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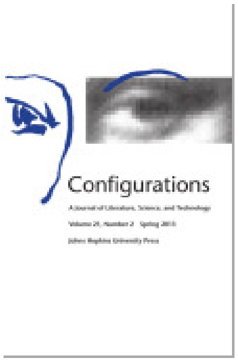

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The Element of the Table: Visual Discourse and the Preperiodic Representation of Chemical Classification

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Visual representations do things: they can sit quietly and be observed; they may aid in the performance of some activity, let's say, in science; they may act as repositories for previously compiled information; they may, through the format of their presentation, guide users or readers toward new ideas, or new practices. In science, and in chemistry particularly, visual representations are vital components of the material culture of practice. (Such an observation is not new.) Classifications in the sciences can be described with many of the same terms as visual representations. Classifications do things: they compile the past; they frame the future; they aid in the practice of a science; either they may be embedded within a theoretical edifice, or a theory may be embedded within them (if there is a difference). When we combine these two singularly rich subjects in scientific and artistic studies to focus on how classification schemes are visually represented, another view of history opens up that questions a presumed temporal order: here the representation is not necessarily the end point of a study; instead, it can be viewed as a productive contributor to the process that creates classifications and science. Those representations have a dual temporal direction, bringing the past into the present while also pointing to the future. Chemistry tables in particular exemplify this role in the practice of chemistry by acting as complex symbol systems defined by tabulations in grids, boxes, and spaces.

This paper is a study in the visual representation of chemical classification. In it, I discuss the active function of tables in the history of chemistry, arguing that those dynamic roles have in fact been en-

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abled and fostered by their visually representative characteristics. To this end, I have two main goals. The first, fairly modestly, is to comment on the dual function of tables that looks to the past by collecting empirical information while directing practice toward the future by providing a view of how chemical substances relate to one another. The second, in which I expand the literature on serial linguistics to include spatial and graphic symbol systems, is to show that the visual discourse of the tables can help us understand that dual role. One popular story, of course, is that the iconic Mendeleevian periodic table of 1869 owes its glory to its uncanny ability to predict the unknown (directing practice toward the future), and as such is a paradigmatic historical example of dually collecting the past and guiding practice forward. But this accomplishment has its own history, one understood better when tables from the history of chemistry are treated as complex symbol systems. In fact, in what follows, I take the introduction of the periodic table as the *end* point to my story.

In general, then, I treat the chemistry table as a technology of representation, or a representational tool—a device used to perform a task—the visual grammar of which could be read. My primary contribution here is to take the idea of a linguistic study of the table (something that can be read) and add to it the idea of a visual study of classifications (a representation for which it mattered how it looked). The theme of treating the table as a discursive visual tool speaks to ideas of visual cognition, of the importance of nomenclature and language, and of how the construction and use of the table may be thought of in terms of a "paper tool."[1] While the history of

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[1] On the issue of visual cognition I refer here to the work of Barbara Stafford, notably *Artful Science: Enlightenment Entertainment and the Eclipse of Visual Education* (Cambridge, Mass.: MIT Press, 1994). On the complex issue of nomenclature and language, in general, I refer to the work of Michel Foucault, *The Order of Things,* trans. Alan Sheridan (New York: Random House, 1970). With particular attention to chemistry, see Jan Golinski, "Chemistry in the Scientific Revolution: Problems of Language and Communication," in *Reappraisals of the Scientific Revolution,* ed. David Lindberg and Robert Westman (Cambridge: Cambridge University Press, 1990), pp. 367–396; idem, *Science as Public Culture* (Cambridge: Cambridge University Press, 1992); idem, "The Chemical Revolution and the Politics of Language," *Eighteenth Century* 33:3 (1992): 238–251. And with even more particular attention to chemistry's tables, see Lissa Roberts, "Setting the Table: The Disciplinary Development of Eighteenth-Century Chemistry as Read Through the Changing Structure of Its Tables," in *The Literary Structure of Scientific Argument,* ed. Peter Dear (Philadelphia: University of Pennsylvania Press, 1990), pp. 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. Ursula Klein has articulated the concept of the "paper tool," and it is from her that I extend the idea. See, in particular, Ursula Klein, "Paper Tools in Experimental Cultures," *Studies in the History and Philosophy of Science* 32:2 (2001): 265–302; idem, "Berzelian Formulas as Pa-

the table is one where both linguistic and pictorial symbols play a central role—since the occupant of the table (say, an alchemical symbol, or the letters "Hg") is a kind of simple symbol, while the table itself is a complex symbol—I will focus here, for the most part, on the actual composite table as a visual representation.[2] This will make more sense as I progress through my discussion. Here is the important point: the table as a pictorial visual representation was not capably reducible to linguistic expression. That is, the visual arrangement of the table was not simply an equal alternative to a written expression of the same information. In this capacity, tables offered, and still offer, distinct cognitive advantages in their suggestive, predictive role.

My other main theme, about the dual temporal role of the table, is a conceptual and heuristic point that can be used to trace the different types of tables in the history of chemistry. Part of the subtext to this

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per Tools in Early Nineteenth-Century Chemistry," *Foundations of Chemistry* 3 (2001): 7–32; idem, ed., *Tools and Modes of Representation in the Laboratory Sciences* (Boston, Mass.: Kluwer, 2001); idem, *Experiments, Models, Paper Tools: Cultures of Organic Chemistry in the Nineteenth Century* (Stanford: Stanford University Press, 2003).

[2] There is a growing body of literature in Science Studies that deals with visual representations in science as nonreducible to linguistics and as deserving of specific attention. Martin Rudwick, "The Emergence of a Visual Language for Geological Science, 1760–1840," *History of Science* 14 (1976): 149–195, is a seminal work in this regard. Some more recent works are Brian Baigrie, ed., *Picturing Knowledge: Historical and Philosophical Problems Concerning the Use of Art in Science* (Toronto: University of Toronto Press, 1992); Steve Woolgar and Michael Lynch, eds., *Representation in Scientific Practice* (Cambridge, Mass.: MIT Press, 1990); Barbara Stafford, *Artful Science* (above, n. 1); idem, *Good Looking* (Cambridge, Mass.: MIT Press, 1996); Alex Soojung-Kim Park, "Visual Representation and Post-constructivist History of Science," *Historical Studies in the Physical Sciences* 28 (1997): 139–171; and Klein, *Tools and Modes of Representation* (above, n. 1). Interestingly, David Knight contributes an essay to Baigrie, *Picturing Knowledge,* which contends that the visual language of chemistry developed in the nineteenth century. Knight does not consider the table in his review of visual representations in chemistry, except to say that the trajectory of visualization in chemistry led *from* pictures and illustrations *to* tables and diagrams; the view I develop in this paper in part undermines the separation that Knight offers between a picture and a table: David Knight, "Illustrating Chemistry," in *Picturing Knowledge,* pp. 135–163. In addition, recent philosophical literature clarifies and extends arguments made with the theory of symbols offered in Nelson Goodman, *Languages of Art* (Indianapolis, Ind.: Hackett, 1976), by noting the differences between a linguistic visual representation—in which the *sequence* of letters, each of which has a shape that is arbitrarily defined, is the important factor—and a pictorial visual representation, where the *arrangement in space* of the elements is the important factor in making meaning. See Michael Ruse, "Are Pictures Really Necessary? The Case of Sewell Wright's 'Adaptive Landscapes,'" in Baigrie, *Picturing Knowledge,* pp. 303–337; Laura Perini, "Explanation in Two Dimensions: Diagrams and Biological Explanations," *Biology and Philosophy* (forthcoming); idem, "Visual Representations and Evidence: Why Do Scientists Use Figures to Defend Their Hypotheses?" (unpublished manuscript).

paper, following this second theme, is a highlight of the active dimension in the history of chemistry and science, a focus on what chemists *do* with a given object, and not just on how that object was created. When chemists read tables of classification, they are not only engaging with an extant system of ordering and relating, but also participating in the history of that table—its production, consumption, and alteration. I mean this in the sense in which Michel de Certeau describes the practice of everyday life, wherein he uses the category of "trajectory" to "suggest a temporal movement through space" that shows us that in the activity of consumption is also a silent production.[3] By focusing on the presentation of the table as only a moment in that larger trajectory I do not seek to undermine current views of the table as an isolated object of study, but to complement and extend them. Historiographically, I suggest a forward-looking temporal focus that indicates the constant motion of science as a creative act—that, in this case, the tables of classification have always been elements of practice which were activated when read in the laboratory or when referred to in the text.[4] De Certeau notes, in perhaps a concise summary of his entire project, that "surveys of routes miss what was: the act itself of passing by."[5] In a similar vein, the table need not be just a survey or an overview, but can be part of the very act of classifying.

This perception of the duality of classifications has wide currency among current historians' views of the development of the chemical sciences, though scholars have not identified the visual aspect of the

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[3] Michel de Certeau, *The Practice of Everyday Life,* trans. Steven Rendell (Berkeley: University of California Press, 1984), p. 35.

[4] Michel Foucault also observes the dual temporal direction of the table, in that with any extant classificatory table, where knowledge from the past is compiled, there are "black squares left to accommodate the invisible" (Foucault, *Order of Things* [above, n. 1], p. 136). Nelson Goodman, writing on a theory of symbols, likewise echoes the sentiment when he writes that "if representing is a matter of classifying objects rather than that of imitating them, of characterizing rather than of copying, it is not a matter of passive reporting" (Goodman, *Languages of Art* [above, n. 2], p. 31). I need to note also that my discussion in the following is based on a study of table producers and of historically well-known chemical actors who used and responded to them—based on discussions of the tables that one finds in texts, memoirs, and journals—and not on lower-level practitioners who would come across such tables in daily use in schools or laboratories or lectures. I encourage and welcome more research into diaries, personal journals, and laboratory notebooks as a useful way to investigate the points I am making, or to study in a different way how the use of tables was aligned with daily laboratory practice. However, with overtures toward material practice and practical contexts, the present paper aims at furthering the conceptual and heuristic point about the role of the visual in the representation of classification.

[5] De Certeau, *Practice of Everyday Life* (above, n. 3), p. 97.

classification as a consistent feature of different tables. In particular, Alistair Duncan has written extensively about the idea in eighteenth-century tables for the purpose of showing how chemistry developed its own theories of matter.[6] Lissa Roberts has also made important contributions to the history of the eighteenth-century chemical table.[7] She does so to establish a more refined point about the manipulative tendency of chemists: that those skills of manipulation and rearrangement help to explain the move from art to science, from dispersed sets of craft skills to disciplined forms of study. Again, both scholars have observed the dual role of the table, but neither did so for the purpose of showing that the table was one means with which the activity of chemistry was performed, nor of demonstrating that the visually representative features of the tables can help explain this usefulness. My goal is to extend the discourse of tables by treating them as discursive tools themselves: as such, they are both useful *and* active, not either instructive *or* static.

This paper comes in two parts. The first, larger section discusses eighteenth-century tables. My story begins with the "Table des rapports" of Étienne-François Geoffroy, and follows from there episodically.[8] From at least the early eighteenth century, practitioners of the chemical sciences have used tables as both organizational devices for collecting the known and practical guides for directing work toward the unknown. This conceptual, practical, and heuristic role was fairly consistent across the broad historical span from Geoffroy's 1718 contribution to Mendeleev's 1869 periodic table, despite the uncountable variations in chemical theory, experimentation, didactic strategy, and institutionalization over that same time period.[9] After Geoffroy, I discuss the Swedish chemist Torbern Bergman's tables

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6. Alistair Duncan, "Some Theoretical Aspects of Eighteenth-Century Tables of Affinity," *Annals of Science* 18 (1962): 177–194, 217–232; idem, "The Functions of Affinity Tables and Lavoisier's List of Elements," *Ambix* 17 (1970): 28–42; idem, *Laws and Order in Eighteenth-Century Chemistry* (Oxford: Clarendon Press, 1996).

7. Lissa Roberts, "Setting the Table" (above, n. 1); idem, "Filling the Space of Possibilities" (above, n. 1); idem, "The Death of the Sensuous Chemist: The 'New' Chemistry and the Transformation of Sensuous Technology," *Studies in the History and Philosophy of Science* 26 (1995): 503–529.

8. Étienne-François Geoffroy, "Table des différents rapports observés en Chimie entre différentes substances," *Mémoires de l'Académie royale des sciences* (1718): 202–212. Geoffroy's was the first table of rapports, though not the first chemistry table to organize known substances. For predecessors to the eighteenth-century tables see John Christie and Jan Golinski, "The Spreading of the Word: New Directions in the Historiography of Chemistry 1600–1800," *History of Science* 20 (1982): 235–266.

9. By writing about collecting (a reference to knowledge already available) and directing (an intimation of where to go in the future) my phrasing sounds much like that

of elective attraction (1770s) and then introduce the change in ordering known substances that was under way with the French chemists, such as Louis Bernard Guyton de Morveau and Antoine Lavoisier of the oft-labeled chemical revolution (1780s). It was the table of nomenclature that took on prominence with those French chemists. In the second, shorter section of this paper, I comment on visual representations of classification in the early nineteenth century and then relate my discussion to the concept of paper tools. As I will show, the paper-tools concept, though explicated by the historian and philosopher of chemistry Ursula Klein in the context of early-nineteenth-century organic chemistry, provides a valuable analytical device for understanding the role of the chemical table as far back as Geoffroy. In brief, there is a basic pattern in most of what follows: I discuss what the representation was, how it was used, in what way its visuality mattered, and how it can be characterized as bidirectional, pulling from the past while looking ahead.[10]

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used in a current debate about the reception of the periodic table of the elements. For this debate, see Stephen Brush, "The Reception of Mendeleev's Law in America and Britain," *Isis* 87 (1996): 595–628; Eric Scerri, "Stephen Brush, the Periodic Table, and the Nature of Chemistry," *Die Sprache der Chemie* (1996): 169–176; Eric Scerri and John Worrall, "Prediction and the Periodic Table," *Studies in the History and Philosophy of Science* 32 (2001): 407–452. The question debated by Brush and Scerri is whether the reception of the Mendeleevian periodic law after 1869 (and its ever-present representation in the periodic table) can be explained more accurately by crediting the law's accommodative or its predictive abilities. My view of chemistry tables differs from the sense deployed in the Brush and Scerri articles in two important ways: first, I am more interested in the use of the table in the practice of chemistry, rather than the question of theoretical viability; and second, I focus on the history of the chemistry table that precedes the introduction of the periodic table by well over a century. Developing the practical context of chemistry tables for the 150 years preceding the periodic table may shed light on Brush's and Scerri's broader arguments about accommodating or predicting chemical knowledge, but forcing that point is a subordinate goal of my work.

10. It is important to clarify that my purpose is to explicate the organizational table's role as a functional visual representation. My focus is not on the particular theoretical or metaphysical issues embedded within the compilation, presentation, and use of the tables, but on the fact that *there are* compilations, presentations, and uses of tables. I use historical examples and introduce philosophical questions only for the purpose of informing the points about the utility of those representative tools. The historical issues embedded within this paper are related mostly to the innovations of chemists over the years developing new forms of tabular representation to assist in their practices. My use of historical exemplars, however, is not meant for the purpose of producing a strict, progressive narrative; instead, it is for the sake of identifying common features of chemical practice in transhistorical contexts. Because of this, philosophical issues come into play as well—such as the role of the visual representation in knowledge-making, the differences between serial linguistic and spatial graphic representations, and the philosophy of praxis necessary to place the table inside the everyday activity of chemists. The two sets of issues, historical and philosophical, are not distinct from one another. For ex-

Tables are components of and contributors to the material culture of chemistry. They are usefully understood as participating in the practice of everyday chemistry in much the same way as the reading of a text. And they can be regarded as tools in much the same way as a laboratory balance, or a set of flasks, or perhaps a reference book. They were something utilized in the process of research that enabled the chemist to fulfill a task. All told, the tables of the history of chemistry share a legacy of visual practices of ordering substances on paper, of long-established habits of teaching and reading chemistry from two-dimensional surfaces, and of investigative practices that drew upon representation. They are, not surprisingly, a constituent element of the activity of chemistry.

Eighteenth-Century Chemistry Tables

Geoffroy

In 1718, Etiénne-François Geoffroy, a physician-chemist working at the Royal Academy of Sciences in Paris, published his "Table des rapports" (Fig. 1).[11] Having worked at the Academy since the 1690s as one of a small group of chemists, Geoffroy sought to provide a device with "transparent pedagogical character" as an "overview of the order in which commonly known substances replaced one another," in the words of historian of chemistry Frederic Holmes.[12] Justifying the enterprise, Geoffroy wrote that "it would be very useful to mark those affinities which the substances commonly met with in chem-

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ample, the philosophy of praxis—the use-value of the tables in practical settings—is a consistent element of the different tables, even though the circumstances surrounding those tables' developments differ markedly. Let me note as well that the episodic presentation of each table is not meant to infer a pseudo-genetic relationship from one table to the next—as might be the goal were my argument predicated on producing a historically progressive story—but rather to maintain a sense of clarity in presentation.

[11] Geoffroy's table has been the subject of many historical treatments. See Duncan, "Some Theoretical Aspects" (above, n. 6); idem, *Laws and Order* (above, n. 6); Frederic Holmes, *Eighteenth-Century Chemistry as an Investigative Enterprise* (Berkeley: University of California Office for History of Science and Technology, 1989); idem, "The Communal Context for Étienne-François Geoffroy's 'Table des Rapports,'" *Science in Context* 9 (1996): 289–311; Ursula Klein, "E. F. Geoffroy's Table of Different 'Rapports' Observed between Different Chemical Substances—A Reinterpretation," *Ambix* 42 (1995): 79–100; idem, "The Chemical Workshop Tradition and Experimental Practice: Discontinuities within Continuities," *Science in Context* 9 (1996): 251–287; Roberts, "Setting the Table" (above, n. 1); William Smeaton, "Geoffroy Was Not a Newtonian Chemist," *Ambix* 18 (1971): 212–214; Stephen Weininger, "Contemplating the Finger: Visuality and the Semiotics of Chemistry," *Hyle* 4 (1998): 3–27. I reference this historical work to discuss the use of the table, while leaving unattended other issues of debate concerning the overriding context of the introduction of the table to the Paris Academy of Sciences.

[12] Holmes, "Communal Context" (above, n. 11), p. 308.

istry show to each other and to construct a table where at a glance one could see the different rapports [*où d'un coup d'oeil on pût voir les différents rapports*] which substances have for one another."[13] With his table, he provided an organizational device for what was known about the displacement of chemical substances, producing a classification of chemical compounds.[14] He displayed visually which kinds of reactions were possible and which were not, each symbol in the table denoting one building-block of the displacement reaction. By the early 1700s, knowledge of chemical compounds had been accumulating, unclarified and unorganized for decades, creating the context of necessity for some manner of ordering. When published in the *Mémoires de l'Académie royale des sciences,* Geoffroy's table was offered as a culmination of accruing experimental results.

As for the actual structure of the table, Geoffroy provided a grid with the substances, represented by their common alchemical symbols, each occupying a box in the header. "The first line of this table indicates different substances used in chemistry," he noted; "below each substance different types of materials are arranged in columns in the order of their rapport with that substance."[15] This means that some substances combined more strongly—made a stronger bond, we might say today—with the header substance. Such, then, were Geoffroy's comments on the construction and formation of the table as he spoke to the reasons for ordering it in his way. His view of the table showed that its actual visual structure was informative for the practicing chemist: it provided an easy reference guide for what to expect in the laboratory and for what experiments might be most fruitful. By reading the table, easily facilitated by the use of symbolic notation as with a picture book, Geoffroy suggested that the practitioner could learn what outcomes to expect and how to get them.[16]

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13. Geoffroy, "Table des différents rapports" (above, n. 8), p. 203.

14. See Klein, "Communal Context" (above, n. 11), for an extended discussion of the experimental basis for the order of the substances in the table. Note also that the table was neither exhaustive nor definitive—that is, as Duncan has observed in "Functions of Affinity Tables" (above, n. 6) the header substances were not an exhaustive list of all known substances at the time.

15. Geoffroy, "Table des différents rapports" (above, n. 8), p. 203. There has been considerable discussion in the literature over the meaning of "rapports," and whether or to what degree the affinity of the substances was set within a Newtonian attraction theory. Here, I interpret "rapport" in the sense of "relationship." See Smeaton, "Geoffroy" (above, n. 11); Holmes, "Communal Context" (above, n. 11); Klein, "Chemical Workshop Tradition" (above, n. 11), for more insight on the issue.

16. Trevor Levere states outright that "affinity tables were above all *useful,* in provid-

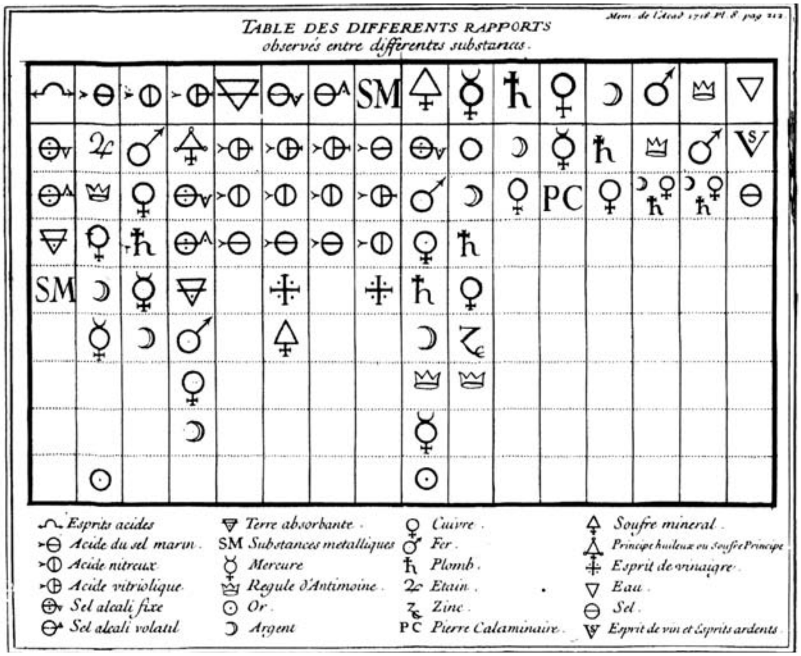

Figure 1. Étiénne-François Geoffroy's "Table des différents rapports observés en Chimie entre différentes substances," from *Mémoires de l'Académie royale des sciences* (1718), p. 212.

How could one make use of the table? Users were directed with the following proposition: "Whenever two substances which have some disposition to join, the one with the other, are combined and a third added which has more rapport with one of the two, the third will unite with one of them, freeing the other."[17] So, as an example, a chemical practitioner would refer to the header of the third column, nitrous acid. Chemists who had a mixture of nitrous acid with silver—silver being listed at the bottom of that (third) column—would mix in lead or iron, both of which were higher up the column than silver; either of those would displace the silver. With such a process, the chemist could perform a task. Thus, Geoffroy said that the table showed the chemist *how to do* things. It acted as a guide in the laboratory. In addition to the widespread use of recipe formulations and instructions, expressed with a linguistic litany that explained how to

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ing a summary of existing knowledge as well as a tool for predicting new reactions" (Trevor Levere, *Transforming Matter: A History of Chemistry from Alchemy to the Buckyball* [Baltimore: Johns Hopkins University Press, 2001], p. 48).

[17] Geoffroy, "Table des différents rapports" (above, n. 8), p. 203.

mix substance A with substance BC to extract substance C and form AB, the chemist could refer to the table and act accordingly. Geoffroy presented the table as a compendium of the relationships among the substances, as organized by prior laboratory practice. He explained the table's function by reference to the order of affinities, easily recognizable from the visual simplicity of the table. For example, in the commentary that accompanied the table, the reader was told how to do things "as appears in the first column," "as appears by the fifth column of the table," "as may be seen in the first column," or "as appears by the eighth column."[18] Within a workshop context, where a chemist's knowledge of chemical substances was derived from practical operations like mining, pharmacy, and other craft traditions, the table was instructive in showing how to move around with chemicals.[19] The innovation of this table lay less in its official construction and static presentation and more in how it could be used by others. It was a tool to be applied in the laboratory.

The table was not complete upon arrival, as could be seen visually in two ways: one, by the triple occupation of singular boxes in the far-right (fourteenth and fifteenth) columns; and two, by the blank spaces at the bottom of the columns. In the former case, Geoffroy admitted that the experimental evidence was not strong enough to differentiate the degree of the relationship, as in column 14, between silver, copper, lead, and the header substance, iron (or, as in column 15, those three with the header substance, regulus of antimony [metallic antimony]). He indirectly appealed to future work, awaiting further exploration before offering the full alignment for those substances; the provisional nature of the boxes indicated that the table could be refined. In the latter case, that of blank spaces in the columns, the table was more directly suggestive for the practitioner. While Geoffroy did not overtly state that yet-unknown relationships would eventually fill in these spots, nor indicate the theoretical nature of those relationships, he did provide the space for future knowledge to be housed. His own commentary on his table summarized these features: "Chemists," he wrote, "will find an easy method to determine what takes place in many of the operations which are difficult to disentangle and to predict what should result when they mix different bodies."[20]

The table's intimation toward the future was a unique consequence of its graphic and spatial organization, as we can tell by criti-

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[18] Ibid., pp. 210–212.

[19] See Klein, "Chemical Workshop Tradition" (above, n. 11).

[20] Geoffroy, "Table des différents rapports" (above, n. 8), p. 203.

cally investigating the format. On this point, it would be helpful to recognize the sequence in which the visual format of the two-dimensional table was activated. That is, put yourself in the shoes of a chemist of Geoffroy's ilk: first, a property of that visual assemblage is that it *requires* blank spaces, since the relations between boxes and grids cannot be collapsed to erase an empty cell; then, the emptiness in the table provides the organizational justification from which future relationships could be coordinated. This indication of potential placement does not exist with a serial, linguistic representation. Here, Geoffroy suggests, the blank space is a performative feature of the table, indicating to the practitioner where future results will be found. In representational contrast to this, blank spaces given in a discursive linguistic format make little sense. The visual feature of emptiness has no counterpart in a serial list. As the historian of chemistry Wilda Anderson characterized it, "The incompleteness of Geoffroy's tables, the blank spaces, therefore, are less a flaw of the theory than an indication to alert researchers as to where work remains to be done."[21] Geoffroy, his readers would understand, presents his table with an intentional forward gaze.

The simple, gridded columnar structure allowed for quick reference for those working in the laboratory and for chemical manipulation. Geoffroy said that the use of this table was "for discovering what takes place in various mixtures of combined bodies . . . and in predicting what may result" from those mixtures.[22] This concept of the table fit neatly within the operational chemical-practitioner context already explored by historians of chemistry, since the physical version of the table was part of a culture of activity. It also fit within a didactic and rhetorical context that would suggest that the table had value as a means of communicating chemical knowledge.[23] For teaching, the table provided quickly and clearly the relations among known substances. For practical laboratory use, the table served as a reference guide. Geoffroy's sense of prediction was admittedly loose, as in "predicting what may result." I characterize it as direction,

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[21] Wilda Anderson, *Between the Library and the Laboratory: The Language of Chemistry in Eighteenth-Century France* (Baltimore: Johns Hopkins University Press, 1984), p. 61.

[22] Geoffroy, "Table des différents rapports" (above, n. 8), p. 203.

[23] For the operational chemical-practitioner context see Holmes, *Eighteenth-Century Chemistry* (above, n. 11); Klein, "Chemical Workshop Tradition" (above, n. 11). For the didactic and rhetorical context, see Owen Hannaway, *The Chemists and the Word* (Baltimore: Johns Hopkins University Press, 1975); Christie and Golinski, "Spreading of the Word" (above, n. 8); Anderson, *Between the Library and the Laboratory* (above, n. 21); Christopher Ritter, "Re-presenting Science: Visual and Didactic Practice in Nineteenth-Century Chemistry" (Ph.D. diss., University of California, Berkeley, 2001).

since the table directed practitioners toward pretested results.[24] In its status as an organizational device, collating the rapports between substances from experimental results, the table directed its users toward the future.

After Geoffroy's contribution, there was a dearth of new tables for several decades; only two were compiled between 1718 and 1749. Toward the latter half of the century, though, chemists rapidly increased the number of table compilations. New versions with more columns and more rows, but without any fundamental change in visual structure, were introduced as quickly as new substances were brought into, or taken out of, the laboratory. By 1783, the tidy, sixteen-column, one-page table of Geoffroy had given way to an unwieldy, fifty-nine-columned, multipage behemoth that had to be presented in duplicate.[25] Several prominent chemists, among them Antoine Baumé, J. L. Clausier, and Joseph Black, had indicated by mid-century that there was a need for tables to be compiled with respect to the method of preparation and experimentation used to determine the order of substances.[26] That is, while Geoffroy's offering was novel because it presented a synoptic view of the results of his research, the novelty of later tables was to recognize that not all laboratory manipulations were performed under the same conditions or with the same techniques.

Bergman

A prime example of a prominent, post-Geoffroy table of relations among chemical substances was that of the Swedish chemist Torbern Bergman. Bergman, who sought to use chemistry for the benefit of mining and industry, was a popular member of a European-wide culture of chemical correspondence, a younger peer to Linnaeus, and a strong proponent of using diagrams and other symbolic representations. Historians have characterized his contributions as being more

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[24] Perhaps this possible ambiguity stems more from the typically used theoretical association of prediction than from the practical component that I am stressing. In that case, the problem is historiographic and not rhetorical.

[25] Torbern Bergman, *An Essay on the Usefulness of Chemistry, and Its Application to the Various Occasions of Life* (London: Murray, 1783).

[26] See Duncan, *Laws and Order* (above, n. 6), pp. 110–170. To be sure, Geoffroy indicated that such a consideration was at play in some of his results: "The theory of this operation [to precipitate corrosive sublimate] is the same as that of the preceding one; here it was carried out in solution—there, in the dry materials" (Geoffroy, "Table des différents rapports" [above, n. 8], p. 211).

practical than theoretical. For example, his tables of affinity were issued as summaries of experimental results, but did not offer explanations for those results. In 1775, Bergman compiled two complete tables, each specific to methods of preparation: one represented results obtained in the "moist" way (with a solvent), and the other represented the "dry" way (with heat). While this extension of the original table indicated attention to process, it also indicated that the table had value as a practical guide. Chemists had learned that the order of relationships between a header substance and those listed in its column was not consistent if the substances were mixed under different conditions. (In fact, Lavoisier later criticized Bergman's wet and dry tables, but not because they were superfluous: on the contrary, he thought there should probably be a table for each degree of temperature.) The innovation that indicated a broader conceptual expansion within the table was still something that fit within the practice-based context of table use.[27]

I include here, as Figure 2, only a portion of one of these tables. Bergman's *Dissertation on Elective Attractions* was written, in part, as a means to explain the table. This literary (serial) expression of the graphic (spatial) representation is itself a testament to the efficiency afforded by the visual nature of the table. Compare, in this case, Geoffroy's twelve-page commentary accompanying the 1718 table with Bergman's dissertation-length treatment; the literary was not equally reducible to the graphical, as the verbiage used to convey the sense given in the tables could not match the visual simplicity of a gridded table.[28] The theoretical implications of "affinity," which over the decades had become the common term of reference for Geoffroy's "rapports," had been a growing concern throughout the century—it is not only today's historians who have debated whether or not affinity was meant to refer to Newtonian attraction. Bergman was aware of such concerns and called his relationships "elective attrac-

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[27] See Torbern Bergman, "Disquisitio de attractionibus electivis," *Nova Acta Regiae Societatis Scientiarum Upsaliensis* 2 ([1775] 1968): 161–250, trans. J. A. Schuffle, *Dissertation on Elective Attractions.* This is a reprint of the first edition of Bergman's dissertation. The preceding paragraph owes much to William Smeaton, "Bergman, Torbern Olof," in *Dictionary of Scientific Biography,* vol. 2, ed. Charles Gillespie (New York: Scribner and Sons, 1980), pp. 4–8.

[28] Torbern Bergman, *A Dissertation on Elective Attractions,* trans. unknown, 3rd ed. (London: Murray, 1785). Interested readers should consult Holmes, *Eighteenth-Century Chemistry* (above, n. 11), p. 58, for a reproduction of Bergman's 1775 table, as the reprint provides a nice visual impression of the growth and expansiveness of the table.

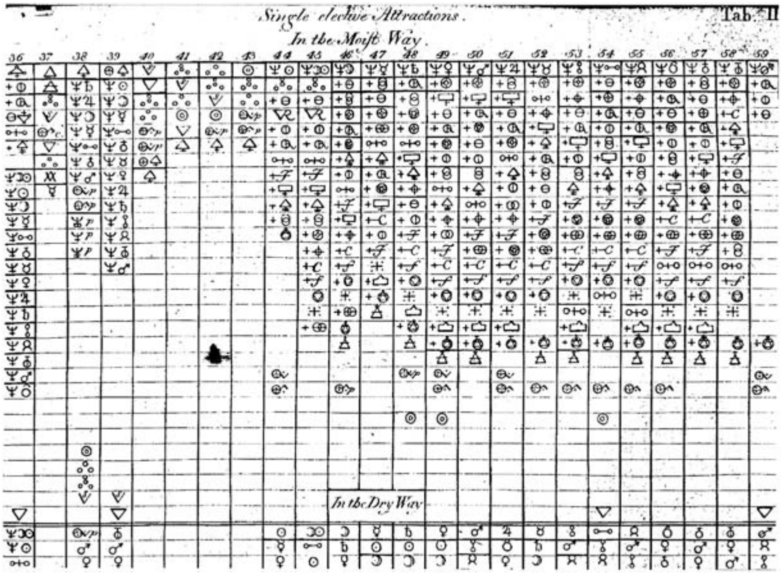

Figure 2. A portion of Torbern Bergman's "Table of Elective Attractions," from "Disquisitio de attractionibus electivis," *Nova Acta Regiae Societatis Scientiarum Upsaliensis* 2 ([1775] 1968): 161–250, trans. J. A. Schuffle, *Dissertation on Elective Attractions*. The portion here shows the right half of a 59-column table, and the top half of its 50 rows. Note that the order of elective attractions is given "In the Moist Way" at the top of the table, and, starting at row 31, "In the Dry Way" at the bottom. This reflects the dual means by which Bergman sought the results he compiled in his tables. Also note that while Bergman utilizes a wider range of symbolic representations, he still uses traditional alchemical symbols consistent with Geoffroy's table of more than fifty years earlier.

tions" instead of "affinities."[29] Nonetheless, he intended his tables of "elective attraction" to serve as guides for practitioners, filling the same role as earlier tables. The change in tabulation that he represents does not shift the emphasis away from a constructive context—but it does elevate the sophistication of the table in both its visual format and its didactic aim.

29. See note 11, above, for discussion of the possible Newtonian context of "affinity." In Nicholson's dictionary of 1795, the entry under "Affinity" says "SEE *Elective Attraction*" (William Nicholson, *A Dictionary of Chemistry* [London: Robinson, 1795], p. 171); compare this to Macquer's earlier dictionary, where he describes "chemical characters" as those "used by many authors, and in tables of affinities" (Pierre Macquer, *A Dictionary of Chemistry,* English trans. [London: Cadell and Elmsly, 1771], p. 154). Also see Mi Gyung Kim, "The Layers of Chemical Language I [and II]: Stabilizing Atoms and Molecules in the Practice of Organic Chemistry," *History of Science* 30 (1992): 69–96, 397–437, for a discussion of the fading role of affinity in classification schemes; and, more thoroughly and recently, idem, *Affinity, That Elusive Dream: A Genealogy of the Chemical Revolution* (Cambridge, Mass.: MIT Press, 2003).

Soon after the tables were published by Bergman, the components *within* them were issued in verbal format. That is, instead of using alchemical symbols to represent the substances, Bergman used words. This too was indicative of both the functional purpose and the confusing character of the tables' earlier presentation. The tables were so large and cumbersome, with so many tiny symbols of substances crowded into them, that for some their meaning had become obscure. (Note, though, that the table itself maintained its identity as a composite visual representation. It was only the items *inside* the structure of the grids that shifted.) The translator's preface to the 1785 English edition of the *Dissertation* sheds light on the issue:

> Two sets of Tables are subjoined. It was thought that many readers would be dissatisfied with the chemical Characters alone [i.e., the symbols], especially as the former edition of the Tables has been already rendered in words. To suppress the signs entirely, seemed improper; for they are so convenient, that every student of chemistry ought to make himself familiar with them.[30]

Such was the practical import of the table that ease of reference became its salient characteristic.

The translator had a broader didactic intent with his work, assuring his readers that all chemistry students should be familiar with the symbols.[31] In this, he demonstrated his trust in and reliance on visual presentation. When Bergman discoursed on the "Usefulness of Chemistry" he stated that the tables were presented "for the sake of conciseness and convenience of inspection," and thought that his form of presentation placed the relation of substances "in a very intelligible view."[32] William Nicholson, in his *Dictionary of Chemistry,* thought that "the tables at the end of Bergman's 'Essay on the Affinities' exhibit in the most speedy and intelligible manner the greater part of many volumes of chemical results"; he bolstered this assessment that symbol-laden tables offered an advantage in cognitive ef-

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[30] Bergman, *Dissertation on Elective Attractions* (above, n. 28), p. v. Duncan says that Thomas Beddoes was the anonymous translator: Duncan, *Laws and Order* (above, n. 6), p. 172. Crosland claims that the translator was "probably J. Beddoes" (Maurice Crosland, *Historical Studies in the Language of Chemistry* [Cambridge, Mass.: Harvard University Press, 1962], p. 243).

[31] Crosland makes a similar observation when discussing the debates over whether or not to use alchemical symbols in the eighteenth-century era when chemists were criticizing the use of such anachronistic (some would say, nonscientific) symbols. He notes that those critics still presented the symbols with explanations, "so that (they said) when the reader came across them in other works he might better understand them" (Crosland, *Historical Studies* [above, n. 30], p. 242).

[32] Bergman, *Essay on the Usefulness of Chemistry* (above, n. 25), pp. 10, 15.

ficiency when he estimated that "whole pages may be read and understood in a few seconds."[33] In each case—with Bergman, his translator, and Nicholson—it was the *use* of the table that informed its presentation, no matter the intent of the compiler. The increased efficiency of the visual format, supplementing the ease of reference, became its leading feature with the ordered arrays (provided by the chemist) leading to ease of inspection (when used by others). More information, less time.[34]

The example of Bergman showed the expanding practical function of the table. Now, in addition to the experimental results that led to the placement of substances in a table, chemists had the consideration of the actual process used to determine that placement. The relationship of the substances, and thus the classification scheme, depended on how the researchers sought their empirical evidence.

Bergman's tables of elective attractions, introduced between 1775 and 1783, would become the last significant set based on affinity. "If Bergman's table represented the finest achievement in the tradition of affinity tables, it also accelerated its ultimate demise," one historian has recently written.[35] The busy grids were filled with information, first represented by alchemical symbols and later by words; they were meant to be a vast extension of earlier tables.[36] In Bergman's "table of double elective attractions" of 1783 (which I have not discussed here), alchemical symbols were again employed to represent the individual substances.[37] The French chemist Guyton de Morveau was a contemporary and peer of Bergman's, elder to Lavoisier, and a fellow member

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[33] Nicholson, *Dictionary of Chemistry* (above, n. 29), pp. 251–252.

[34] The issue of "efficiency" is not philosophically simple. See Philip Kitcher and Achille Varzi, "Some Pictures Are Worth $2^{\aleph_0}$ Sentences," *Philosophy* 75 (2000): 377–381, for one view on the issue of efficiency, explanation, and the nonreducibility of spatial to linguistic representations.

[35] Kim, *Affinity* (above, n. 29), p. 267. Kim goes on to explain that the same attempt to present the "sum total of chemical knowledge in an all-encompassing table" made evident the apparent flaws in such a unified paradigm. Those flaws were clearly visible with "the limit of such a representational format," even though efforts to improve the system—in part, with nomenclature reform—still sought "a systematic ordering and prediction of chemical actions" (pp. 267–268).

[36] Despite the fullness of those works, Bergman believed that his "slight sketch will require 30,000 exact experiments to be brought to any degree of perfection" (Bergman, *Dissertation on Elective Attractions* [above, n. 28], p. 70). He hoped to do this himself, but, as he said, "the shortness of life" always gets in the way (ibid.).

[37] Lissa Roberts comments that "the Brilliance of his symbolic depiction was that in contrast to discursive language, which described chemical activity step by step (unable to portray simultaneity of occurrence), it captured the whole of a given operation within the confines of its symbolic borders, mirroring the instrumental confines of the

of the most well-known circle of European chemists. He viewed this use of symbols as problematic for disciplinary, theoretical, and didactic reasons: he argued, first, that the graphical symbols brought a historical connection to the anachronistic alchemical (and possibly occult) traditions; and second, that they were hard to read and easy to forget.[38] (Recall that it was for didactic purposes alone that the English translator of Bergman's work had departed from the use of alchemical symbols.) Thus, Guyton's attention was aimed at the visual features of the classifications. The same concerns could be introduced against the affinity tables, and might suggest why syntactic linguistic explanations were later used. I mention this here not to expand my discussion to include the disagreement in representative style between Guyton de Morveau and Bergman, but to provide a link to the French chemists of the 1780s. Next, along those lines, I consider the various tables of nomenclature of the latter eighteenth century.

Tables of Nomenclature

Soon after the introduction of Bergman's tables, and notably after the translations and updates that occurred through the 1780s, the more storied French chemists were setting out to revise the nomenclature of chemistry. I have not discussed Bergman's own designs on the reform of nomenclature, but it is worth noting that his work on the matter was significant. The innovations that he offered in tables of combination and classification were not disconnected from his work on revising the nomenclature of the substances represented inside them. To be sure, Bergman of Uppsala and Guyton of Dijon, who were frequent correspondents, were at the forefront of nomenclature reforms. More to the point, it was Guyton's 1782 reforms that would ally him with Lavoisier and other Parisian chemists later that decade in the pursuit of a total reform of all chemical nomenclature.[39]

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laboratory . . . and making the entire process observable at a glance" (Roberts, "Filling the Space of Possibilities" [above, n. 1], p. 528).

[38] Louis Bernard Guyton de Morveau, Hugues Maret, and Jean Durande, *Élémens de chymie théorique et pratique* (Dijon, 1777), p. 91, as quoted in Roberts, "Setting the Table" (above, n. 1), p. 116. Also, see Ritter, "Re-presenting Science" (above, n. 23), pp. 34–53, for a discussion of Hassenfratz and Adet's contribution of graphical characters to the new nomenclature of Guyton et al.

[39] See Crosland, *Historical Studies* (above, n. 30), pp. 144–152. Note that Bergman died in 1784. Crosland gives details of Bergman's role in the reform of nomenclature. The French chemists of this era have received a great deal of attention; in fact, earlier historiographic overtures toward chemical history used the concept of a chemical revolution as a common area of focus. See Arthur Donovan, ed., "The Chemical Revolution: Essays in Reinterpretation," *Osiris,* 2nd ser., 4 (1988): 5–231, for more on this subject.

The *table* of nomenclature took on greater prominence in the 1780s and brought into focus the issues surrounding transitions in the representation of classifications. Those tables existed within a broader framework of classification in the sciences, a framework that helps show the place of categorization as closely linked with issues of language and knowledge—popular Enlightenment topics, all. In terms of general theories of organization, the tables of nomenclature were partly continuous with affinity tables, in that they still sought to organize what was known about chemical substances and to explain what happened when those substances combined. However, they were not designed in emulation of the earlier ones, nor were the new tables mere extensions of affinity theories or theories of attraction. In terms of visuality, the major discontinuity was that the representative symbol system inside the table was serial and linguistic instead of spatial and graphic. Tables of nomenclature were intended to bring order to chemistry's language, much as other types of tables brought order to chemistry's facts. Both affinity and nomenclature tables had chemical organization as a goal, and both were founded in part on utilitarian criteria. Even though the internal characters of the tables differed, the visuality of the composite structure of the table provided the same cognitive advantage.

I mention here three examples from the 1780s that stood in juxtaposition, visually, to the earlier affinity tables: Guyton de Morveau's 1782 "Tableaux de nomenclature chymique" (Fig. 3); the series of tables used by Antoine Lavoisier in his *Traité élémentaire de chimie* of 1789 (Fig. 4); and the 1787 table of nomenclature included in the multiauthored *Méthode de nomenclature chimique* (Fig. 5).[40] Many of these names come up several times: Guyton de Morveau, whom I just discussed, was in the middle of early debates about nomenclature reform and held his own concerns about the virtues and utility of Bergman's tables; Lavoisier, the historiographic archetype of the new chemist, also played a large role in table-making. But what is important here is the visual format and practical import of their tables, and not the names and personal character of the chemists. Guyton de Morveau had published his 1782 table alongside his first effort at language re-

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[40] Louis Bernard Guyton de Morveau, "Sur les dénominations chymiques," *Observations sur la physique, sur l'histoire naturelle et sur les arts et métiers* 19 (1782): 370–382; Louis Bernard Guyton de Morveau, Antoine Lavoisier, Antoine François Fourcroy, and Claude Berthollet, *Method of Chymical Nomenclature proposed by Messrs. de Morveau, Lavoisier, Berthollet, and de Fourcroy; to which is added A New System of Chymical Characters, adapted to the Nomenclature, by Mess. Hassenfratz and Adet* [1787], trans. James St. John (London: Kearsley, 1788); Antoine Lavoisier, *Elements of Chemistry* [1789], trans. Robert Kerr (Edinburgh, 1790).

Règnes.	Acides.	Les Sels formés de ces Acides prennent les noms génériques de	Bases ou ſubſtances qui s'uniſſent aux Acides.	Exemples pour la claſſe des Vitriols.	Exemples pris de diverſes claſſes.
Des trois Règnes.	Méphitique ou Air fixe.	Méphites.	Phlogiſtique.	Soufre vitriolique ou ſoufre commun.	Soufre méphitique ou Plombagine.
	Vitriolique	Vitriols.	Alumine ou Terre de l'argille.	Vitriol alumineux ou Alun.	Nitre alumineux.
	Nitreux	Nitres.	Calce ou Terre calcaire.	Vitriol calcaire ou Sélénite.	Muriate calcaire.
Minéral.	Muriatique ou du ſel marin.	Muriates.	Magnéſie.	Vitriol magnéſien ou Sel d'epſom.	Acète de magnéſie.
	Régalin.	Régalins.	Barote ou Terre du Spath peſant.	Vitriol barotique ou Spath peſant.	Tartre barotique.
	Arſenical	Arſeniates.	Potaſſe ou Alkali fixe végétal	Vitriol de potaſſe ou Tartre vitriolé.	Arſeniate de potaſſe.
	Boracin ou ſel ſédatif	Borax.	Soude ou Alkali fixe minéral	Vitriol de Soude ou Sel de Glauber.	Borax de Soude ou Borax commun.
	Fluorique ou du ſpath fluor.	Fluors.	Ammoniac ou Alkali volatil	Vitriol ammoniacal.	Fluor ammoniacal.
			Or	Vitriol d'or.	Régalin d'or.
	Acéteux ou Vinaigre	Acètes.	Argent.	Vitriol d'argent.	Oxalte d'argent.
	Tartareux ou du Tartre.	Tartres.	Platine	Vitriol de platine.	Saccharte de platine.
Végétal.	Oxalin ou de l'Oſeille	Oxaltes.	Mercure	Vitriol de mercure.	Citrate de mercure.
	Saccharin ou du Sucre	Sacchartes.	Cuivre	Vitriol de cuivre ou Vitriol de Chypre.	Lignite de cuivre.
	Citronien ou du Citron	Citrates.	Plomb	Vitriol de plomb.	Phoſphate de plomb.
	Ligneux ou du Bois.	Lignites.	Etain	Vitriol d'étain.	Formiate d'étain.
			Fer	Vitriol de fer ou Couperoſe verte.	Sébate martial.
	Phoſphorique	Phoſphates.	Antimoine (au lieu de Régule d')	Vitriol antimonial.	Muriate antimonial ou Beurre d'antimoine.
Animal.	Formicin ou des Fourmis	Formiates.	Biſmuth	Vitriol de biſmuth.	Galacte de biſmuth.
	Sébacé ou du Suif	Sébates.	Zinc	Vitriol de zinc ou Couperoſe blanche.	Borax de zinc.
	Galactique ou du Lait	Galactes.	Arſenic	Vitriol d'arſenic.	Muriate d'arſenic.
			Cobalt	Vitriol de cobalt.	Saccharte de cobalt.
			Nickel	Vitriol de Nickel.	Formiate de Nickel.
			Manganèſe	Vitriol de manganèſe.	Oxalte de manganèſe.
			Eſprit-de-vin	Ether vitriolique.	Ether lignique ou Ether de Goettling, &c. &c. &c.

N. B. Lorſque les acides particuliers déjà entrevus dans la molybdène, l'étain, &c. ſeront plus connus, on en formera les noms d'acide *molybdique* & *molybdes*, d'acide *ſtannique* & *ſtannes*, &c. Il en ſera de même des nouvelles baſes. Le nouveau demi-métal trouvé par M. Bergmann dans les fers caſſans, pourra être nommé *ſydérotète*, caché dans le fer.

Les ſoufres & les éthers deviennent aux mêmes noms de genres, & ſe diſtinguent par l'épithète de l'acide.

Les noms de ces baſes, ou leurs adjectifs, ajoutés aux ſubſtantifs qui indiquent les genres des acides, forment les dénominations actuelles, comme on le voit dans les exemples ſuivans.

Les dix-huit acides, les vingt-quatre baſes & les produits de leur union, forment ainſi quatre cents ſoixante-quatorze dénominations claires & méthodiques, indépendamment des *hépars* ou compoſés à trois parties, dont les noms viennent encore dans ce ſyſtème, comme *hépar de ſoude*, *hépar ammoniacal*, *pyrite d'argent*, &c. &c.

Figure 3. Louis Bernard Guyton de Morveau's "Tableaux de nomenclature chymique," from his article "Sur les dénominations chymiques," *Observations sur la physique, sur l'histoire naturelle et sur les arts et métiers* 19 (1782): 370–382; plate follows p. 382. This was an early effort of Guyton's to carry forth the project of nomenclature reformation that was called for earlier by Torbern Bergman. (Figure reproduced from Wilda Anderson, *Between the Library and the Laboratory: The Language of Chemistry in Eighteenth-Century France* [Baltimore: Johns Hopkins University Press, 1984], p. 153, by permission of the Johns Hopkins University Press.)

form, which contained an implicit argument against Bergman and symbols with its verbally constituted columns for more than just didactic reasons, as stated above. Guyton de Morveau, Lavoisier, Claude Louis Berthollet, and Antoine François de Fourcroy coauthored the 1787 *Méthode de nomenclature chimique,* in which they sought to provide not just the names of the basic substances, but their order in nature. In Part II of his *Traité,* Lavoisier presents four kinds of tables, of which I will consider the "Table of Binary Combinations of Oxygen with Simple Substances" (the other three kinds of tables break from the grid format of earlier ones and thus lose some sense of their visual utility). Lavoisier's "Table of Binary Combinations" is designed and presented in a form similar to the 1782 and 1787 tables of nomenclature, but the three differ in scale and headings.[41]

Each of the tables of nomenclature followed the left-to-right for-

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[41] The complex association of nature, language, and knowledge that was bound up in the pursuits of these chemists (and their mentors before them) has been the subject of numerous studies. See William Albury, "The Logic of Condillac and the Structure of French Chemical Theory, 1780–1801" (Ph.D. diss., Johns Hopkins University, 1972); Anderson, *Between the Library and the Laboratory* (above, n. 21); William Brock, *The Norton History of Chemistry* (New York: Norton, 1992), pp. 116–126; Lissa Roberts, "Condillac, Lavoisier, and the Instrumentalization of Science," *Eighteenth Century* 33 (1992): 252–271; Trevor Levere, "Lavoisier: Language, Instruments, and the Chemical Revolution," in *Nature, Experiment, and the Sciences,* ed. Trevor Levere and William Shea (Dordrecht: Kluwer, 1990), pp. 207–233. Holmes, *Eighteenth-Century Chemistry* (above, n. 11), provides a concise review of many of these interpretations.

mat used by Guyton in 1782.[42] On the left of Guyton's table was a column of some known substances. In this case, these were acids classified by their kingdom of mineral, vegetable, or animal. The columns were then followed to the right by the salts derived from their combination with bases (see Fig. 3). In its left-to-right organization, the table implied motion. The order of things implicit in the construction of the table was not one of how *all* substances relate to one another—indeed, Guyton did not provide an exhaustive list of substances. But his table was one that carried with it a practical guide: to know chemistry was to know how to utilize the known chemical substances. The process of combining chemicals was intimated by the stepwise process of reading the table, starting with basic constituents and combining them to produce a known compound. By means of its visual arrangement, it guided users in much the same way Geoffroy had guided his. Guyton's first table was relatively compact, with eighteen acids in the left column, and a total of five columns. It became clearer in the much-expanded 1787 table of nomenclature that the table not only represented the history of experimental order used to construct it, but was also meant to be read and to guide chemists in their own practice. As opposed to the manageable one-page table of Guyton's 1782 article, the table of 1787 measured 80 cm by 50 cm when unfolded from its insert. This attention to practical utility has been widely observed with respect to the very concept of the new nomenclature, in that names could easily be assigned to substances within the basic binomial format, similar in fact to that of Linnaeus.

To emphasize the how-to nature of these representations, consider Lavoisier's 1789 "Table of Binary Combinations of Oxygen with Simple Substances" (Fig. 4). It was not labeled a table of nomenclature, but it served the same role while acting to extend the legitimacy of the already-presented nomenclature reforms. The first column on the left (not a first row, at the top) provided the names of the "simple substances." When combined with "Oxygen" the simple substance created, for example, "Nitrous oxide"; a second "oxygenation" yielded "Nitrous acid," and a third yielded "Nitric acid." The binomial nomenclature spelled out, in an orderly fashion, within a structured procedure, how reactions worked and how the simple substances went together. The table had grown not only in size but now too in manipulative sophistication. It first presented, at a glance, information about how substances combined; its role was then ex-

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[42] Roberts notes that Guyton's 1782 table differed little in the context of discursive structure from earlier organizational attempts, while the 1787 table challenged not only the names of substances but the entire disciplinary structure of chemistry: Roberts, "Setting the Table" (above, n. 1), pp. 119–122.

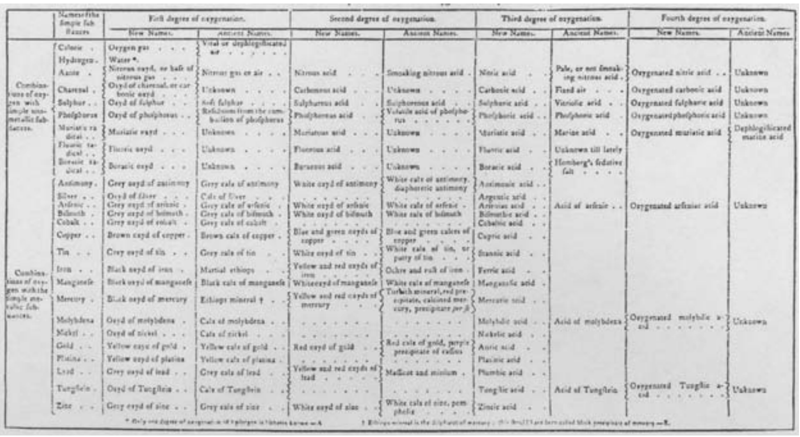

Figure 4. Antoine Lavoisier's "Table of Binary Combinations of Oxygen with Simple Substances," from *Elements of Chemistry* [1789], trans. Robert Kerr (Edinburgh, 1790).

panded to account for the various processes of combination; and finally the table was the storehouse and preferred form of presentation for the new nomenclature, a system that would guide chemical activity from reliance and adherence to a single referential system.

I would be overstating my case if I suggested that the flurry of activity in table construction in the 1780s can define the oft-labeled revolutionary era. However, I think it is fair to suggest that the tables were not mere passive representations of theoretical decisions, but also played an active role in either supporting arguments or disassembling them. As a case in point, consider the late-eighteenth-century correspondence between the Irish chemist Richard Kirwan and Guyton de Morveau.[43] The basis for this correspondence was the contested merit of the dominant phlogiston theory against Lavoisier's competing oxygen theory. While the full details of their discussion are interesting, I want to highlight Kirwan's reference to and use of affinity tables in his prophlogiston argument against Guyton de Morveau and, by extension, Lavoisier.[44]

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[43] This correspondence has been discussed in greater length and detail in Seymour Mauskopf, "Richard Kirwan's Phlogiston Theory: Its Success and Fate," *Ambix* 49 (2002): 185–205. I thank Professor Mauskopf for discussing an earlier version of his paper with me.

[44] Bernadette Bensaude-Vincent and Isabelle Stengers reference another instance of the use of a table in a theoretical argument, noting that Berthollet was able to draw "a radical conclusion [that] the direction of a reaction was not an *absolute,* determined by the elective tendencies of the bodies present," by using Bergman's tables (Bernadette Bensaude-Vincent and Isabelle Stengers, *A History of Chemistry* [Cambridge, Mass.: Harvard University Press, 1996], p. 72).

When questioning the merit of Lavoisier's oxygen as an explanatory mechanism for experimental results, Kirwan referred to the order of affinities in Lavoisier's tables: "*According to Mr. Lavoisier's table,* water should be decomposed by charcoal at least in a boiling heat, which is fully sufficient to communicate as much specific heat to the inflammable part of water as is necessary to its aerial form: yet water has not been decomposed in that manner"; this is "an evident sign that it is not from water [that the inflammable air proceeds], but from iron."[45] Kirwan drew this conclusion by referring to the table of affinity strengths that Lavoisier provided. He went on to argue with Guyton de Morveau that either the affinity tables had to be revised, or the antiphlogiston explanation of how affinity works could not be correct: "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?"[46]

The debate came to a head with the table. Kirwan's concerns left open two options: either construct a better table, or scrap the notion of affinity. In both cases, the table was used as an argumentative and evidentiary tool. As Sy Mauskopf describes it, "Kirwan reproduced Lavoisier's list of relative affinity strengths of the oxigenous principle with various combustibles [from his table], and used it as a club to beat anti-phlogistic chemical assumptions." Mauskopf adds, "These imperfections [of the tables], Kirwan acknowledged, were common to all affinity tables, but they had nevertheless been very useful."[47] What is striking in this interpretation, and in Kirwan's original sentiment, is not just the metaphorical crossover of the tool-like nature of the table—as a club with which to beat opponents—but also the presupposition of the utility and reliability of these tables. Kirwan seems to take advantage of them in two ways, having his table and eating it too: he uses it *as* a resource while questioning the theoretical conclusion to be drawn *from* that resource. His suggestion was not that the table was a poor tool, but that it illustrated the problems of the antiphlogiston position. My earlier discussion of the instructive utility of the table emphasized how tables were helpful for those following procedures; now that utility can be extended to consider

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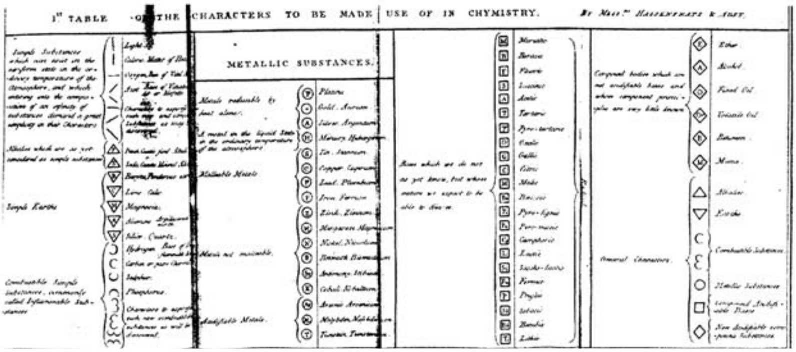
[45] Richard Kirwan and Louis Bernard Guyton de Morveau, *A Scientific Correspondence During the Chemical Revolution: Louis-Bernard Guyton de Morveau and Richard Kirwan, 1782–1802* [1788], Berkeley Papers in the History of Science, 17, ed. Emmanuel Grison, Michelle Goupil, and Patrice Bret (Berkeley, Calif.: Office for the History of Science and Technology, 1994), p. 44 (emphasis added).

[46] Ibid., p. 198.

[47] Mauskopf, "Kirwan's Phlogiston Theory" (above, n. 43), pp. 198, 202.



1st TABLE OF THE CHARACTERS TO BE MADE USE OF IN CHYMISTRY.

METALLIC SUBSTANCES.

Figure 5. Jean Henri Hassenfratz and Pierre August Adet's "1st Table of the Characters to be Made Use of in Chymistry," from Louis-Bernard Guyton de Morveau, Antoine Lavoisier, Antoine François Fourcroy, and Claude Berthollet, *Method of Chymical Nomenclature proposed by Messrs. De Morveau, Lavoisier, Berthollet, and De Fourcroy, to which is added A New System of Chymical Characters, adapted to the Nomenclature, by Mess. Hassenfratz and Adet* [1787], trans. James St. John (London: Kearsley, 1788); the table is provided as a fold-out at the end of the bound text. The memoir of Hassenfratz and Adet that discusses the characters is included in the *Method* as pp. 191–214 of the translation. (Reproduced courtesy of The Bancroft Library, University of California, Berkeley.)

their use in argument, where they are helpful for those supporting or refuting a theoretical claim.

I want to make one more point about the visual representation of the new nomenclature: the contribution of Jean Henri Hassenfratz and Pierre August Adet to its presentation (Fig. 5). The two young French chemists were commissioned by Guyton, Lavoisier, Berthollet, and Fourcroy to develop a new graphic symbol system that would accompany the new nomenclature in their *Méthode de nomenclature chymique*.[48] Their symbols would be used as shorthand notations for the new names, as easily referenceable and transferable between national contexts as the Latinate names themselves. "Should the chymical characters become uniform among the chymists of every nation, they will resemble the writing of the inhabitants of China, Tonking, and of Japan. Although these people have different languages and consequently different sounds to express the same ideas, they notwithstanding, have common characters to represent

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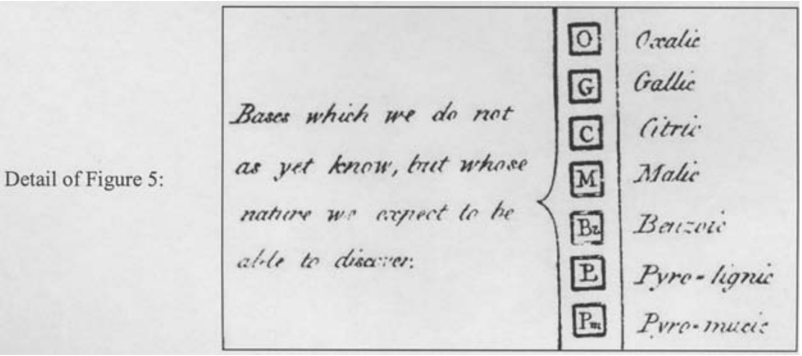
[48] Crosland discusses the relative successes and failures of the actual common use of these new symbols, noting in particular that, though favored by the four authors of the new nomenclature, they did not become commonly deployed (thus perhaps explaining why they are not well known, or at least discussed, anymore). He suggests that typographical issues lay at the root of the problem, since Hassenfratz and Adet's symbols were not easily reproduced: Crosland, *Historical Studies* (above, n. 30), pp. 247–252.



Detail of Figure 5:

Bases which we do not as yet know, but whose nature we expect to be able to discover:

Figure 6. Detail of Figure 5.

them," said the two colleagues.[49] Unlike ancient chemists, whose "mysterious veil" screened their science from the "eyes of the vulgar," Hassenfratz and Adet sought, they said, "to render our knowledge as communicative as possible."[50] After a short examination of the "most modern table of chymical signs, which are the tables of Bergman," they proposed a new sign system more in keeping with "the modern improvements."[51] As a recent study of these visual representations has shown, "the most important feature of this new system of chemical characters was how it represented a visual grammar of chemical combination: compound substances were denoted by combinations of simple characters representing simple substances that formed compound substances."[52] Hassenfratz and Adet made visible the facts of the new nomenclature. Their symbols would not only serve purposes of convenience and efficiency, but would play an actual constitutive role in proctoring the new truth of chemistry. As evidenced in Figure 6, the young chemists were fully aware of the import of their system, venturing so far as to claim, without elaboration, that the list of "Radicals," from Muriatic to Lithic, were "Bases which we do not as yet know, but whose nature we expect to be able to discover."

Hassenfratz and Adet's graphical system represented both composition and combination, providing a classification completely evident and easily accessible through its graphical, spatial symbolic format. They offer an excellent example of the representation of

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[49] Hassenfratz and Adet in Guyton de Morveau et al., *Method* (above, n. 40), p. 192.

[50] Ibid. Their "memoir" is included as a portion (pp. 191–214) of Guyton de Morveau et al., *Method* (above, n. 40).

[51] Ibid., pp. 195, 197.

[52] Ritter, "Re-presenting Science" (above, n. 23), p. 47.

classification as a visual endeavor. In the role of visual communicants, and as presented separately from the table of nomenclature, their symbols indicated a transition point in the representation of basic constituents. Previously, the symbol system had always been a subset of the actual table. It was for this reason that I have thus far focused on the composite structure of the table. But after the innovations of the nomenclature reformers and the symbolic contribution of Hassenfratz and Adet, the representations of classification came more often in the form of ungridded, disassembled lists.

Guyton de Morveau, Lavoisier, Berthollet, and Fourcroy made a particularly interesting recommendation in favor of the new system in the *Méthode,* endorsing the symbol system as such:

> [The characters] proposed by Hassenfratz and Adet are far preferable to the ancient; that they have the advantage of painting to the sight, not words, but facts, and giving just ideas of the combinations, which they represent. This method seems to possess also another advantage; it determines beforehand the characters of such substances as may be discovered in the future . . . and a complete table of these characters represents at the same time all that has been done in science by former chymists, and all that yet remains to be discovered.[53]

The endorsement was noteworthy for more than one reason. Not only did the organizational reformers highlight the distinct and useful advantage of the visible, pictorial characters—"painting to the sight, not words, but facts"—but they also precisely outlined the dual role of those visual representations, representing "all that has been done" while predefining "all that yet remains to be discovered." Guyton de Morveau and his coauthors thought that it was "up to chemists to extract these 'truths' [of the laboratory] from manipulative situations in which they occurred, to translate and map them onto a spatial grid of chemical tabulation—a map of past discovery, future exploration, and manipulation," in the words of Lissa Roberts.[54] It was verbal, instructive, and practical, bidirectional in its temporal overtures with a knowing, rearward gaze and an active, forward look. And while the sense of prediction and the performative blank space differ from that of Geoffroy's table, the visual representation of this classification still performs the function of future orientation via its visual composition.

Guyton de Morveau and his coauthors said that their new nomenclature "must naturally adapt itself to future discoveries, and indicate before-hand, the place and name of such substances as may

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53. Guyton de Morveau et al., *Method* (above, n. 40), p. 236.

54. Roberts, "Setting the Table" (above, n. 1), p. 115.

be found out."[55] A decade earlier, Guyton de Morveau had already expressed the view that a good synoptic table would not only summarize extant knowledge but mark "as upon a grid of the world map, the lands we have yet to discover."[56] Not only was the creation of the table crucial for the advancement of a research program in the laboratory, but the representation of that organizational device provided the actual means by which it could be communicated and understood. Even those elements still unknown had a place reserved in the table, with a name already picked out. Later, once the full presentation of the new nomenclature had been made, the linguistic table was the innovation: it presented the theory of oxygen, which for Lavoisier was the basic principle of chemistry; it literally spelled out how to do chemistry. The full import of such a new system of nomenclature was announced by its creators: those who profess chemistry "must either reject the nomenclature or irresistibly pursue the delineated course."[57] To perceive the table as a static device would then be to deny the creative and utilitarian aspect of its future orientation. Much as the chemical balance became a necessary tool for those practicing the new chemistry, so too did the new nomenclature. For reasons consistent with earlier tables, the cognitive advantage of the visual format facilitated the ease of transfer and use of that new structure of knowledge.

Though the tables of Geoffroy fit within an altogether different context in the history of chemistry, they do share representative characteristics with Lavoisier's tables. For one, both examples were predicated on assisting with concrete material operations. For another, "Seeing the sign of the substance, whether formed from linguistic (Lavoisier) or non-linguistic (Geoffroy) symbols, [was] to grasp almost immediately the route for preparing it."[58] Torbern Bergman and Guyton de Morveau fit within the same lineage. By interpreting the very table itself as the imagistic contributor, another aspect of similarity becomes clear: that each table provided a classification of known chemical constituents, while providing the means to discover new ones—and that *seeing* the table, thus allowing for the importance of its visual structure, mattered.

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[55] Guyton de Morveau et al., *Method* (above, n. 40), p. 12.

[56] Guyton de Morveau, Maret, and Durande, *Élémens* (above, n. 38), p. 89. Stephen Weininger, in his analysis of visualization in chemistry, has noted the same function in that "the categories of what could possibly be known have already been prefigured by the nomenclature" (Weininger, "Contemplating the Finger" [above, n. 11], p. 12).

[57] Guyton de Morveau et al., *Method* (above, n. 40), p. 9.

[58] Weininger, "Contemplating the Finger" (above, n. 11), p. 8.

Early-Nineteenth-Century Visual Representation and the Paper Tool

Dalton

The chemistry table, by the turn of the nineteenth century, had been organized variously: by the principles of affinity, solubility, and degree of oxygenation; as lists of substances ordered through their use in commercial practice; as relations based on the method of experimentation that led to their degree of combination; and as the means of presenting the signifiers of the new chemistry. In the early nineteenth century, John Dalton presented a new type of table, the table of relative weights, which illustrated the same dual practical role as these others.[59] As for collecting the known, it was offered as an ordered array and intended to present a vision of the basic constituent of chemistry—the atom. It also played a role of forecasting similar to that of the earlier tables. However, while Dalton's contributions on this count have been given a good deal of attention for their theoretical aspects, the practical elements of his table of weights are not often remarked upon. The focus on theory usually places Dalton into a different chemical context from that of his predecessors and makes comparisons between the eighteenth and the new nineteenth century awkward; grouping Guyton or Lavoisier and Dalton together is thus fairly difficult, a fact I do not deny on theoretical grounds. But when we treat Dalton for his visually discursive contributions, we find that he does fit within the common tenets of visual practice.[60]

The table of relative weights was copresented in *A New System of Chemical Philosophy* with engraved plates, serving as an explanation of the visual diagrammatic figures therein (Fig. 7). The linguistic counterparts of the "signs chosen to represent the several chemical elements or ultimate particles" were shown adjacent to the plates at the end of the text.[61] Importantly, in offering his view of the atom visually, Dal-

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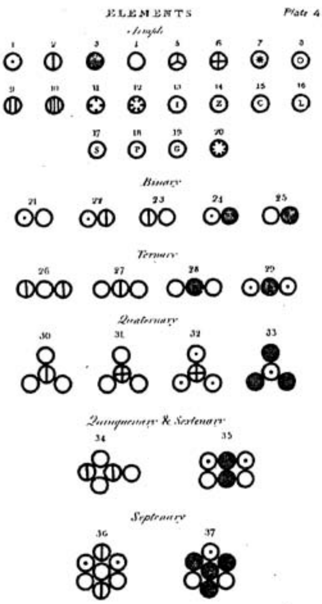
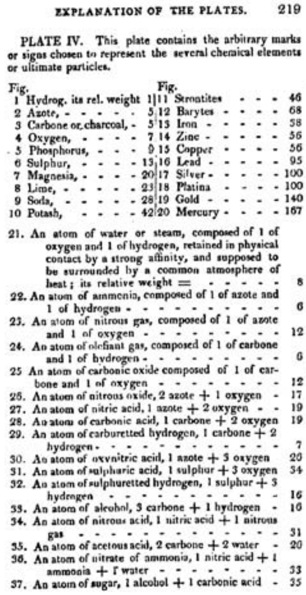
[59] Dalton's 1808 form of presentation was the first of its kind. A mere seven years later, though, six more chemists had published their own tables in similar formats, indicating the credibility quickly gained by such a system of ordering. See Alan Rocke, *Chemical Atomism in the Nineteenth Century: From Dalton to Cannizzaro* (Columbus: Ohio State University Press, 1984), pp. 80–82.

[60] Dalton was a devoted visual scientist, leaning often on the explanatory power of the graphical and pictorial over the linguistic. In fact, a recent interpreter has considered that "visual practice was important, perhaps crucial to Dalton's chemistry" (Ritter, "Re-presenting Science" [above, n. 23], p. 69). In addition, see also Crosland, *Historical Studies* (above, n. 30), pp. 256–264; Arnold Thackray, *John Dalton: Critical Assessments of His Life and Science* (Cambridge, Mass.: Harvard University Press, 1972).

[61] John Dalton, *A New System of Chemical Philosophy,* part 1 (London: Bickerstaff, 1808), p. 219, and part 2 (London: Bickerstaff, 1810), p. 546.





EXPLANATION OF THE PLATES. 219

PLATE IV. This plate contains the arbitrary marks or signs chosen to represent the several chemical elements or ultimate particles.

Fig.			Fig.		
1	Hydrog. its rel. weight	1	11	Strontites - - -	46
2	Azote, - - - - -	5	12	Barytes - - - -	68
3	Carbone or charcoal, -	5	13	Iron - - - - -	38
4	Oxygen, - - - -	7	14	Zinc - - - - -	56
5	Phosphorus, - - -	9	15	Copper - - - -	56
6	Sulphur, - - - -	13	16	Lead - - - - -	95
7	Magnesia, - - - -	20	17	Silver - - - - -	100
8	Lime, - - - - -	23	18	Platina - - - -	100
9	Soda, - - - - -	28	19	Gold - - - - -	140
10	Potash, - - - -	42	20	Mercury - - - -	167

21. An atom of water or steam, composed of 1 of oxygen and 1 of hydrogen, retained in physical contact by a strong affinity, and supposed to be surrounded by a common atmosphere of heat; its relative weight = - - - - - - 8
22. An atom of ammonia, composed of 1 of azote and 1 of hydrogen - - - - - - - - - - - 6
23. An atom of nitrous gas, composed of 1 of azote and 1 of oxygen - - - - - - - - - - 12
24. An atom of olefiant gas, composed of 1 of carbone and 1 of hydrogen - - - - - - - - - - 6
25 An atom of carbonic oxide composed of 1 of carbone and 1 of oxygen - - - - - - - - - - 12
26. An atom of nitrous oxide, 2 azote + 1 oxygen - 17
27. An atom of nitric acid, 1 azote + 2 oxygen - - 19
28. An atom of carbonic acid, 1 carbone + 2 oxygen 19
29. An atom of carburetted hydrogen, 1 carbone + 2 hydrogen - - - - - - - - - - - - - 7
30. An atom of oxynitric acid, 1 azote + 3 oxygen 26
31. An atom of sulphuric acid, 1 sulphur + 3 oxygen 34
32. An atom of sulphuretted hydrogen, 1 sulphur + 3 hydrogen - - - - - - - - - - - - - 16
33. An atom of alcohol, 3 carbone + 1 hydrogen - 16
34. An atom of nitrous acid, 1 nitric acid + 1 nitrous gas - - - - - - - - - - - - - - 31
35. An atom of acetous acid, 2 carbone + 2 water - 26
36. An atom of nitrate of ammonia, 1 nitric acid + 1 ammonia + 1 water - - - - - - - - - 33
37. An atom of sugar, 1 alcohol + 1 carbonic acid - 35

Figure 7. John Dalton's table of relative weights, from *A New System of Chemical Philosophy*, part 1 (London: Bickerstaff, 1808); the plate is included as p. 219 of modern reprints of the Bickerstaff edition, although the original edition contained engraved plates that were appended outside the main body of the bound text.

ton presupposed the legitimacy of an organizational method based on discrete and determinate atoms. His explanation of the plates served to bolster the figures of simple elements by emphasizing the individuality and quantifiability of the atoms. The "Plate" and adjacent "Explanation" were mutually supportive, addressing the ontological status of the entities through their tandem representational format.[62]

Dalton's tables of relative weights, when coupled with the figures in his engraved plates, were organizational devices that exemplified the dual role in every sense that I have described with the previous cases. The combination of the two forms of presentation, diagrams and ta-

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[62] Note here that the table's role is not facilitated by its own visuality—one of my main arguments in the other cases—*except* insofar as it is used in conjunction with the figures. This tandem presentation complicates the nature of the visual representation that I have been careful to keep disentangled in previous examples: before, the table itself could be treated as a visual representation, not just the symbols inside it; now, there are clearly different and complementary symbol systems to consider. As I note below, the periodic table does demonstrate both tasks—the dual role and the visual facilitation of that role—on its own.

bles, was the new feature of Dalton's visual representation of classification. Figure 7 shows that the figures of the simple elements of Plate 4 were translated verbally and listed in the explanation to the plate. While working in conjunction with the figures, the table furthered the point that each atom had a particular weight (as listed), was a precise entity (something that could be weighed), and had a specific ontological role (to account for what it was that chemists worked with). It was also explicitly classificatory, with the elements organized as "simple," "binary," "ternary," and so forth and presented in increasing atomic weight down the page. As such, the table performed the function of collecting what was known about the basic constituent. This visual format even had implicit empty spaces at the end of the given set of symbols, indicating where and how future discoveries would be placed within his system. To wit, Dalton remarked on his presentation of the figures that "enough has been given to shew [*sic*] the method; it will be quite unnecessary to devise characters and combinations of them to exhibit to view in this way all the subjects that come under investigation."[63] He had established a method of devising characters. The results of future investigations could be fit within this representative system much as the new nomenclature had predefined future discoveries. Dalton's system would be enabled through the ability of chemists to envision what they were working with and toward.

Paper Tools

Not surprisingly, considering his reliance on the visual, Dalton also provides an example of a "paper tool." Ursula Klein has developed this concept most convincingly in the context of early-nineteenth-century organic chemistry with reference to the Swedish chemist Jöns Jacob Berzelius's alphabetical representation of a chemical reaction. (Berzelius, one of the most famed and influential chemists of the nineteenth century, first ascribed letters to elements and wrote them out in a formula equation—for example, $2H + O = H_2O$.) Briefly, the paper tools idea is this: after Berzelius's representational innovation, "new possibilities of combinations emerged as chemists were tinkering with formulae on paper."[64] Chemists could perform research on paper, at their desks, by manipulating the Berzelian formulas; they did not always need to perform the actual reaction in the laboratory. Furthermore, the idea of the formulaic system did not necessarily follow theoretical innovations: the two were coproduced in the context of Berzelius's desire to present a co-

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[63] Dalton, *New System* (above, no. 61), part 1, p. 220.

[64] Klein, "Berzelian Formulas" (above, n. 1), p. 20.

herent atomic system—so that, for example, "the formulaic system became a tool to forge a theory which overlapped with Dalton's atomic theory without being identical to it."[65] What matters for us, with Berzelius and paper tools, is that the visual representation of an element as a letter or a linguistic abbreviation offered advantages for chemists working in practical settings.[66]

The concept of paper tools has been broadened in scope and developed by others to include discussions of all manner of visual representations. To this body of work, we can add both John Dalton and the chemistry table.[67] First, Dalton. He had such a firm belief in the legitimacy of visual expression that he claimed to have developed parts of his atomic theory by manipulating atomic figures on paper. His musings on the formative thoughts of his atomic theory confirmed this: "I set to work to combine my atoms upon paper. I took an atom of water, another of oxygen, and another of azote, brought them together, and threw around them an atmosphere of heat, as per diagram."[68] Here Dalton claimed that his characterization of atomic theory was worked out by tinkering with formulas on paper. Later, he claimed that "there was only one alternative left" to solve the problems he was having with arranging water, oxygen, and azote: the alternative became apparent, he reported, by extending the lines used to represent heat around each of the atoms.[69] The pictorial representation, in Dalton's explanation, accounted to a large

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[65] Ursula Klein, "The Creative Power of Paper Tools in Nineteenth-Century Chemistry," in idem, *Tools and Modes of Representation* (above, n. 1), pp. 13–34, on p. 15.

[66] The complete explication of how a "paper tool" fits into the larger category of tools in general is beyond the scope of the present paper. In brief, though, a sufficient philosophy of technology on this count would have to address the structuring and informing presence of any tool as well as the extent to which practitioners are constrained by those tools—be they paper tools, hammers, institutions, or texts. I thank an anonymous reviewer for noting the larger issues at stake when utilizing Klein's paper-tool concept. For further commentary on these questions, see Klein, *Experiments, Models, Paper Tools* (above, n. 1).

[67] See Klein, *Tools and Modes of Representation* (above, n. 1). Ritter has in fact discussed Dalton in the context of paper tools, noting as well that typographical limitations go far in explaining why his figures were not manipulated in any widespread fashion: see Christopher Ritter, "An Early History of Alexander Crum Brown's Graphical Formulas," in Klein, *Tools and Modes of Representation* (above, n. 1), pp. 35–46. Scerri discusses the table as a paper tool, a point to which I return soon: see Eric Scerri, "The Periodic Table: The Ultimate Paper Tool in Chemistry," ibid., pp. 163–177.

[68] John Dalton, "Lecture 17—Chemical Elements," in Henry Roscoe and Arthur Harden, *A New View of the Origin of Dalton's Atomic Theory* (1896; London: Macmillan, 1970), p. 14. The lecture was given on 27 January 1810.

[69] Ibid.

extent for the choices he made when developing his ideas on the combinations of atoms.

Dalton's example is useful in helping to express the nature of the paper tool as neither solely practical nor wholly theoretical.[70] Paper tools force our attention to material inscriptions as elements of chemical practice, and in the process they muddle the clear distinction between theory and practice. For my purpose, they express an attention to the active dimension of science, where reading pictures and utilizing extratextual symbols assist in the everyday performance of that science. They are as much about what chemists do with the table—that is, read its visual grammar—as with what the table represents statically. Without belaboring the point further, chemistry tables can be thought of as paper tools also. They were never just stagnant repositories of facts, but also devices that were used by chemists for chemical order to be established, well before the infamous periodic table did much the same.[71] The practical intentions of Geoffroy with his table, Kirwan's use of Lavoisier's tables, and painting to the sight the ideas of combination while representing all that yet remains to discovered, as Guyton de Morveau and his collaborators said of Hassenfratz and Adet's graphical contributions, can each now be read as a case of paper tools in action. Through their visual construction and reading, these tables did not function in the practice of science as an adjunct to didactic and investigative procedures, but moved along with them, aiding and abetting as they did.

The idea of the table as an object that could be read and put to use refashions the formerly simple temporal explanation of creation, presentation, and use. Notions of paper tools infer the dual role of the table that collects the known and directs practice. Though one cannot manipulate the table as one can a formula, by moving it around, it can be changed in a broad temporal sense by adding to it, filling in blank spaces, expanding its array, or identifying inconsistencies that require further investigation. In the early 1800s, the visually enhanced synopses of chemical classification schemes accounted for atomic weights, the proposed basic principle of order.

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[70] By this I hope to avoid the reduction of either the paper tool or the chemistry-table-as-visual-representation to *only* a semiotic or signification characterization or *only* an instrumental one.

[71] Eric Scerri considers the periodic table "The Ultimate Paper Tool" (above, n. 67). However, the periodic table's function *as a paper tool* is not far different from the role of preperiodic tables and schemes of organization, and thus I would not consider it ultimate. The basic distinction I would make between Scerri's discussion of paper tools and my own is that Scerri treats them as theoretical tools (see ibid., pp. 163–166), whereas I emphasize their role as (not necessarily atheoretical) elements of and for practice.

But all along, well before Dalton and even after Mendeleev, the chemistry table acted as a technology of representation that could help create practical goals—that is, goals of chemical practice—while encouraging and facilitating chemical innovation. It exemplified the principle that a representation of classification looks in both directions, backward and forward, as it is activated while being read as visual grammar by practitioners.

Conclusion

The chemistry table, from at least Geoffroy's "Table des rapports" of 1718, was meant to serve a dual purpose, acting as a storehouse for what was known about the basic constituents in chemistry and playing a practical, often generative role by guiding chemical practice from the known to the unknown. We know this much from the chemists themselves. As those utilizing organizational devices, the table builders and users attempted to structure knowledge by relating different substances—be they simple substances, atoms, or elements—in a visual field. They took the results of research in nature and constructed them into portable, legible displays of information. By relegating the search for nature to a tabulated scheme, the table creators extended the program of the chemists who worked within a commercial, practical, and didactic context to provide a useful tool. And so the table's microhistory—the history of each individual table, or diagram, or list—was not exhausted once the device had been presented.

The table, to be sure, cannot sufficiently explain the history of chemical practice: visual representations of chemical classifications were not the sole means by which knowledge was translated from chemist to chemist; the writings of all practitioners do not claim that the use of tables should be credited solely to the visual features of those tables; and, as with the appropriation, rather than reception, of textbooks, there is far more to say about how tables came into use and conceptual manipulation in daily practice.[72] But, even with this caution, my point should be read differently, since my goal has been to make this a study of visual representations and not of knowledge transfer. The theory of practice that helps describe the

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72. One area of inquiry that touches on these issues is the study of textbooks in the history of science. For good entry points into this area, relating specifically to chemical textbooks, see Bernadette Bensaude-Vincent, "A View of the Chemical Revolution through Contemporary Textbooks: Lavoisier, Fourcroy and Chaptal," *British Journal of the History of Science* 23 (1990): 435–460; Bernadette Bensaude-Vincent and Anders Lundgren, eds., *Communicating Chemistry: Textbooks and Their Audiences, 1789–1939* (Canton, Mass.: Science History Publications, 2000).

philosophy of praxis of a visual representation is not in evidence from written records of chemists, or reflections of education and research. Rather, we find the forward motion of the chemistry table from its visual features, recognizing that the silent blank space, as Geoffroy, Bergman, Guyton, Lavoisier, Dalton, and Mendeleev noted, has been constructed both to allow room for future research and to suggest, and in that suggestion constrain, how one would set up such research.

I highlight the consistency of the dual temporal role as a means to emphasize a thread of continuity in chemical practice, with spatial and graphic visual elements helping us to recognize just how the dual function of the table worked. This study thus extends previous analyses of the more prominent symbol system in history, serial linguistics, to the spatial and graphical symbol systems of chemistry. With respect to the discursive focus, Wilda Anderson has explained that, for Lavoisier, his elder contemporary Pierre Macquer, and their predecessor Abbé de Condillac, the "structure of knowledge is the only order that can be relied upon to reproduce the order inherent in Nature."[73] Anderson continues:

> It is through the transformation of physical phenomena into words that Macquer can attempt to deal with the chaotic universe of material objects. The things words represent may be inexorably different from each other, but if one collapses the analysis of chemistry onto the analysis of grammar, then they can be manipulated as words all subject to the same operations in the mind of the philosopher and related in ways that nullify or neutralize or simply ignore these differences.[74]

Anderson's viewpoint informs not only the linguistic aspects of late-eighteenth-century chemistry, but the underlying principles that help explain the changes in tables occurring then, from affinities to nomenclature. As well, her comments can be echoed with attention to visual grammar.

For us, the association of symbols and their referents becomes even more complex when we expand the idea of a symbol from serial representations to spatial ones, in the process forcing attention to broader ideas of visual practice. That association has been described with respect to concepts of scientific classification, though mainly as they relate to natural history. Michel Foucault claims in his discussion of taxonomy that "the natural history room and the garden, as created in the Classical period, replace the circular procession of the

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[73] Anderson, *Between the Library and the Laboratory* (above, n. 21), p. 4.

[74] Ibid., p. 51.

'show' with the arrangement of things in a 'table.' What came surreptitiously into being between the age of the theater and that of the catalogue was not the desire for knowledge, but a new way of connecting things both to the eye and to discourse. A new way of making history."[75] He believes there was a new way to see things; the form of presentation became more than merely aesthetic, since it also added to the substance of what was being presented and to the understanding and interpretation of what was being grouped together. Chemically, the practitioner performing a reaction, or the student studying it, was already utilizing a symbolic system that could prescribe the outcome of a reaction while describing the results from past reactions. Foucault adds that for taxonomy it was "not other words, texts, or records, but unencumbered spaces in which things [such as herbariums, collections, gardens] are juxtaposed, . . . grouped according to their common features, and thus already virtually analyzed."[76] We can add the chemical table to the category of the natural history room and the garden, because in the spirit of display that grew throughout the eighteenth century, "vision was cognitive, just as images were about demonstration, not satiation."[77] As such, the table's ability to present and re-present information was not simply a matter of show, but also of tell.

The format and prevalence of the table changed during the early nineteenth century. The chemists' quantifying, instrumental, and systematic goals undergirded the organization of atoms and their new classifications as the chemistry community debated newer concepts of atomism and chemical transformation. As the format changed, though, the element of visual practice remained. This element of practice is clearly expressed in debates about the periodic table of 1869, where scholars have argued whether it was the accommodative or the predictive aspects of the table that enabled its reception.[78] While I do not contend that the earlier affinity table somehow *produced* the later periodic table, or that the latter relied on a common theory of organization developed by the former, I maintain that the affinity and periodic tables were both integrated into an aspect of chemical practice that had been established for a long time. Likewise, accommodation and prediction are neither mutually exclusive to nor unique features of the periodic table. By presenting an ordered display of substances, chemists could codify prin-

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[75] Foucault, *Order of Things* (above, n. 1), p. 131.

[76] Ibid.

[77] Stafford, *Artful Science* (above, n. 1), p. 238.

[78] See note 9.

ciples of table membership while indicating how and where unknown elements would be constructed. Despite, or perhaps in addition to, many changes in chemical knowledge and institutionalization over time, the importance of visual practice thus provides a common theme in chemical history. Such a view of the extraordinary continuity of this feature of practice, rather than being a surprising sidebar as a study of the visual, implicates tables' salient place in chemical knowledge-making. In the process of highlighting this prominence, we can bolster the importance of visual practice in scientific activity.

This much can be said about the tables: they were not treated as passive entities (and thus they encouraged a functional view), their form of presentation was important (indicating that practicality was a goal of the table maker and an expectation of the user), and the dual role of collection and direction was relatively consistent for the century-and-a-half preceding the creation of the iconic periodic table of the elements (demonstrating that this dual role is not unique to the periodic table). In addition to my interest in the visual representation of chemical classification, I am interested in the active dimension of the history of science. Treating the table as a component of practice is meant to highlight the forward, dynamic dimension in the history of chemistry. This is a subtle shift in temporal orientation, a change in historical emphasis that can reveal relevant features of practice. It is not a view that denies theoretical constraint or disciplinary limitation; rather, it exists within them.

Finally, and probably in the least, I have attempted to problematize the view that classifications and their representations can be treated singly as either offerings to the world or tools to be used. Instead, they can be understood better as complex combinations of both, looking to the past and the future as they are used in the present. The chemistry table has always been a useful, practical tool contributing to the material and experimental culture of chemistry. This active function was facilitated by the visual nature of the table, so that tables can be treated as visual representations of classification and organization, constitutive of and not ancillary to the history of chemistry.

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