'Exalting Understanding without Depressing Imagination'

Depicting Chemical Process

David Knight

Abstract: Alchemists' illustrations indicated through symbols the processes being attempted; but with Lavoisier's Elements (1789), the place of imagination and symbolic language in chemistry was much reduced. He sought to make chemistry akin to algebra and its illustrations merely careful depictions of apparatus. Although younger contemporaries sought, and found in electrochemistry, a dynamical approach based upon forces rather than weights, they found this very difficult to picture. Nevertheless, by looking at chemical illustrations in the eighty years after Lavoisier's revolutionary book, we can learn about how reactions were carried out, and interpreted, and see that there was scope for aesthetic judgement and imagination.

Keywords: *visualization of chemical process*, *chemical manipulation*, *laboratory apparatus*, *textbook illustrations*.

1. Chemistry as poetry, realized

Friedrich Schlegel used the method or logic of chemistry, illuminating mixture and combination, in his romantic fragments (Chaouli 2002, pp. 27-9), thus taking the science into literature. Samuel Taylor Coleridge declared[1] that in the work of the chemists Humphry Davy, Charles Hatchett, and William Hyde Wollaston "we find poetry, as it were, substantiated and realized in nature: yea, nature itself disclosed to us [...] as at once the poet and the poem". The key was imagination; and he quoted Shakespeare[2]

> Lovers and madmen have such seething brains,
> Such shaping fantasies, that apprehend
> More than cool reason ever comprehends.
> The lunatic, the lover, and the poet,
> Are of imagination all compact.

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The chemist in dynamical relationship with matter looked very different from the chemist in the popular image of today, when 'chemical' is set against 'natural', or 'organic', and associated (despite all the poisonous animals, vegetables, and minerals in the world) with danger to ordinary people, artificiality, forbidden knowledge, and weapons. Imagination and enthusiasm were conveyed about 1800 in demonstration lectures, which might even have a slight spice of danger from explosions or liberated gases. However, it seems worth investigating how, in the eighty years before about 1870, such chemical dynamics could be got across on the printed page, and what was then its aesthetic impact. Looking at illustrations may anyway cast light on what chemistry was like in these years, before its dynamics could be much understood. It may help us in various degrees to appreciate what was understood about the chemical process, how chemistry was perceived as an inductive science, and to see the chemist at work in the experiments which were so central to the science.

Physicists have long opposed dynamics, the science of forces, to statics; and also (since the mid-nineteenth century in English) to kinematics (Little *et al*. 1964, vol. 2, pp. 575, 1086), as the science of pure motion, considered without reference to masses or forces. One can thus say that Tycho's analysis of planetary motions was kinematically the same as Copernicus', with the signs changed, while dynamically it was very different, with its requirement that the Sun carrying all the planets moved in orbit round the Earth. In chemistry, on the other hand, and generally in discussions in the Romantic period, dynamical science was opposed to the study of masses and recipes, and went along with interest in *Natura naturans* rather than *Natura naturata*.

2. A dynamical chemistry

Davy, when he wrote at the end of his life that "whilst chemical pursuits exalt the understanding, they do not depress the imagination or weaken genuine feeling" (Davy 1830, p. 245), was recycling material from his lectures at the Royal Institution into a kind of testament or legacy, which was posthumously published as *Consolations in Travel*. With its beginning in the Colosseum, the book recalls the ancient world and Boethius, whose *Consolations of Philosophy,* written by another eminent man facing death, had been first translated into English by King Alfred. Davy had sought to show, in performance at the Royal Institution (Knight 2002) and in his writing, that chemistry was not simply an 'art', a series of useful techniques to be mastered like advanced cookery, but involved the highest faculties, and was indeed creative. The chemist was neither a mere artisan nor simply an analyst, an accountant of matter, seeing what things were made of and balancing his equations; he was godlike, manipulating the powers of nature, making new substances, improving the world (Knight 2003).

He might also be manly, even macho (Knight 2000), a master interrogating nature with his instruments, rather than a passive scholar. He had to think with his fingers. Chemistry required manual skills in ways that astronomy or mathematical physics did not, and was a science of secondary qualities – colors, tastes, textures, and smells, hard to describe exactly, but once experienced, unforgettable. It was beautiful, and also dynamically unstable, and labile. Affinities were revealed and expressed through the chemical process: few substances were incorruptible, like gold, and everywhere chemical change was going on with the inexorable passage of time.

Davy learned his chemistry in the 1790s (Fullmer 2000), through Thomas Beddoes in Bristol whom he assisted at the Pneumatic Institution, set up with Josiah Wedgwood's money and James Watt's expertise to see whether Joseph Priestley's factitious airs might be medically useful. These three had all been members of the Lunar Society of Birmingham (Uglow 2002), in eclipse after Priestley's house was sacked by a 'Church and King' riot in 1791. They shared with their protégé Beddoes a sympathy with the French revolutionaries which marked them out as dangerous subversives in the climate of world war. In 1794 Priestley had been forced into exile in the USA, while a police spy trailed Beddoes' friends, the poets Coleridge and William Wordsworth.

Men of science in France, *philosophes*, were perceived in Britain to have been responsible for the revolutionary ideology now threatening the 'sceptered isle'. For Sir Joseph Banks, President of the Royal Society, and his friends it was essential to establish that science was compatible with the British model of constitutional representative government (Gascoigne 1998). This went with an emphasis (congenial to Britons of the time) upon utility, and upon cautious Baconian generalization rather than broad-brush theorizing (Smith 1994). When Davy moved on to London, and his astonishingly successful career and social mobility, he took pains to distance himself from democrats and emphasized how the unequal division of property made economic and scientific progress possible.

However, with his work on electrochemistry leading to his hypothesis that 'electrical energy' and chemical affinity were identical (Davy 1839-40, vol. 5, pp. 39-40), Davy was also an important pioneer of dynamical science against the Newtonian clockwork universe, which had been given new life in William Paley's *Natural Theology* of 1802. Chemistry was a science that appealed to Romantic writers such as Coleridge, who went to Davy's lectures to improve his stock of metaphors; and Percy and Mary Shelley – in Mary's *Frankenstein* (Shelley 1994), Professor Waldman who enthused young Victor echoed the rhetoric of Davy, whom she knew. Chemistry went well with the romantic active universe: thus in Germany, not only with Schlegel (Chaouli

2002, pp. 27-9) and what he believed to be a kind of chemical logic, but also with Johann Wolfgang Goethe's *Elective Affinities* (Goethe 1971) where the adventures of the humans (falling in and out of love) parallel the chemistry they are studying. It is not only the visual arts that have chemical connections; we may still speak of our 'chemistry' as responsible for our moods, and use words like 'catalyst' metaphorically. Words do resonate, but the imagination is quickened especially by visual symbols.

3. The rich language of symbols

In Antoine Lavoisier's work, the science had turned its back on its speculative, alchemical past; but chemical philosophers were still intrigued by their inheritance. Davy was among those who thought that metals might be complex and transmutable, and even compared his newly discovered potassium with the alkahest (Davy 1839-40, vol. 5, pp. 66, 89). Alchemists had had a very rich tradition of illustration (Principe & De Witt 2002, p. 8). In the Orthodox Churches of the East, theology was expressed in icons, where truths about God and His dealings with the world could be conveyed visually when ordinary language fell short and Western thinkers got entangled in logic (Armstrong 1999, pp. 256-9). Similarly, Nature's workings (and the chymists' efforts to quicken them, ripening metals more speedily) might be better depicted than described (Vertesi, no year): "A picture is not merely 'worth a thousand words'; a picture can tell us more than words alone can effectively express." The genre paintings of alchemists' workshops or laboratories often seem to portray a team at work, though the focus is upon their leader. They may indicate either futility and bankruptcy, perhaps with the chymist's ruined family in evidence, or deep scholarship and a kind of tranquillity achieved through activity.

Modern chemistry was rather different, but symbolism is there. Jacques Louis David's famous and triumphant portrait of Lavoisier and his wife has been shown to merit close study because of what it manifests: its affinities to a canonical portrait of Descartes, the curious way in which the sitters are very formally dressed but apparently in the laboratory with identifiable apparatus on display, and the look that he is giving to her (perhaps as his muse) all make it extremely striking (Beretta 2001), indeed stunning, and have ensured that it has eclipsed other portraits of Lavoisier. Perhaps from our point of view, however, the plates at the back of his *Elements of Chemistry* are more significant (Lavoisier 1790). His idea was to portray exactly what apparatus he had used, and how, so that anybody could repeat his experiments and thereby come to his theoretical conclusions: but the plates were not merely illustrative, but handsome.

4. An exact and sober science of weights

Lavoisier had no need to spare expense, being indecently wealthy.[3] Indeed to duplicate the equipment in his laboratory would have been impossible for most people or institutions. In his book, one of his intentions was to replace the rich, suggestive, and ambiguous language of earlier chemistry with a precise (almost Linnaean) nomenclature akin to algebra. Metaphor, echo, different levels of meaning, poetry, or coded messages – imagination indeed – had in principle no place in this classic work of the Enlightenment. In the same way, the plates (which are copper-plate engravings) are like accurate topographical art: they are descriptive rather than interpretative, even though they form part of a book specifically designed to bring about a revolution – Lavoisier being one of the first men of science to use that word in the modern sense, and of science. Publishing in 1789, he knew that he was doing in the realm of chemistry what he then hoped and believed that the reformers were doing in France as the Estates General was convened, and the Bastille fell. Unfortunately, by the fourth edition of 1799 the translator could deplore the death of the author on the guillotine at the hands of the sanguinary monster and tyrant Robespierre (Lavoisier 1799, p. xi).

The third section of the book, occupying pages 291 to 479, is devoted to the instruments and operations of chemistry, but it is the former that lend themselves to illustration in the thirteen plates that follow. There, the flasks and other apparatus are carefully shaded, so that we get the impression of perspective and of their shape in three dimensions. For the larger objects there is a scale of feet, so that we can see how big the pieces are. It is clear in the plates what is made of glass, and what of wood. Complicated pieces are shown in cut-away form, so that we can see the inside. The coiled worm of tubing forming a condenser is shown in dotted lines within its vessel of cold water, and some long chains of apparatus are shown linked together. There are pestles and mortars, and files, and carefully fluted filter-papers.

5. Forces and equilibria

For capturing the chemical process, as alchemists had sought to do with lions, kings, and serpents, Lavoisier's plates are not very helpful, though there is conventional fire beneath some retorts or alembics, a tube or gun-barrel being kept hot in a furnace, and an illustration of the sun's rays being concentrated by a lens. Since a furnace with an oxygen blast is among the equipment available, there was every chance of some dramatic experiments. However, unlike several eminent chemists, Lavoisier seems to have avoided serious personal injury in what Davy perceived as the service of danger in the laboratory. Although Lavoisier was greatly concerned with the role of heat in chemical reactions (and professionally at the Arsenal with explosions), his chemistry of the balance sheet (Holmes 2003) lacked the dynamical emphases which William Odling (perhaps slightly tongue in cheek) detected in his opponents. Odling sought to rehabilitate Becher and Stahl, in a lecture on chemical thermodynamics as "The Revived Theory of Phlogiston", at the Royal Institution in April 1871 (Odling 1870-2). Phlogiston for him was an anticipation of chemical energy, and seen in that light its supporters had the right end of the stick.

Lavoisier had worked on heat and chemical reactions, and his associate Claude Louis Berthollet, the doyen of French chemists in the Napoleonic years when he was a prime mover in the Society of Arcueil (Crosland 1967), had a strong feeling for chemical dynamics. He was one of the team of men of science who went to Egypt with Bonaparte, and while there he set out his ideas about chemical affinity, announcing them in Cairo in the seventh year of the republic (1799). They were duly published in a little book, translated into English in 1804 (Berthollet 1804), with an American edition in 1809 (Berthollet 1809). The book is surprisingly free from illustrations or diagrams, unlike those of some predecessors in the study of affinity (Duncan 1996, pp. 145-8, 201-24), but it did provide an impetus toward understanding process with its idea that the masses of the reacting substances were crucial for the outcome.

Berthollet expanded the little book into a two-volume study (Berthollet 1803), and set off a great deal of discussion and major research on definite proportions by John Dalton and Joseph-Louis Proust (Brock 1992, pp. 144-5), which led into the world of chemical statics (weights) rather than dynamics. But Berthollet did not try to illustrate this book either. In his controversy with Proust he was generally held to have lost, so that, although Davy felt in 1806 that his electrochemical work supported Berthollet's ideas (Davy 1839-40, vol. 5, p. 41), they did not catch on and a chemistry of weights prevailed. Chemical equations (when they began gradually to come in) thus expressed masses rather than forces; and as has been recently remarked:[4]

> the usual chemical equations tell us about the atoms that are involved and about the compositions of the molecules. However, they tell us nothing about the reactions. In this sense we are still using 19th century notation in chemistry. There is need for a notation that would allow us to see that $H + Cl_2$ is the same reaction as $K + CH_3I$. At first glance, a chemist would not have anticipated that.

6. An algebra of chemistry

Following Maurice Crosland (1978, pp. 227-81), Marco Beretta (1993) has described the various symbols (some descending from alchemy) used in the chemistry of the late eighteenth century, which did include those for operations and processes, such as distillation and sublimation, as well as for apparatus and substances. However, these seem to be cases where the symbol is just a shorthand, or maybe an *aide memoire*,[5] bearing no resemblance to what is symbolized, and therefore, while more or less elegant and convenient, not necessarily of any great aesthetic significance. Though the symbols in Diderot's great *Encyclopedie* are rather beautiful, they would have involved the chemist in learning something like Chinese characters. They were also problematic on utilitarian grounds: like email addresses, they lacked the redundancy helpful in ordinary words, where mild misspelling is not fatal to understanding.

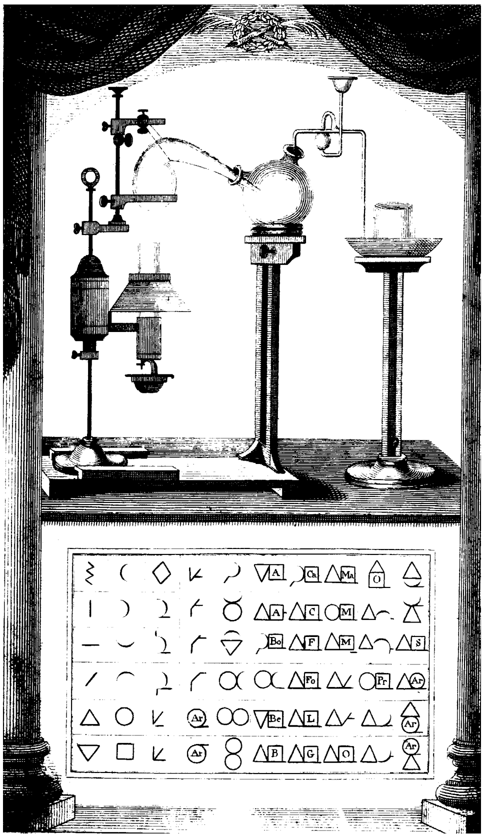


Figure 1: Frontispiece, with apparatus and symbols (from Parkinson 1801).

The famous surgeon James Parkinson in his *Chemical Pocket-book* (Parkinson 1801) (Figure 1) illustrated some apparatus on his frontispiece (curiously, set out as in a theatre, with pillars and stage curtains) with a selection of the symbols of Lavoisier's pupils Jean Henri Hassenfratz and Pierre-Auguste Adet. William Nicholson in his *Dictionary of Chemistry* gave a full table of this attempt to express chemistry as algebra (Nicholson 1808, plate 4). But although there were symbols for substances yet to be discovered, there were by this time none for processes. The algebraic tradition (by then Boolean) was revived in the 1860s by Benjamin Brodie (Brock 1967) in his 'Calculus of Chemical Operations', but despite its title his system was concerned with an 'ideal chemistry' of imaginary operations rather than symbolizing actual processes. Brodie did at least use Greek letters, easier to remember than previous hieroglyphs. However, none of these notations caught on, any more than Dalton's circles, which were to his chagrin finally rejected at the British Association for the Advancement of Science's Dublin meeting in 1835, in favor of Jacob Berzelius' much less suggestive alphabetical notation. Illustrating the chemical process proved very difficult; to show how things were to be done was easier.

7. Hands-on chemistry

Davy's description of his experiment isolating potassium is spirited, but there is no picture of "the globules [that] often burnt at the moment of their formation, and sometimes violently exploded and separated into smaller globules, which flew with great velocity through the air in a state of vivid combustion, producing a beautiful effect of continued jets of fire" (Davy 1839-40, vol. 5, p. 62). Nor in his illustrations do we get what was common in the nineteenth century, the inclusion of disembodied hands (and occasionally mouths) as an indicator of how apparatus is to be used.

Frequently the plates of apparatus were copied from one book into another, sometimes getting reversed; and sometimes they were essentially advertisements. Thus Friedrich Accum's illustrations include scientific apparatus and equipment labeled as available from him in 1807, and his book thus has some aspects of a trade catalogue (Accum 1807, plates III, IV, VI, vol. 2, p. xxiv). His description of the plates is a useful introduction to chemical manipulation. While some plates, like that of a test-tube rack, will (though static) evoke nostalgia among those of us who remember such things still as standard equipment 150 years after his book was published, some show experiments going on, and thus have a dynamical aspect. Thus a flame is being blown by steam in a patent self-acting blowpipe, while in another (advertising a self-acting thermometer) a bladder with stop-cock is held in a cuffed hand indicating how to squeeze the air out of it (Figure 2). Hands similarly appear in the engravings (done in 1809) in Jane Marcet's *Conversations on Chemistry* (Figure 3), where complicated apparatus is also shown in use (Marcet 1828, plate XI). In Accum's *Chemical Re-agents or Tests*, we actually see both of the chemist's hands and his mouth (Accum 1828, plate 3): he is directing a candle flame onto a sample held in a pair of tongs, using a blowpipe (Figure 4).

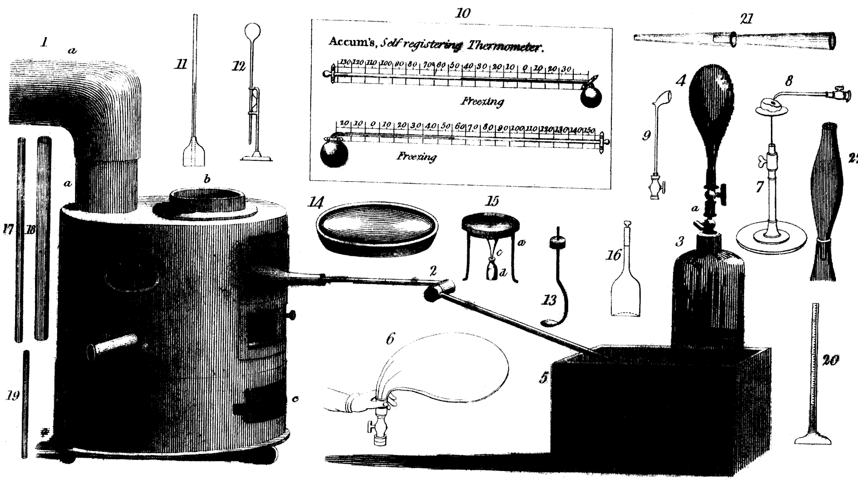


Figure 2: Apparatus including a furnace, a bladder, a clay pipe, and thermometers (from Accum, 1807, plate VI).

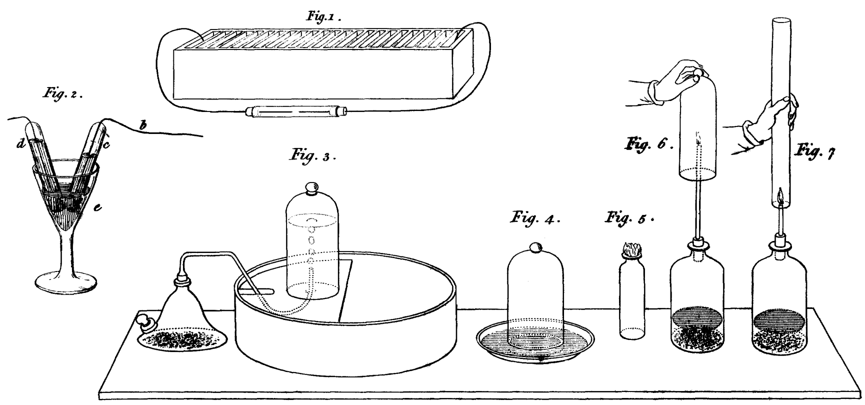


Figure 3: Apparatus for decomposing water and studying hydrogen (from Marcet 1828, plate XI).

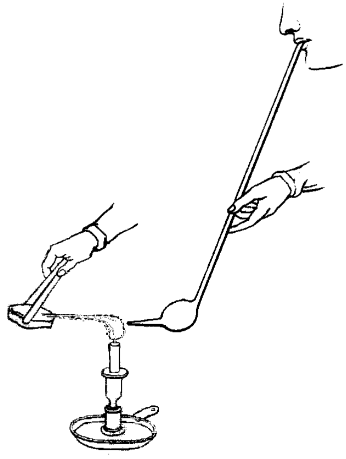


Figure 4: Apparatus (from Accum 1828, plate 3).

Mme. Lavoisier did famous sketches of her husband's laboratory, where five people were working on respiration experiments, and she was taking notes,[6] but active, peopled laboratories are unusual in art. There are splendid illustrations of laboratories, notably in William Brande's *Manual of Chemistry* (1830) where the frontispiece shows the Royal Institution's in the days of Davy and Faraday; and another plate depicts a portable laboratory, engraved from a drawing by Faraday (Brande 1830). However, neither the fixed nor the portable apparatus is in use. The laboratory is empty of human interest, as it is in Colin Mackenzie's *One Thousand Experiments in Chemistry* (Mackenzie 1822) – though that book has a magnificent colored frontispiece of a gas works with heroic workers drawing the retorts, and a crescent moon shining through a grated window overhead, giving a wonderful impression of a process going on.[7] Rather weirdly, an alchemical eagle is emerging from an alcohol blowpipe in his plate 9 (Figure 5). Other illustrations include a jolly little coal train apparently chugging along without a driver and an elaborate heating and plumbing system for a house – but there is little feeling of real chemical dynamics. Faraday's *Chemical Manipulation* (Faraday 1842) has excellent descriptions of doing experiments, but the illustrations (which are woodcuts scattered through the texts, rather than copperplate engravings), are static, with the convention as in Lavoisier's book of showing by dotted lines the shape of concealed pieces of apparatus.

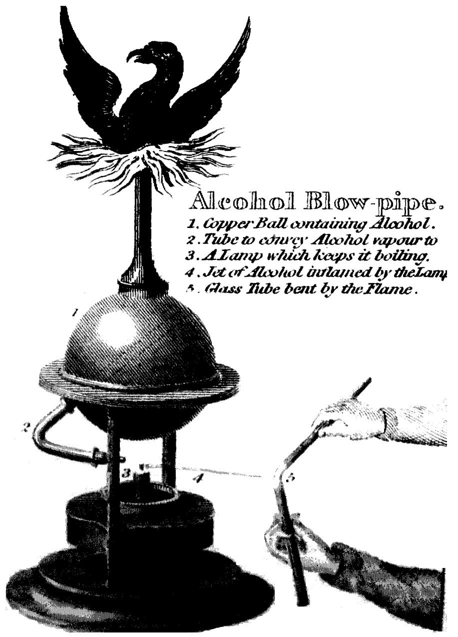


Figure 5: Apparatus for generating gases, and alcohol blowpipe (Mackenzie 1822, plate IX).

8. Picturing chemical reactions

William Henry's *Epitome of Chemistry* (Henry 1803) contains affinity diagrams in the eighteenth-century manner, but no illustrations. His *Elements of Chemistry,* however, which was revised by the popularizer J. Scoffern as a volume in the 'Circle of the Sciences' published about 1852, has fascinating illustrations of experiments going on (Scoffern 1852, pp. 191, 357). Thus the effect of putting water into white-hot silver vessels is graphically depicted (Figure 6). Elsewhere, we find a picture including an experimenter's hand, a diagram indicating the play of affinities, and a chemical equation, between them telling the reader much about the reaction (Figure 7). Faraday's friend and admirer J. B. Daniell, whose *Chemical Philosophy* approaches the subject in the direction of what we would call physical chemistry, did something like this too (Daniell 1839, pp. 301). His title emphasized forces (echoing the 'causes' of his colleague Charles Lyell's *Principles of Geology* [Lyell 1830-3]), and rather than atoms (he was a slightly uneasy admirer of Dalton, fearing that atomists might get lost in metaphysics) he preferred to think of volumes. His reactions are therefore set out with little boxes representing volumes of reactants, shown alongside the apparatus, here for the analysis of ammonia contained in a bladder by blowing it through a tube containing heated copper (Figure 8). Berzelius, however, in his work on the blowpipe, kept illustrations and formulae well apart (Berzelius 1845). This seems to have been usual in the middle years of the nineteenth century, perhaps a high-tide of positivism.

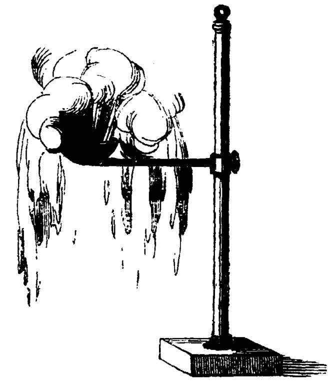
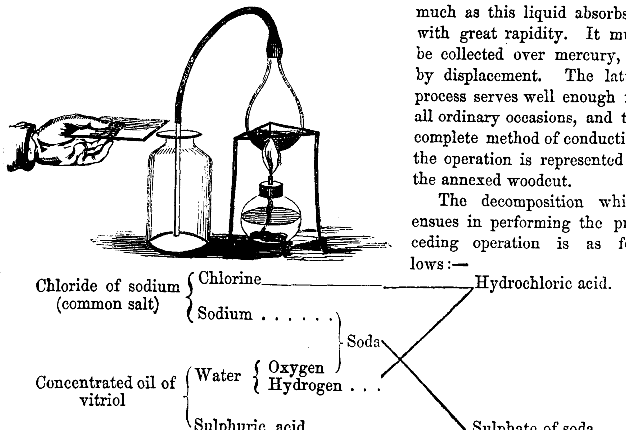


Figure 6: Effects of rapid boiling (from Scoffern 1852, p. 191).



much as this liquid absorbs it with great rapidity. It must be collected over mercury, or by displacement. The latter process serves well enough for all ordinary occasions, and the complete method of conducting the operation is represented in the annexed woodcut.

The decomposition which ensues in performing the preceding operation is as follows:—

Or, in chemical symbols, the decomposition stands thus :—

$$NaCl + SO_3 + HO = NaO . SO_3 + HCl$$

Figure 7: Three ways of depicting the preparation of hydrogen chloride from common salt (from Scoffern 1852, p. 357).

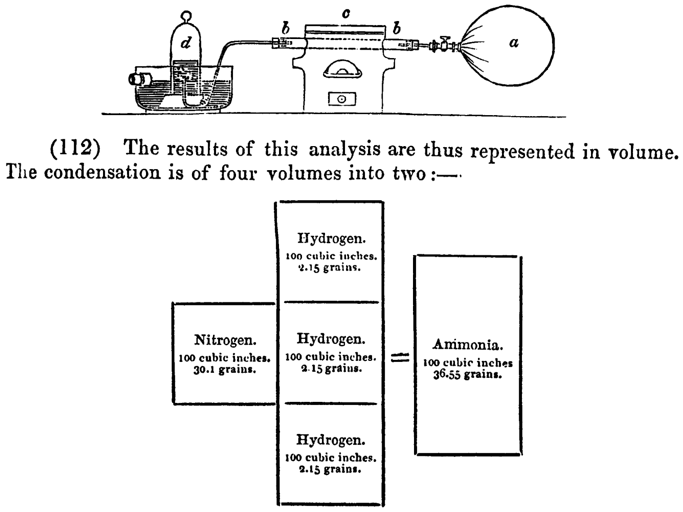


Figure 8: Analysis of ammonia (from Daniell 1839, p. 301).

Alexander Williamson, who had indeed studied with Auguste Comte, in 1851 lectured on his ether synthesis[8] under the promising title ‘Suggestions for the Dynamics of Chemistry’ and did not make use of illustrations. But August Wilhelm Hofmann, lecturing in 1862 about the new synthetic dyes, mauve and magenta (Hofmann 1862), used ‘type moulds’, wire frames into which little boxes could be put, to bring the ‘type’ theory to life. In his subsequent lecture on the combining power of atoms,[9] he showed little tin boxes as “a simple mechanical contrivance” to represent volumes and demonstrate types and reactions. These were duly illustrated, rather unexcitingly from the aesthetic point of view, when the lecture was published (Figure 9). Along with them, there was a very detailed and carefully-shaded picture of apparatus, showing the grain of the wood of which the laboratory bench was made, the wooden block upon which the new-fangled Bunsen burner was raised, the design of the gas taps and the base of the retort-stand, and the hand of the operator carefully pouring liquid into the tube (where he would have been wise to have made use of a glass rod) (Figure 10). But then, with what seems to hindsight an enormous leap forward, we meet (Figure 11) his

> [...] illustration from that most delightful of games, *croquet.* Let the croquet balls represent our atoms, and let us distinguish the atoms of different elements by different colours. The white balls are hydrogen, the green ones chlorine atoms; the atoms of fiery oxygen are red, those of nitrogen, blue; the carbon atoms, lastly, are naturally represented by black balls.

Into the balls, metal tubes and pins were screwed so that he could build up models. Soon sets of these 'glyptic formulae' were available to arouse the ire of Brodie as materialistic joiner's work, unworthy of the attention of chemists, and set off debates at the Chemical Society of London about the value and truth of atomic theory (Brock 1967). There was no longer any doubt that it could generate handsome and heuristically-useful models, having their own kind of aesthetic appeal, and making chemistry much easier to learn.

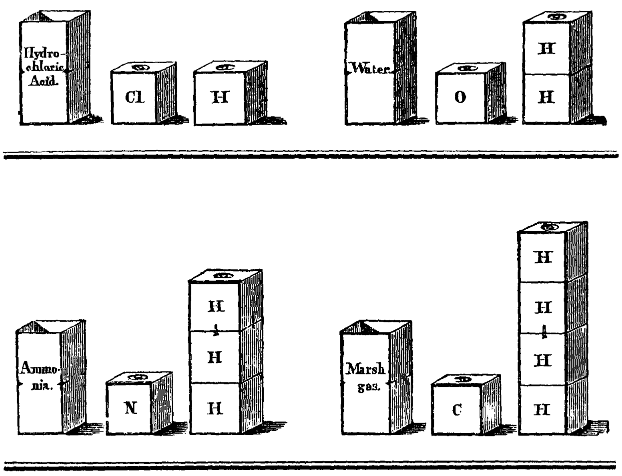


Figure 9: Tin boxes illustrating the type theory (from Hofmann 1862-6, pp. 412-3).

We have met with some attempts to depict rapid reactions, but the importance of time in chemical reactions – some explosively fast, others extremely slow – was only appreciated during the hundred years that followed our chosen time. Williamson's insight in his work on ethers that reactions go in stages could only be developed in the light of the atomic theory and agreed formulae that were a feature of the 1870s. However, whether the series of equations, which covered the pages of the journals from the later nineteenth century and that indicate how syntheses were achieved and how reactions go, were of aesthetic merit is another question – usually they are seen as turning-off all but dedicated professionals, and blinding (rather than enlightening) everyone else with science. Something less austere is needed to feed the outsider's imagination.

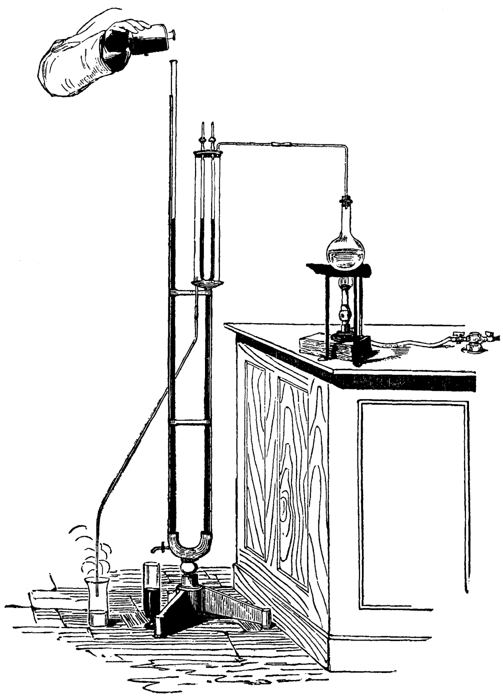


Figure 10: Demonstrating the gas laws (from Hofmann 1862-6, p. 415).

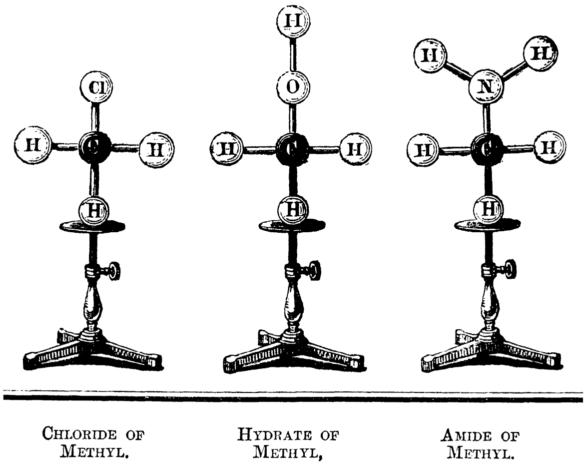


Figure 11: Molecular models (Hofmann 1862-6, p. 426).

9. Finding conceptual tools

We have encountered chemists at work in the laboratory, found visual clues indicating how experiments were done, and seen some 'stills' as it were from chemical processes like distillation. However, showing movement was not easy, and our search for depictions of chemical dynamics has not been very fruitful. To go to lectures and witness experiments was enlightening, and to listen to the enthusiastic lecturer was exciting. But what was seen there proved hard to convey in pictures or indeed in vivid prose.[10]

In eighteenth and nineteenth-century works of natural history, natural historians like Thomas Pennant and J. J. Audubon sometimes sought to portray a bird not at rest on a branch or twig, but in flight or eating, while Josef Wolf showed exotic animals fighting.[11] This was not easy because artists were usually working from stuffed specimens, with at best a sketch done in the field. Edward Lear's studies of parrots were unusual in being done from living specimens, in the newly founded London Zoo (Jackson 1975, pp. 32-8). As we have seen, it was much more difficult in chemistry.

As Trevor Levere remarks,[12] "Until the 1870s […] chemists lacked the conceptual tools to picture and model three-dimensional molecules". The innovations of Hofmann and then of Jacobus Henricus Van't Hoff (Ramberg 2003) allowed interactions to be visualized and depicted – in a process that has subsequently gone on, most evidently in Roald Hoffmann and Vivian Torrence's *Chemistry Imagined* (Hoffmann & Torrence 1993) with its evocative pictures as in ancient traditions, in association with structural diagrams, some of considerable elegance and even beauty. In synthesizing molecules unknown in nature, the kind of creative activity that Davy talked about, the playful chemist (Nickon & Silversmith 1987) can prepare 'churchane' and 'barrelene' – though the beauty of the equations leading to them is an acquired taste, caviar to the general, and only loosely connected to ordinary ideas of the aesthetic.

Despite the opposition to atoms and visualization, led notably by Marcellin Berthelot, Brodie, and Wilhelm Ostwald, Lavoisier's austere notions of what was metaphysical and what chemical did not endure beyond the early twentieth century. Now diagrams are essential, and everyone recognizes that chemistry is dynamic. To claim that it is poetry realized would surprise most readers today; but that it requires imagination cannot be doubted.

Notes

[1] Coleridge 1969, vol. 1, p. 471; Levere 1981.

[2] William Shakespeare, *A Midsummer-Night's Dream,* V, I, lines 4-8.

[3] Poirier 1996, pp. 1-3; Donovan 1993, pp. 110-29; and on language, pp. 159-67, but see also Anderson 1984.

[4] Dudley R. Herschbach in Hargittai 2003, p. 396.

[5] The British Museum has in the summer of 2003 mounted an exhibition on this theme.

[6] Beretta 2001, pp. 48-9; Holmes 2003.

[7] See Figure 4a in the online version of this paper http://www.hyle.org/journal/issues/9-2/knight.htm

[8] Williamson 1851. For reprints of this and other papers, see Knight 1998, vol. 1.

[9] Hofmann 1862-6, quotation from p. 416.

[10] But see the new book by Klein (2003).

[11] Ellenius 1985, pp. 123, 147-65; Knight 1977, pp. 4, 117.; Desmond 2003, p. 128.

[12] In Ramberg 2003, p. xxi.

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David Knight:
Department of Philosophy, University of Durham, 50, Old Elvet, Durham DH1 3HN, UK; D.M.Knight@durham.ac.uk