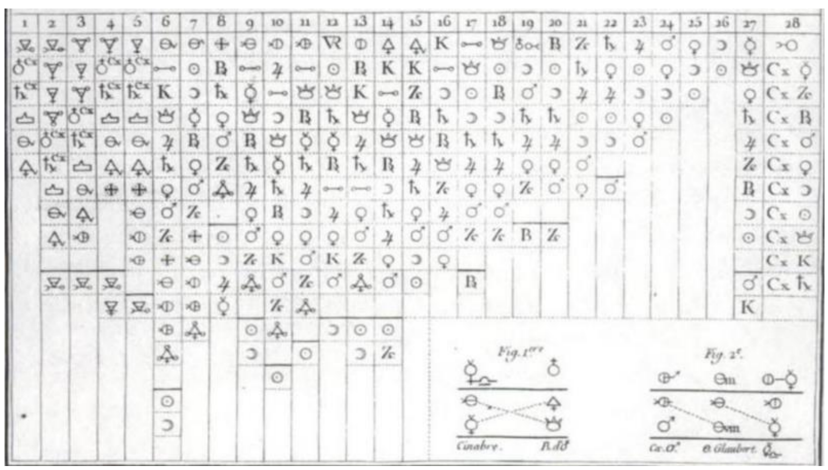

Figure 4: The Twenty-Eight Column Affinity Table of Christlieb Ehregott Gellert. This tabulated expansion also features two small reaction diagrams in the bottom right corner, 1750.

Early alterations to Geoffroy's table sought to include more substances, which their designers hoped would make the contents of the table more comprehensive. By 1730, German chemist Jean Grosse had expanded chemical affinity tables to include columns for nineteen substances.[69] Two decades later in 1751, the table had expanded even further to now include

[69] Found in: Mi Gyung Kim, *Affinity That Elusive Dream: A Genealogy of the Chemical Revolution*, (Cambridge, MA: MIT Press, 2003), 223.

twenty-eight columns, with rows ordered based on increasing solubility, as shown in Christlieb Ehregott Gellert's German text *Anfangsgründe zur metallurgischen Chymie*.[70] Throughout the 1750s and beyond, additional columns, representing the inclusion of new substances, continued to be added. The tables devised by German chemists Jean Philippe de Limbourg and Philipp Ambrosius Marherr exemplify this tendency, and in the case of Marherr, bring it to the extreme.[71] By expanding the table to an impressive 120 columns, Marherr established a chart capable of summarizing a denser range of information than ever before. Having to print this table across multiple pages, however, made his diagram impractical to use.

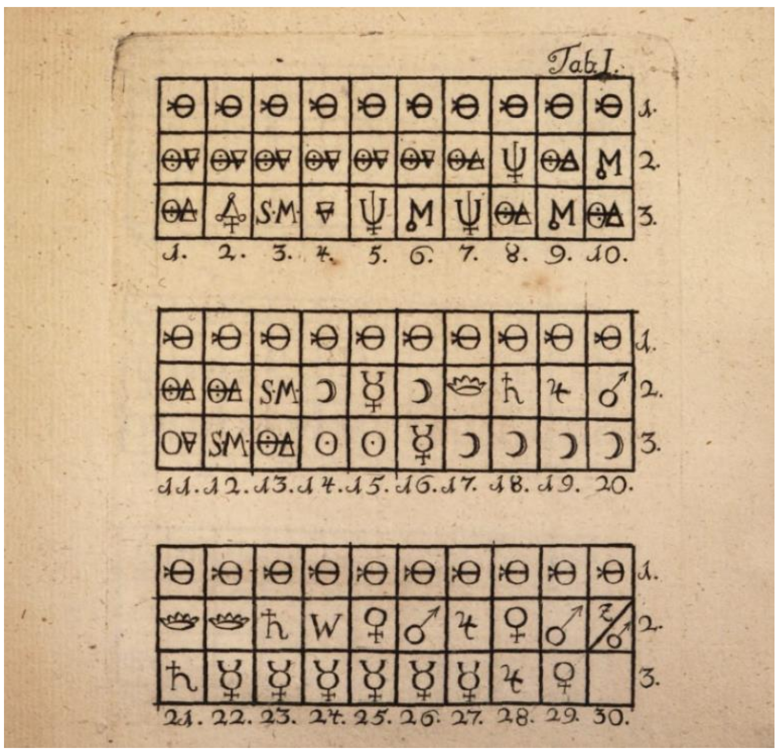

Figure 5: A Fragment of the 120-column Affinity Table of Philipp Ambrosius Marherr. This fragment taken from the left-hand side of the complete table suggests how impressively large and dense chemical affinity tables had become. This revision shows complex, double-elective attractions, in addition to its vastly expanded number of substances, 1762.

[70] Christlieb Ehregott Gellert, *Anfangsgründe zur metallurgischen Chymie*, (Leipzig: 1751). Reproduced in: Jacques-François Demachy, *Recueil de dissertations physico-chymiques, présentées à differentes academies*, (Paris: Nyon and Barrois, 1781), figure appended to the end of the text.
[71] Jean Philippe de Limbourg, *Dissertations sur les Affinites Chymiques*, (Liege: 1761), 79; Philipp Ambrosius Marherr, *Dissertatio Chemica de Affinitate Corporum*, (Vindobonae: 1762), 101-106. Owing to the small size of the book, these tables were printed across multiple pages and included in a separate appendix to the rest of the volume.

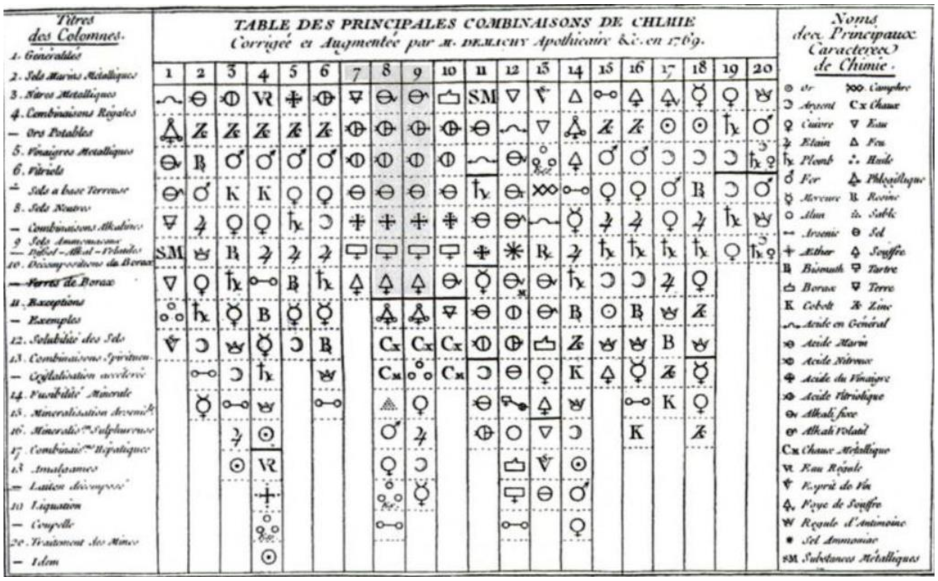

Figure 6: The Twenty-Column Affinity Table of Demachy. This table is significantly smaller in size than previous tables, and also includes written labels for each of its constituents, 1769.

After this development, shortened versions of the expanded tables began to appear once again. It is in 1763 that French chemist Guillaume-François Rouelle designed the nineteen-column affinity table that would be printed across subsequent copies of French encyclopedias, while in 1769, Demachy produced a twenty-column affinity table that included more explicit labels for the symbols contained therein.[72] The contraction of table sizes following the unwieldly version proposed by Marherr suggests that the construction of these tables not only had to convey large amounts of information, but also had to facilitate their use within a printed setting. In these instances of gradual expansion and contraction, the affinity table became an almost lively, breathing object that chemists could refine to suggest granular differences in their purposes and capabilities.

[72] Demachy, *Recueil de dissertations,* figure appended to the end of the text.

For example, Gellert's twenty-eight-column table is significant for its incorporation of early versions of chemical reaction diagrams. In the two figures of the bottom righthand corner of his table, Gellert introduced dotted lines to show how the force of chemical affinity affected the behavior of substances and resulted in their tabulated order shown above. Conversely, in Demachy's twenty-column table, he chose to include a written identification of the alchemical symbols he used as well as labels for each individual column. These identifications ground his table firmly in the physical world and emphasize the importance of practical experimentation for the design and use of the table. These contrasting revisions exemplify that, as the boundaries of each table changed to accommodate or exclude additional substances, so too did the boundaries of their theoretical implications. For the chemists studying the reactive relationships between various substances, the chemical affinity table thus became a space where they could experiment with different organizational forms in order to express specific and refined views of chemical theory.

While notable for their changes, chemical affinity tables are also significant for the consistencies that they reproduced over time. As each of the aforementioned affinity tables have shown, these diagrams can be uniformly classified by their use of alchemical symbols and straightforward gridded structures which has a three-fold effect: each row indicates substances of different affinity strengths, each column classifies substances belonging to different reagent groups, and at their intersection, each substance is identified individually.[73] The physical design of the table therefore provided chemists with unambiguous *objects* and *properties* to study. By creating clear bounds to contain various chemical substances, chemists emphasized the

[73] Consider the word "strength" here with caution, as historical notions of bond strengths were quite different from those of today. As I will later explain, however, these tables suggest proximal relations that allow such conceptions to emerge.

disciplinary boundary they were devising between chemistry and the mechanical arts through the establishment of objects and relational properties that were unique to chemistry.[74] These tables also helped to foster a consistency of chemical notation emerging across diverse ranges of literature, which further propagated a unified, consistent disciplinary appearance.

It was not until 1775 that the most significant change to Geoffroy's original chemical affinity table occurred, marking a conceptual divergence that illustrates the communication promoted by chemical affinity tables. In his textbook, "Disquisitio de Attractionibus Electivis," the Swedish chemist Torbern Bergman began, unlike authors before him, with a discussion of chemical forces.[75] He argued that attraction was a universal property which, regrettably, had not yet been causally investigated. Bergman continued further to distinguish between long- and short-range attractions. These distinctions, he maintained, would prove that the shape of chemical substances reacting with one another has an effect on their attraction because each point on one substance attracts certain points of the other.[76] After presenting these new theoretical explanations, Bergman remarks on the implications and limitations of the work of his predecessors. The failure of previous chemical affinity tables to address the conditions under which the listed reactions occurred, Bergman believed, was a fundamental hindrance to the descriptions they provided and their utility.[77]

Throughout eleven chapters of his dissertation, Bergman explored these various dependencies and ultimately offered a more nuanced explanation of chemical affinities than that which was first given by Geoffroy. Bergman traced how the number of participants within a

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[74] Taylor and Klein both offer extended commentary on this form of boundary-work. See: Taylor, "Variations on a theme," 100; and Ursula Klein, "E F Geoffroy's Table of Different Rapports Observed Between Different Chemical Substances - A Reinterpretation," *Ambix*, 42, (1995): 92-93.
[75] Bergman, "Dissertation on Elective Attractions," 93.
[76] Ibid., 96.
[77] Ibid., 98.

reaction, as well as the nature of the interaction itself, affected the resulting interrelationships of substances. In so doing, Bergman distinguished between reactions where aggregation, dissolution, and fusion, among other transformations, occurred. Even more vitally, Bergman considered both "moist" and "dry" reaction conditions, in which the moist method was conducted at room temperature with a solvent, while the dry method was performed at elevated temperatures with heat.[78] This extensive inquiry into various reaction conditions resulted in the creation of one of the largest chemical affinity tables produced at the time, consisting of 59 columns including 25 for acids, 15 for metals, 3 for alcohols, and still others for earths, sulfur, spirit of wine, vital, air, phlogiston, the matter of heat, and water.[79]

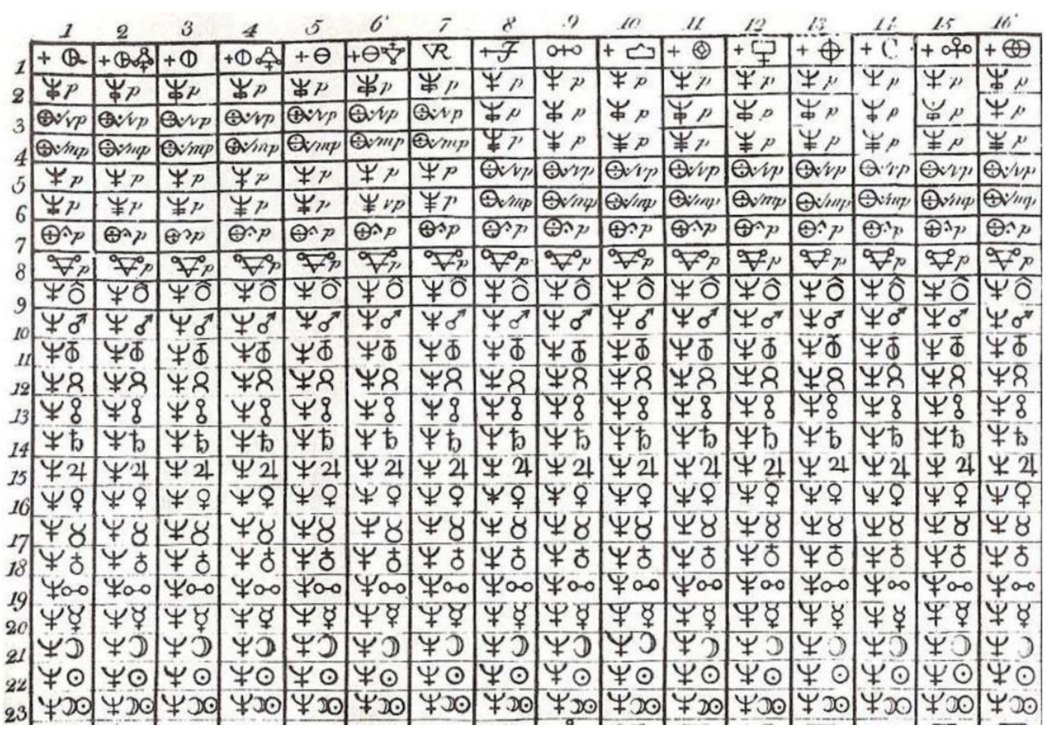


Figure 7: Fragment of the 59-Column Affinity Table of Torbern Bergman. Much like that of Marherr, this table contains a dense amount of information, including attention to specific reaction conditions and complex double-elective attractions, 1775.

[78] Ibid., 93-100.
[79] Complete table found reproduced in: Kim, *That Elusive Dream*, 264.

One of these tables was compiled for moist conditions, and a second, separate table was formed for dry conditions. Bergman placed these tables together in a foldout included with his textbook, which once again suffered the problems previously faced by Marherr, in that Bergman's expansive table was not able to be printed on a single, standard page.[80] Bergman's version, however, not only accounted for different reaction conditions, but also showed the results of more complex chemical interactions. The expansion that he offered, therefore, was not simply in the sheer number of substances he described, but rather in the circumstances impacting their behavior. This was a visual, organizational change that was further echoed by his written description.

Indeed, unlike Geoffroy, Bergman did not simply present his table as a summary of experimental findings, but rather elucidated the experimental conditions upon which his table was built. He then connected these physical circumstances to established concepts of the chemical nature of matter and of chemical reactions. Keeping with the Swedish tradition that valued both the theory and practice of chemistry, Bergman maintained that:

> the doctrine [of a fixed order] deserves to be cultivated…the whole of chemistry rests upon it, as upon a solid foundation, at least if we wish to have the science in a rational form, and that each circumstance of its operation should be clearly and justly explained.[81]

For Bergman, the order that could be achieved through the organization of substances within an affinity table was essential for the establishment of chemistry as a legitimate science.

While the chemical affinity table compiled by Bergman was one of the most complete and comprehensive tables ever assembled, he alone could not fully address all of the irregularities identified throughout his textbook. In order to do this, Bergman would require the completion of more than 30,000 separate experiments, a task for which he readily requested the

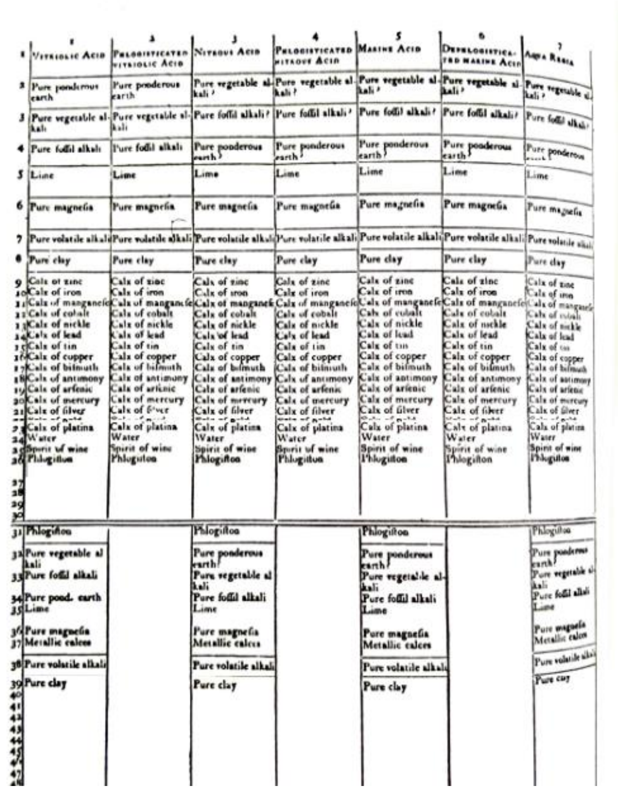
[80] Bergman, "Dissertation on Elective Attractions," 100.
[81] Ibid., 94.

help of other practicing scientists.[82] This call for experimental verification and collaboration demonstrates how affinity tables opened up new avenues for communication and fostered cooperation within the field. By creating his expansive affinity table, Bergman was not only responding to the work of his predecessors, but also creating a dialogue among future experimenters. Although Bergman's work demonstrated a greater commitment to conceptual explanations for the results displayed within his tables, his published tables were, ultimately, issued as summaries of empirically derived results. Yet his extension of Geoffroy's initial table demonstrated a newfound commitment to process by carefully accounting for and controlling reaction conditions. The very construction of these affinity tables, therefore, required new forms of standardized practices that would support the study of these uniquely chemical objects and their uniquely chemical properties.

Bergman's table visually expanded the range of affinities shown by Geoffroy while also literarily expanding the conceptual explanation of their causes and implications in its accompanying textbook. Geoffroy presented his simplistic table without theory and without instructions.[83] While the visuals of Bergman's table were only slightly more complex than those of Geoffroy's table, a full description of Bergman's version required the extensive language of its accompanying textbook.[84] In the decades between the developments of these two tables, then, the verbiage used to convey the information given by tables of chemical affinities could no longer equal the visual simplicity of the gridded array of rows and columns. Indeed, Bergman, by this time, had even abandoned use of the would "affinity" altogether in favor of the term

[82] Ibid., 98.
[83] Geoffroy, "Table des différents rapports," 202-212.
[84] Torbern Bergman, "Disquisitio de Attractionibus Electivis," *Nova acta Regiae societatis scientiarum upsaliensis,* 2, (1775): 108-160.

"elective attraction" in order to improve the precision of the table's theoretical implications.[85] In his perpetuation of a familiar tabulated structure, Bergman demonstrates that he wanted his tables to fulfill many of same purposes of earlier tables. By redefining the name of his representation, however, Bergman shows that he desired to enhance the sophistication of his table and its didactic potentials.



	1	2	3	4	5	6	7
1	Vitriolic Acid	Phlogisticated vitriolic Acid	Nitrous Acid	Phlogisticated nitrous Acid	Marine Acid	Dephlogisticated marine Acid	Aqua Regia
2	Pure ponderous earth	Pure ponderous earth	Pure vegetable alkali?	Pure vegetable alkali?	Pure vegetable alkali?	Pure vegetable alkali?	Pure vegetable alkali?
3	Pure vegetable alkali	Pure vegetable alkali	Pure fossil alkali?	Pure fossil alkali?	Pure fossil alkali?	Pure fossil alkali?	Pure fossil alkali?
4	Pure fossil alkali	Pure fossil alkali	Pure ponderous earth?	Pure ponderous earth?	Pure ponderous earth?	Pure ponderous earth?	Pure ponderous [illegible]
5	Lime	Lime	Lime	Lime	Lime	Lime	Lime
6	Pure magnesia	Pure magnesia	Pure magnesia	Pure magnesia	Pure magnesia	Pure magnesia	Pure magnesia
7	Pure volatile alkali	Pure volatile alkali	Pure volatile alkali	Pure volatile alkali	Pure volatile alkali	Pure volatile alkali	Pure volatile alkali
8	Pure clay	Pure clay	Pure clay	Pure clay	Pure clay	Pure clay	Pure clay
9	Calx of zinc	Calx of zinc	Calx of zinc	Calx of zinc	Calx of zinc	Calx of zinc	Calx of zinc
10	Calx of iron	Calx of iron	Calx of iron	Calx of iron	Calx of iron	Calx of iron	Calx of iron
11	Calx of manganese	Calx of manganese	Calx of manganese	Calx of manganese	Calx of manganese	Calx of manganese	Calx of manganese
12	Calx of cobalt	Calx of cobalt	Calx of cobalt	Calx of cobalt	Calx of cobalt	Calx of cobalt	Calx of cobalt
13	Calx of nickle	Calx of nickle	Calx of nickle	Calx of nickle	Calx of nickle	Calx of nickle	Calx of nickle
14	Calx of lead	Calx of lead	Calx of lead	Calx of lead	Calx of lead	Calx of lead	Calx of lead
15	Calx of tin	Calx of tin	Calx of tin	Calx of tin	Calx of tin	Calx of tin	Calx of tin
16	Calx of copper	Calx of copper	Calx of copper	Calx of copper	Calx of copper	Calx of copper	Calx of copper
17	Calx of bismuth	Calx of bismuth	Calx of bismuth	Calx of bismuth	Calx of bismuth	Calx of bismuth	Calx of bismuth
18	Calx of antimony	Calx of antimony	Calx of antimony	Calx of antimony	Calx of antimony	Calx of antimony	Calx of antimony
19	Calx of arsenic	Calx of arsenic	Calx of arsenic	Calx of arsenic	Calx of arsenic	Calx of arsenic	Calx of arsenic
20	Calx of mercury	Calx of mercury	Calx of mercury	Calx of mercury	Calx of mercury	Calx of mercury	Calx of mercury
21	Calx of silver	Calx of silver	Calx of silver	Calx of silver	Calx of silver	Calx of silver	Calx of silver
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	Calx of platina	Calx of platina	Calx of platina	Calx of platina	Calx of platina	Calx of platina	Calx of platina
24	Water	Water	Water	Water	Water	Water	Water
25	Spirit of wine	Spirit of wine	Spirit of wine	Spirit of wine	Spirit of wine	Spirit of wine	Spirit of wine
26	Phlogiston	Phlogiston	Phlogiston	Phlogiston	Phlogiston	Phlogiston	Phlogiston
27							
28							
29							
30							
31	Phlogiston		Phlogiston		Phlogiston		Phlogiston
32	Pure vegetable alkali		Pure ponderous earth?		Pure ponderous earth?		Pure ponderous earth?
33	Pure fossil alkali		Pure vegetable alkali		Pure vegetable alkali		Pure vegetable alkali
34	Pure pond. earth		Pure fossil alkali		Pure fossil alkali		Pure fossil alkali
35	Lime		Lime		Lime		Lime
36	Pure magnesia		Pure magnesia		Pure magnesia		Pure magnesia
37	Metallic calces		Metallic calces		Metallic calces		Metallic calces
38	Pure volatile alkali		Pure volatile alkali		Pure volatile alkali		Pure volatile alkali
39	Pure clay		Pure clay		Pure clay		Pure clay
40							
41							
42							
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Figure 8: Fragment of the Written Chemical Affinity Table of Torbern Bergman. This chemical table details the results of the same experiments previously shown within the symbolic representation, but now makes use of written names to facilitate its clarity, 1785

To improve the theoretical clarity of his tables even further, Bergman began replacing the alchemical symbols used within them with written words which designated the various chemical substrates he included.[86] Tiny alchemical symbols had for years crowded the rows and columns of chemical affinity tables, obscuring the meaning of these tables for some users while also

[85] Cohen, "The Element of the Table," 53-54.
[86] Bergman, "Dissertation on Elective Attractions," 100.

making them difficult to read and use.[87] In the English translation of Bergman's text, first appearing in 1785, the translator described how "Two sets of Tables are subjoined," one which contained the chemical symbols and one which showed the names of the substrates written out in full.[88] For this translator, the intelligibility of the table was of primary importance, but "To suppress signs entirely," the translator argued, "seemed improper; for they are so convenient that every student of chemistry ought to make himself familiar with them."[89] The most vital characteristic of the table was its ease of reference, yet such a fluid comprehensibility would only be achieved in conjunction with a chemical education which would make students more familiar with the traditional and expedient chemical symbols.

Here, the initial didactic purposes of the earliest chemical affinity table were shown to be reinforced over time. Developing the ability to assess symbolic tables such as these facilitated improved cognitive efficiencies, as entire pages worth of informational content could be understood in a matter of seconds. Even though Bergman altered the appearance and underlying theory of Geoffroy's original table, its service to students of chemistry remained a constant that allowed these tables to be translated across Sweden, Great Britain, and France. Bergman was perhaps keenly aware of the didactic functions of these diagrams, as his table combined the standard gridded structure of early tables with the interactive symbols utilized in the classroom of Joseph Black in order to impart new theoretical significance to the reactions displayed by his table.[90] This suggests that, even as the content of the table would change, its experimentally derived content and appearance remained the central character around which theory was formed.

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[87] Ibid., 55.
[88] Quoted in Cohen, "The Element of the Table," 55.
[89] Ibid.
[90] Bergman, "Dissertation on Elective Attractions," 95; Maurice Crosland, "The use of diagrams as chemical 'equations' in the lecture notes of William Cullen and Joseph Black," *Annals of Science,* 15, no. [2], (1995), 78-82.

This demonstrates, at length, how the distinctly Swedish commitment of Torbern Bergman to derive a comprehensive chemical theoretical framework from thousands of experimental trials was facilitated by the creation and continual revision of chemical affinity tables.

The contents of "Disquisitio" become even more interesting, however, when they are considered in comparison to Claude-Louis Berthollet's 1804 *Researches into the laws of chemical affinity,* which was a 200-page treatise commenting on the relative virtues of the theory of chemical affinities discussed by Bergman.[91] Here, Berthollet introduced the ideas of reaction directionality and equilibrium, as well as a new physical property, mass, and suggested how these different properties influenced the progression of chemical reactions.[92] He primarily desired, "A theory of chemical affinities, solidly established, and serving as the basis for the explanation of all chemical questions," which echoed the sentiments of French authors from decades past who committed themselves to the elaboration of chemical theories.[93] With each of his new assertions, Berthollet took special care to note how his theories differed specifically from those included in Bergman's textbook.[94] Accordingly, this text can be read as a representation of the increasing complexity of chemical affinity theory, but much more importantly, a demonstration of how textbooks containing chemical affinity tables prompted critical responses that offered further development within the field of chemistry. Understanding that textbooks serve as a means of theory popularization, by commenting directly on the textbook of Bergman, Berthollet was able to leverage the recognizability of the established

[91] Berthollet, "Essay on Chemical Statics," 1-215.
[92] The "mass" which Berthollet described was decidedly different from modern conceptions, but was nonetheless a useful construct which Berthollet incorporated within his theoretical treatise.
[93] Berthollet, "Essay on Chemical Statics," 195.
[94] Ibid., 193, 194, 197, 199.

empirical data contained within Bergman's text in order to make his own theory appear more legitimate and to chart a new frontier for the chemical discipline.

The changes that countless international chemists made to Geoffroy's first chemical affinity table exemplify expanding practical, theoretical, and didactic functionalities of chemical tables. Nonetheless, these tables share striking visual similarities even as they were distributed within textbooks and treatises across Europe. The reprint and reproduction of these tables over time signify their concurrent evolution with chemical theory and experimentation. As new substances were tested, new columns were added to the tables. As new conditions were considered, new rows were added to the tables, and new methods of communication were provided to facilitate understanding of these complex reactions.[95] Chemical affinity tables, and the textbooks through which they travelled, were essential for the dissemination of information throughout the eighteenth-century, and they established the foundation of a visual culture within the discipline of chemistry in which visual tables and symbols were used to describe theoretical concepts, physical observables, and future reactions.

IV. SHAPING THE STUDY

To bring this story to its completion, I would now like to revisit the classrooms of William Cullen and Joseph Black at the Universities of Glasgow and Edinburgh. Travelling through textbooks across Europe, I have shown how chemical affinity tables were able to facilitate new forms of discourse between various authors over time and act a bridge between competing national approaches to chemistry. The true utility of chemical affinity tables, however, cannot be properly understood until they are placed within the hands of teachers and

[95] Roberts has remarked on similar changes. See: Roberts, "Setting the Table," 117-121.

students. It is here that the practical and didactic purposes envisioned by Geoffroy for his table could finally coalesce, and it is in this context that chemical affinity tables were used to establish an autonomous doctrine of chemistry.

Chemistry teaching in the early eighteenth-century was indeed rare in England, as it was in most other European nations. Cullen began teaching chemistry at Glasgow University in 1747, which represented Britain's first independent lectureship in chemistry.[96] Although these were the early years of chemical education, Cullen's lecture course soon achieved great popularity, as attested by the large number of copies of lecture notes that still survive in and belong to library collections across the world. These lecture notes would leave the walls of the classroom to be copied and sold to interested buyers, who were often separate from the circle of students enrolled in chemistry courses.[97] Just as these lecture notes escaped the confines of their university origins, so too did the chemical theories that were contained within them. A thorough examination of these archives provides an excellent characterization of Cullen's teaching, in terms of both the methods that he used and the theories included therein.

In Cullen's earliest lectures, he referred his students to a French text by Pierre Macquer, which was one of the earliest texts to feature Geoffroy's table alongside a chapter providing instructions for its use.[98] As he drew diagrams for his students on the board, Cullen extended the practical range of this early table by adding new columns that would describe the affinities of substances not previously described by Geoffroy. Simultaneously, however, Cullen expanded the theoretical range of the table by including new components that discussed complex affinity

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[96] Berry, *From Classical to Modern Chemistry*, 112.
[97] Taylor, "Variations on a theme," 67; William Wightman, "William Cullen and the teaching of chemistry," *Annals of Science*, 11, no. [2], (1955): 154-162.
[98] Taylor, "Variations on a theme," 61.

behaviors and the role of heat.[99] Just like the authors who had published new versions of chemical affinity tables, Cullen found this diagram highly amenable to changes required for his academic curriculum. With these alterations, the chemical affinity table shaped a significant portion of Cullen's pedagogic strategy. Cullen maintained that chemists investigated the "particular properties of bodies," reinforcing the notion that the substances shown within the table, and their relation to one another, established specific objects ("bodies") and properties of chemical inquiry.[100] He often demonstrated these definitions by interspersing his lectures with experiments such as the one described in the introduction of this paper.[101] Yet while basic explanations relating directly to the observed demonstration were provided, causal speculation was generally avoided throughout most of Cullen's lectures, much like in Geoffroy's initial presentation of the table itself.[102] Indeed, chemical affinity tables were empirically founded and offered a systematization of chemical information, but at the same time, placed limits on inquiry.

As Britain's first lecturer in chemistry, Cullen undoubtedly had personal motivations for demarcating this new discipline from other fields of study. His personal aspirations are evidenced by his decision to transfer later to the University of Edinburgh, which allowed him to acquire a more influential social status and an improved roster of patrons.[103] A man who desired a secure position, Cullen was quick to incorporate theories of chemical affinity as outlined in chemical affinity tables in order to distinguish chemistry from mechanical philosophy. For Cullen and his students, these chemical affinity tables were all at once a foundation for the operations of reagent behavior, a way for explaining how substances combine and separate, and

[99] Notes taken by Sir Charles Blagden, MS 1922.
[100] Ibid.
[101] See, again, for example: Cullen, "Lecture on Saltpetre;" idem "The Plan of a Course of Chemical Lectures and Experiments."
[102] Lecture notes entitled "The Operations of Chemistry," n.d., MS 268/1, Cullen Papers, Glasgow University Library, Glasgow.
[103] Taylor, "Variations on a theme," 72.

instructions for how to manipulate these substances in order to achieve these results. Cullen further enhanced these capabilities by describing complex affinity relationships in his introduction of "double elective attractions," suggesting that the affinity table was adaptive to describing advanced observations which would further demarcate chemistry from other similar academic disciplines.[104]

Yet when Cullen gave his first lecture in Glasgow, a chemical affinity table had not yet been published in an English text. Nevertheless, William Cullen insisted on using the theory of chemical affinities to teach his students, suggesting the pivotal roles that Cullen and, in a larger sense, pedagogy, served for the popularization of chemical affinity tables outside of France.[105] Many individuals practicing chemistry, whether pharmacists, metallurgists, or researchers, were well-acquainted with the behaviors outlined by Geoffroy's table in 1718.[106] For the students just starting chemistry in the classroom of William Cullen, however, the processes described by the chemical affinity tables were neither familiar nor previously observed. These students thus studied the table before they witnessed the syntheses and displacements that gave rise to the rows and columns found in the table. Each reaction they observed was filtered through the theory they had learned in the table, and the explanations provided to them by Cullen. This initial prominence provided the chemical affinity tables with a new and refined explanatory and predictive role. Pedagogy reconfigured the chronological order in which individuals experienced observations and recordings, and from this, William Cullen established a tradition of using chemical affinity tables in teaching that would later be perpetuated by his own former students in Britain and all across Europe.

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[104] "The Operations of Chemistry," MS 268/1
[105] Ibid.
[106] Taylor, "Variations on a theme," 52.

It is worth interrogating, then, if there is any quality unique to chemical affinity tables that allowed them to be so readily accepted, but only when they were introduced in an educational context. Indeed, as I have described before, the initial response to Geoffroy's chemical affinity table was as non-existent as the theory which accompanied it. A reproduction of Geoffroy's table did not occur until 1730, nearly 15 years after the first appearance of the table in literature, while an English translation was not present until the 1760s.[107] The uneven distribution of chemical affinity tables during the course of the eighteenth-century further illustrates the pivotal role that pedagogy played in their dissemination and incorporation.

The educational precedent set by Cullen was taken up by many of his students who continued on in their careers to become lecturers themselves.[108] The affinity tables now not only provided predictive communication of chemical reactions, but also enabled predictive communication of chemical education in the way that they fostered dialogue between successive lecturers. Few students of Cullen accomplished this task so successfully and prolifically as Joseph Black, whose lecture notes, like those of Cullen, survive in abundance across the world today.[109] Black, however, seemed to take the didactic techniques of his predecessor a bit further through his incorporation of diagrammatic demonstrations. These demonstrations added a new dimension to the table, in the sense that they bridged the relationship between the active experimentation of the professor/chemical reaction and the passive recording of the student/printed table.[110] At the time when Black was teaching in Scotland, students were practiced in "recognizing, reading, and inscribing visual patterns," as it was commonly held that straight lines and geometric shapes were visual representations of how ordered thought was

[107] Kim, *Affinity That Elusive Dream*, 223; Roberts, "Setting the Table," 102.
[108] Wightman, "The Teaching of Chemistry," 155.
[109] Crosland, "The Use of Diagrams," 75.
[110] Ibid., 75.

meant to work.[111] The ordered nature of chemical affinity tables, then, made them highly valuable and accessible to students first entering the chemistry classroom. Moreover, the regular, ordered structure of these tables demonstrated strong agreement with English desires for a moral and socially conscientious science. Featuring these tables prominently in the education of chemistry, then, underscored its moral foundation and would help to legitimize chemistry as a scientific discipline in Britain.

Black was not content simply to have his students memorize printed tables, however, as he repurposed the patterns of Geoffroy's chemical affinity table to create his own tables and figures that he would use as diagrams in his lectures to represent experimental designs and chemical reactions. When the collection of Black's remaining lecture notes is considered as a whole, they are notable for the emphasis placed on chemical affinity by his various diagrams.[112] Excluding the notes that depict experimental preparation and the apparatus used to do so, Black dedicates his diagrams nearly exclusively to depictions of affinity relations, indicative of the central role that these reactions played in the foundational education of chemistry in the mid-eighteenth century.[113] His diagrams are visually familiar in their use of straight lines, columnated information, and symbols, but they also feature unique shapes that help to differentiate the conceptual information that they were meant to convey. These visualizations took the form of three different shapes: a chiasm, a rectangular table, and a circle. Each of these shapes would be modified with various headings in, around, or on the diagrams, and these labels helped to establish the directionality of each unique diagram.[114] Chemical affinity tables, then, proved

[111] Eddy, "How to See a Diagram," 182.
[112] Joseph Black, *Lectures on the elements of chemistry, delivered in the University of Edinburgh,* (Edinburgh: Mundell and Son, 1803), 88, 91, 93.
[113] Ibid.
[114] Eddy, "How to See a Diagram," 185.

themselves to be highly adaptable to deliberate variations and manipulations that would be useful for highlighting specific aspects of chemical theory while simultaneously maintaining the same theoretical and experimental basis despite changes in appearance.

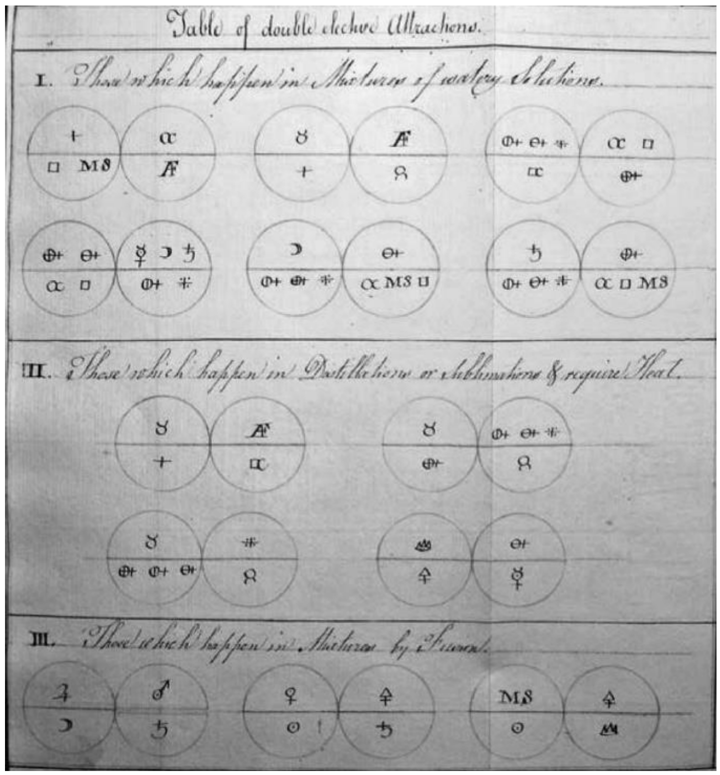

Figure 9: A Circle Diagram Drawn by Joseph Black to Show Double-Elective Affinity Relationships. In this instance, the familiar grid-structure of affinity tables has been remade to incorporate circles, which were useful for the instruction of more complex reactive relationships.

Black used his diagrams to demonstrate that the concept of affinity could both explain and predict the course of a chemical reaction, solidifying the import of chemical affinity tables in Scottish pedagogy. His affinity charts were typically lined tables with an outer square border separated into a series of rows and columns by straight, intersecting lines. Alchemical symbols representing different chemical substances would fill the internal cells, and they would be arranged according to attractive relations such that information could be gleaned when reading the table from left to right and from top to bottom.[115] His tables, exactly like those printed within textbooks, explained how one substance would leave its initial compound in order to combine with another substance for which it had a greater attraction. Black would offer his students reproductions of a large table depicting several common substances, just as Geoffroy had done, but he would also present his students with smaller tables that represented a specific group of chemical affinities or reaction conditions, such as heat.[116] Each of these tables used the same principles of visual proximity to suggest that objects located nearer to one another share greater similarities than those placed far away. This implicit understanding, however, only gained significance as Black coordinated these meanings with oral explanations of chemical behavior during his lectures. Throughout the notes of his students, Black is recorded as regularly referring to "weak" and "strong" attractions between chemical substances.[117] While these qualifiers are commonplace in the chemistry lectures of today, for Joseph Black and his students they were novel verbal expressions that conceptualized the relationships implied by the visual proximities of different substances found within the affinity tables. Throughout his lectures, Black utilized the unique visual principles afforded by chemical affinity tables in order to demonstrate the underlying chemical theory of elective attraction that governed their creation.

The distinct unifying quality of chemical affinity tables is made most apparent when the classrooms of France are examined in comparison to those of England. As in England, by the mid-eighteenth century, an expansive variety of chemistry courses were available to French students.[118] The courses were taught by either professors or demonstrators, who, although not

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[115] Joseph Black, *Notes from Dr. Black's Lectures on Chemistry 1767/8*, Thomas Cochrane (Note-taker), Douglas McKie, ed., (Cheshire: 1966), 48.
[116] Ibid., 23, 33-35, 38-41, 118.
[117] Eddy, "How to See a Diagram,"
[118] Christine Lehman, "Innovation in Chemistry Courses in France in the Mid-Eighteenth Century: Experiments and Affinities," *Ambix*, 57, no. [1], (2010): 3; Belmar and Sanchez, "French Chemistry Textbooks," 19.

necessarily trained at universities, had worked as apothecaries, pharmacists, or medical practitioners to gain artisanal experience with chemistry.[119] Accordingly, the instruction offered in France was initially marked by an emphasis on both the theoretical and experimental aspects of chemistry. The object most often chosen to complement these two differing principles was the chemical affinity table, which was incorporated by the prominent courses taught by professors and demonstrators alike.

Trained as an apothecary, Guillaume François Rouelle offered a private course in his laboratory as a way to teach practical chemistry. In order to do so, Rouelle slightly altered Geoffroy's original table so that it included nineteen columns while maintaining the use of alchemical symbols.[120] His students scribbled reminders of relationships shown in this table in the margins of their notes, illustrating that even in this highly practical course, chemical affinity tables were the common means for interpreting chemical operations and predicting chemical behaviors.[121] In this way, the chemical affinity table was made an active tool that allowed the chemist to predict, design, and justify experiments. Alternatively, Macquer, when serving as a lecturer, often used the aid of a demonstrator to experimentally show the reactions which were predicated on theories derived from chemical affinity tables.[122] For Macquer, the affinity table served as the basis of reasoning from which the structure of his course took shape. By acting as both a conceptual framework and a guide for experimental work, the chemical affinity table was indispensable for the lecturers and students of chemistry in mid-eighteenth-century France. The international range encompassed by these diagrams exemplifies their broad applicability and centrality in disseminating chemical theory in their facilitation of education.

[119] Lehman, "Chemistry Courses in France," 4.
[120] Ibid., 5.
[121] Ibid., 18.
[122] Ibid., 21.

As tables became representations of theories and a means to communicate these theories, they also took on a role in supporting arguments or disassembling them. The 1770s and 1780s were marked by an influx of new tables which drastically restructured and reimagined the original form of Geoffroy's chemical affinity table, suggesting a slight shift in the underlying purpose of these figures.[123] Notably, the tables that emerged during these decades were founded on nomenclature while maintaining the same goal of chemical organization. Guyton de Morveau's 1782 "Tableaux de nomenclature chymique" sought to provide the names of basic substances, ordered according to their behavior in nature.[124]

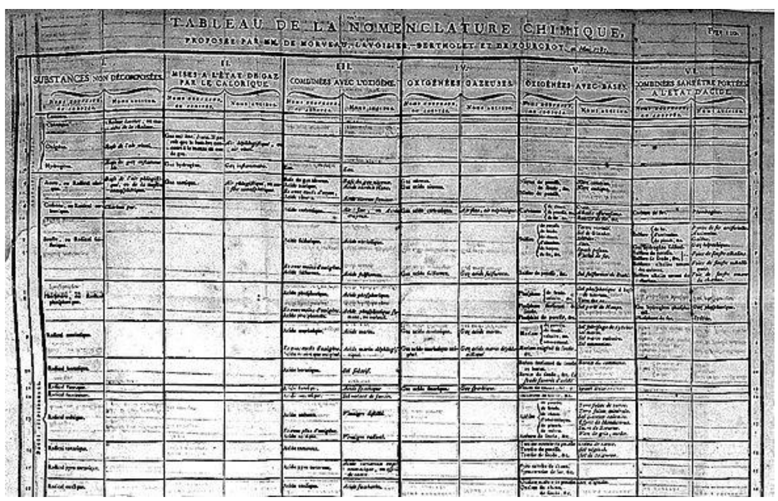
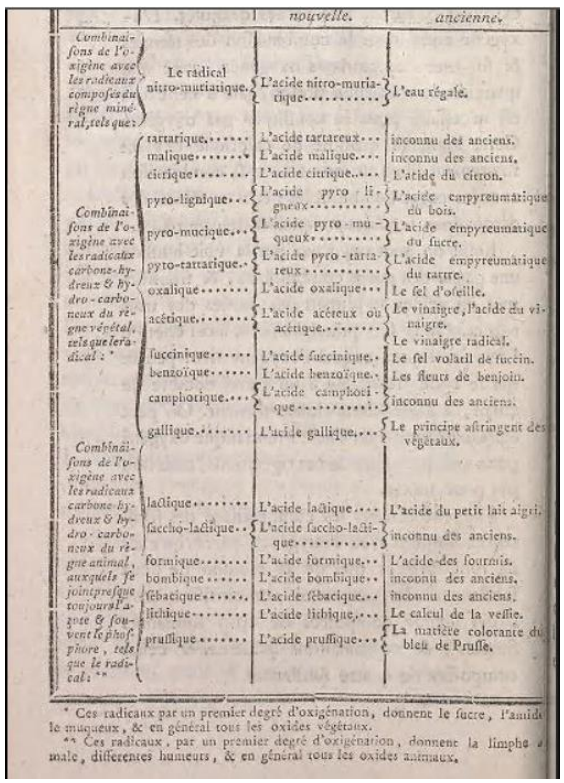


Figure 10: "Tableaux de nomenclature chymique," 1782. This new tabular form emphasizes a fluid left-to-right reading directionality.

On the left-hand side of the table was a column of certain known acids classified as either animal, vegetable, or mineral. To the right of this were columns listing the salts derived from the combination of the acids with various bases. de Morveau's table was meant to be read left to

[123] See: Kim, *That Elusive Dream*, 223, 264; Roth, "table of relations," 193; Demachy, *Recueil de dissertations*, appendix*;* de Limbourg, *Dissertations sur les Affinites Chymiques*, 79; Marherr, *Dissertatio Chemica de Affinitate Corporum*, 101-106.
[124] de Morveau et al., "Méthode de Nomenclature," 48.

right, much like the text of a book, imbuing the table with a fluid sense of motion not present in Geoffroy's original table. Moreover, de Morveau's table featured a much less comprehensive listing of substances than even the earliest chemical affinity tables. The goal of de Morveau's table was thus not to recite how all substances related to one another, but to provide a step-by-step guide on how to combine known chemical substances to produce desired products. Reading the across the table mimics this physical process of combining elements, thus demanding interaction from the user. Here, the predictive and practical nature of the table appear even more explicitly.



		nouvelle.	ancienne.
Combinaiſons de l'oxigène avec les radicaux composés du règne minéral, tels que:	Le radical nitro-muriatique.	L'acide nitro-muriatique..........	L'eau régale.
Combinaiſons de l'oxigène avec les radicaux carbone-hydreux & hydro-carboneux du règne végétal, tels que le radical: *	tartarique.......	L'acide tartareux...	inconnu des anciens.
	malique........	L'acide malique....	inconnu des anciens.
	citrique........	L'acide citrique.....	L'acide du citron.
	pyro-lignique...	L'acide pyro-ligneux..........	L'acide empyreumatique du bois.
	pyro-mucique...	L'acide pyro-muqueux..........	L'acide empyreumatique du ſucre.
	pyro-tartarique..	L'acide pyro-tartareux..........	L'acide empyreumatique du tartre.
	oxalique.......	L'acide oxalique...	Le ſel d'oſeille.
	acétique........	L'acide acéteux ou acétique.........	Le vinaigre, l'acide du vinaigre. Le vinaigre radical.
	ſuccinique......	L'acide ſuccinique..	Le ſel volatil de ſuccin.
	benzoïque......	L'acide benzoïque..	Les fleurs de benjoin.
	camphorique....	L'acide camphorique..........	inconnu des anciens.
	gallique........	L'acide gallique....	Le principe aſtringent des végétaux.
Combinaiſons de l'oxigène avec les radicaux carbone-hydreux & hydro-carboneux du règne animal, auxquels ſe joint preſque toujours l'azote & ſouvent le phoſphore, tels que le radical: **	lactique........	L'acide lactique....	L'acide du petit lait aigri.
	ſaccho-lactique..	L'acide ſaccho-lactique..........	inconnu des anciens.
	formique.......	L'acide formique...	L'acide des fourmis.
	bombique......	L'acide bombique..	inconnu des anciens.
	ſébacique.......	L'acide ſébacique...	inconnu des anciens.
	lithique........	L'acide lithique....	Le calcul de la veſſie.
	pruſſique.......	L'acide pruſſique...	La matière colorante du bleu de Pruſſe.

* Ces radicaux par un premier degré d'oxigénation, donnent le ſucre, l'amidon, le muqueux, & en général tous les oxides végétaux.

** Ces radicaux, par un premier degré d'oxigénation, donnent la limphe animale, différentes humeurs, & en général tous les oxides animaux.

Figure 11: Binary Combinations of Oxygen with Simple Substances. Here, Lavoisier presents a simpler chart than that which was previously developed by de Morveau, while also adhering to the fluid directionality of left-to-right motion, 1789.

Maintaining this same left-to-right style as de Morveau, in 1789 Antoine Lavoisier produced a series of tables in his *Traité élémentaire de chimie* which displayed binary combinations of oxygen, nitrogen, and hydrogen with simple substances.[125] The first column on the left-side of the table gave the names of a variety of these simple substances. Following the table across the page, it showed the compounds that were created when each specific substance reacted with oxygen, spelled out in binomial nomenclature, with details of how the substances came together. These foundational changes reflect the significant evolution that occurred on the surface of these chemical tables. Once mere repositories for experiments in the writing of Geoffroy, chemical affinity tables eventually became sites of discussion and education for William Cullen and Joseph Black, before the tables themselves transformed into active sites of experimentation for de Morveau and Lavoisier. These experimentations with form changed the types of information that the table could convey and reshaped the experience of the reader using it, thereby reconfiguring the expressional power of chemical affinity tables.

With an increased theoretical significance, chemical affinity tables no longer acted only as domains of local communication, but also fostered dialogue between users internationally as they acted as arbiters in debates regarding dominant chemical theories. Writing to de Morveau, Irish chemist Richard Kirwan referenced the order of affinities provided in Lavosier's tables in order to rebuke de Morveau's anti-phlogiston explanation for the process of chemical affinity.[126] Kirwan presented de Morveau with an ultimatum: either revise the tables, or disregard the theory, explaining, "Have I not destroyed your table of affinities from top to bottom, and, without such a table, is it possible to make progress in chemistry?"[127] The chemical affinity table remained the critical link between theoretical explanation and practical experience, and it is evidenced from this exchange that the table constructively facilitated communication between

[125] Antoine Laurent Lavoisier, "*Traité élémentaire de chimie*," (Paris, 1789): 208, 212, 216.
[126] Cohen, "The Element of the Table," 61.
[127] Quoted in: Cohen, "The Element of the Table," 62.

scientists of different regions and different fields of thought. Within this isolated system, the table continues to perform multiple functions. The table, as printed, is in and of itself a resource that Kirwan uses to question the theoretical conclusions drawn from this resource. Here, the fault that Kirwan identified is not in the table, but in the theory constructed around it; that is, the table itself generated issues within theoretical positions. The structure and function of chemical affinity tables are accordingly shown to have evolved along with the theoretical development of chemistry and to have forwarded international communication that fostered the development of a singular and consistent theoretical framework, thereby helping to establish chemistry as a legitimate and autonomous scientific discipline.

CLOSING REMARKS

The persistence of chemical affinity tables throughout the eighteenth-century indicates their great significance during a precarious time for the discipline of chemistry. Simultaneously needing to demarcate themselves from the practical world of alchemists and the purely theoretical realm of mechanical philosophy, chemists across Europe were unified by their use of affinity tables. Along these frontiers of theory and practice, the boundaries of chemistry needed to continually expand and contract in order to meet the changing demands of the societies in which it was practiced. The chemical affinity table, from its first introduction by Etienne-François Geoffroy, provided a productive space where boundaries could literally be redrawn and redesigned as chemists navigated their newly emergent discipline. This boundary-work, although deliberate, was by no means a story of linear progression: sometimes, reagents were found to be inert, and groundbreaking publications were met with decades of silence, other times, experiments bubbled over, and chemists were left with tables housing more columns than

Ancient Rome. Yet as the affinity table gradually spread across Europe, its form and contents changed many times to reflect the continual, ongoing, and messy process of creating a chemical discipline.

Simultaneously, these tables recorded observed experimental phenomena and predicted chemical behavior that influenced experimental design and justification. The table itself thus was derived from and a driving force of experimentation. Yet their prominent role in the classroom, as accessible representations of the forces governing chemical behavior, allowed these tables to be linked to discussions of chemical theory throughout the century. Indeed, before the introduction of affinity tables, much of the study of chemistry was focused on the character of matter and of individual particles. The form of the table that necessitates understanding *relational* behavior completely transformed the objective of the science. Now, chemists concerned themselves with compounds and reactions, creating a framework within which new, experimentally verifiable and practically applicable, theories could be developed. As such, the chemical affinity table was all at once reconstructive, predictive, didactic, and communicative, ultimately emerging as the fundamental object that fostered the disciplinary a disciplinary chemistry *evolution* in eighteenth-century Europe.

[Word Count: 11,909]

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Bibliographic Essay:

When I first started this project, I had intended to write about how the periodic arrangement of chemical elements fostered new modes of scientific prediction. As a chemist myself, I thought it would be interesting to investigate the history of an object that I use every day in order to understand better how the construction of physical forms of organization simultaneously sets new potentialities and limitations on scientific activities. Although I wandered into the Medical Historical Library at Yale University with little more than this topic and a general idea of the time-period I wished to study, I soon found myself inundated with secondary sources that traced the emergence of the Periodic Table from nearly every perspective imaginable. Other scholars, it would seem, shared my interests. While reviewing one of the odd books I had picked up for my research on the periodic table, I came across a photo of a chemical affinity table, dated 1718. This peculiar little chart, with its lack of any textual information and use of alchemical symbols, was unlike anything I had seen before. I was absolutely enchanted, and I wanted to learn more about this object that seemed wholly familiar but, at the same time, entirely unique.

I started my research by reviewing the current scholarship present on chemical affinity tables regarding their histories, uses, and implications. I came across several secondary-sources that acknowledged the relationship between the structure of the table and the work which chemists performed. Notably, the essays from Matthew Eddy and Benjamin Cohen, which examine how the visual appearances of these diagrams changed how the practice of chemistry, echoed many of the sentiments that I felt when I looked at the table. These objects were so successful, they argued, because of how they imbued familiar structures with new meaning. These documents further led me to different works by Lissa Roberts, who has written extensively on this subject, and Maurice Crosland, who writes on the unique reaction diagrams that were made possible by the extension of chemical affinity tables. Although each one of these analyses essentially offers the same conceptualization of chemical affinity tables—that they were dynamic spaces of construction capable of reshaping various relationships—they all present these tables within different contexts, enabling each argument to distinguish itself from the others. In reviewing further this secondary-literature, I began to consider how I would come to differentiate my own argument regarding these tables.

I moved then to the examination of broad accounts of the history of chemistry during the eighteenth-century in addition to secondary-literature written about critical approaches to visual anthropology and visual culture within science. I wanted my essay, more than anything, to tell a story, and I felt that having both a strong contextual basis and a robust theoretical framework would be essential for me to accomplish this. There is a vast catalogue of secondary-literature written about the history of chemistry, though in quite a few of these texts, chemical affinity tables are nothing more than a footnote. Nevertheless, these resources provided me with an expansive overview of the status of chemistry at this time, and signaled that this field lacked a cohesive, disciplinary identity. Additionally, I found the scholarship regarding visual culture to be equally robust, with reports analyzing different forms of representation readily available. I decided to place my main focus in the works of Ursula Klein, as she pioneered the notion of a "paper tool," which I hoped to apply to my object of interest, the chemical affinity table. In reviewing related works on diagrammatic paper tools, however, I did not find any that referenced chemical affinity tables beyond those I had already read. This seemed like an interesting opportunity for a new scholarly contribution, and from these general histories and theoretical backgrounds, I began to build the framework for my essay. Although chemical affinity tables would lie at the heart of my analysis, the various chemists who used them, and the ways in which they traveled, would ultimately reveal their true utility.

I turned next to an examination of primary literature. I started with the published writings of the scientists who continually appeared in my readings: Etienne-François Geoffroy, Torbern Bergman, Antoine Lavoisier, and Claude-Louis Berethollet, just to name a few. These chemists of the eighteenth-century proved to be very prolific writers, producing innumerable textbooks, treatises, dissertations, and public lectures throughout the century. Many of these documents were either available through online databases, in republished collections or anthologies, or as part of the Yale University library system, so I was able to review a comprehensive variety of these historical writings. With my survey of scientists stretching all across the European continent, I encountered these texts appearing in various languages over time. Although I can read English, German, Latin, and French, I found it very challenging to understand the scientific writing style of this time-period, and I often elected to read English translations of works when they were available in order to avoid misinterpretations. Initially, I had imagined that understanding how chemical theories were translated across texts would be a vital part of my argument, but as I came to realize how limited my command of these different languages was, I decided to refine my focus even more. Accordingly, I started to become much less concerned with the language that was used to elaborate chemical theory and focus even more intently on the visual appearance of these chemical affinity tables to help guide further reading.

While it was easy to find a publication of Geoffroy's first chemical affinity table and its accompanying memoire, locating other complete examples of chemical affinity tables proved to be a little more difficult. Often, chemical affinity tables were printed as foldouts within textbooks or appended across multiple pages at the end of texts. Because of this, I found that tables would often be missing from textbooks completely or have significant sections missing when I looked for them within literature. In 1781, Jacques-François Demachy reproduced a large number of different affinity tables in his text, *Recueil de dissertations physico-chymiques, présentées à differentes academies,* and this source proved vital for locating many examples of tables to observe how they changed over time. More recently, Mi Gyung Kim has done similar work and compiled a book containing several examples of tables from Demachy as well as other sources. In all instances, I made my best attempt to find chemical affinity tables as close to their original publications as possible, but often I found that I had to refer to these two reprints in order to obtain a useful visual.

Once I had developed a decent understanding of how chemical affinity tables changed in appearance over time, I looked to other primary texts of the eighteenth-century to ascertain why these changes happened and what they meant for chemists and the discipline of chemistry as a whole. Two names that continually appeared in the literature I reviewed, both primary and secondary, were Joseph Black and William Cullen. These two lecturers of chemistry in Scotland had some of the most influential careers of any of their contemporaries, so I started to review archives of their lectures in order to see what made these individuals distinct. I found that the Glasgow University Library and the Wellcome Library for the History and Understanding of Medicine both hold significant manuscript collections of lectures from William Cullen, while those of Joseph Black exist within a comprehensive reprinted publication and in public databases. I was able to access a few key scans of the manuscript archives from both library sources, though the pieces that I was able to receive and review are just a fraction of the entire collection of lecture notes that exist from this source. Nonetheless, these archives provided me with a newly personal perspective from which to view chemical affinity tables. In the lecture notes of these men, chemical affinity tables came alive and demonstrated a new sense of activity that I had not observed for them before. It is here that I wish I had a better command of French and German or Swedish, as this would have allowed me to complete similar analyses for these regions as well. Unfortunately, when reviewing the teaching styles of Rouelle and de Morveau, I remained dependent on English translations that were present within secondary-literature in order to draw comparisons between different didactic intentions. Reviewing even just this small sample of archival information, however, provided me with the overarching metaphor that I would use throughout my argument; that is, that chemical affinity tables were able to expand and contract with the changing disciplinary boundaries of chemistry in order to reflect the specific purposes of the chemists who employed them.

With this new idea in mind, I revisited the primary publications from eighteenth-century authors and now read them in relation to one another, finding that many texts originating from the same nation seemed to have distinct characteristics. I was then able to place these findings in dialogue with my secondary-literature, which describes different national objectives and how this changed the landscape of chemistry within these areas. Moreover, I was able to find that several authors specifically invoked ideas of chemical affinity or chemical affinity tables themselves in order to initiate discussions with other chemists. This added a further layer to the utility of chemical affinity tables, and inspired me to seek out literature describing how textbooks, in general, foster scientific communication. Throughout my research, I was thus able to acquire not only a considerable amount of contextual information, but also a number of personal accounts, public writings, and a diverse theoretical framework which helped me to interpret all of these competing details.

As I explain throughout my essay, the trajectory followed by chemical affinity tables was, ironically, a disordered one that was marked by continual revisions, redesigns, and reinterpretations. The path followed by my research was a similarly messy route, in which I often found myself revisiting sources multiple times as I would find new uses for them, going back and forth between the validity of using translations or reading a source in its native language, and discounting certain material only to find it more valuable later on. Finding a balance between these competing limitations did, at times, prove to be a challenge, but I believe that through careful and critical analysis of each source I was able to craft an argument reflective of the complexities of both this topic and the research process as a whole.