THE 2003 EDELSTEIN AWARD ADDRESS* MAKING CHEMISTRY POPULAR

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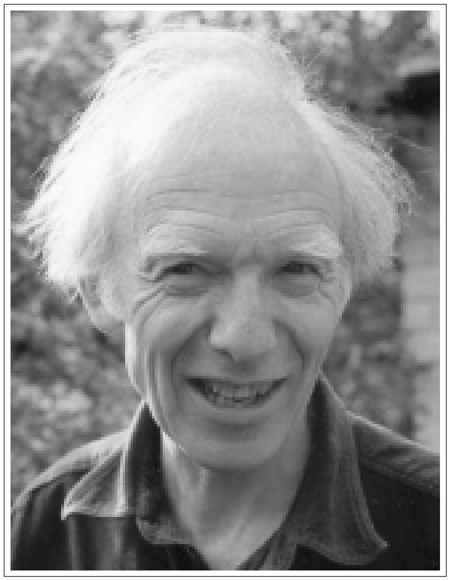
"Chemistry is wonderful," wrote Linus Pauling (1), "I feel sorry for people who don't know anything about chemistry. They are missing an important source of happiness." That is not how the science has universally been seen in our time. We would not expect to see lecture-rooms crowded out, chemists as stars to be invited to fashionable parties, or chemistry books becoming best-sellers. And yet, in the half century following the publication of Antoine Lavoisier's revolutionary book in the revolutionary year of 1789 (2), chemistry gave that pleasure to many, drew crowds, was seen as the fundamental science, and was made attractive to women as well as men, girls as well as boys, in accessible books and lectures. It was an important aspect of modernity, a science in which understanding the world went hand in hand with changing it.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Chemistry made good theater (3), if the experiments worked as they always did at the Royal Institution in London (or even if they did not) and before the heavy hand of 'health and safety' legislation was laid upon the science. Fertilizers and explosives seemed wholly beneficent in those optimistic days, the gas industry transformed urban life with well lighted winter evenings, and a bright dawn gleamed over a chemically-based society. Intellectually, the science did not demand the mathematics required for serious pursuit of the sublime science of astronomy. Chemists like Joseph Priestley thought it the ideal Baconian science in which everyone might join, for its theoretical structure was still unformed. Others in our Edelstein symposium have looked at France, Germany, and Russia, where government initiatives were crucial. Our chief focus will be Britain, a prospering society based upon patronage, where committees of interested people ran things, where there might be a black market in tickets for a chemistry lecture, where Humphry Davy was a chemical star (4), and where chemical literature was readable, and widely read (by the 1830s often on chemically-bleached paper).

One way to understand chemistry's popularity is to see it as appealing to body, mind, and spirit. Chemistry is the science of the secondary qualities, concerned with colours, tastes, smells, textures, and even sometimes (as with the 'pop' of ignited hydrogen) noises: there is endless stimulation for the senses in doing, or even watching, chemistry. The smell in particular of a laboratory is amazingly evocative, transporting one back vividly across the years. Chemistry also requires, or required, manual skills: it was necessarily experimental, and with experience the pleasure of manipulating apparatus (from weighing to blowing glass and handling dangerous substances) and getting results increased steadily. Then, in the years we are considering, chemical theory was fluid and not too recondite. There was not yet an enormous amount to learn. Journals were informal and open. The able person might move into the science and with astonishing rapidity be making serious contributions to knowledge, respected by peers. Then, like other sciences, chemistry could cast light upon God's working in nature. But chemistry was useful. Chemical natural theology therefore differed from other kinds in that the chemist sought to improve the world, whereas the astro-theologian contemplated, awestruck, the perfection of the heavens, and the physico-theologian the design evident in the eye of the eagle or the fly (5). Nevertheless, using God-given reason and manual skill to overcome pain, disease and hunger was highly significant spiritually (6).

Chemistry and the Body

Chemistry had always had connections with medicine, and academic chemistry was taught in medical schools in our period (7), during which drugs like 'Jesuits' bark' and opium, of doubtful provenance and efficacy, were analyzed and their active components prepared as white crystals (8). This meant that dosage could be controlled and effectiveness determined. Such analysis became a major research program, leading by the middle of the century to jobs in industry or in controlling pollution; though by 1840 synthesis (guided by the use of Jöns Jakob Berzelius' symbols on paper) was becoming extremely important (9) as the key to understanding chemical processes. Clearly, pharmacy was an important way in which chemistry would be useful; and with the isolation of 'airs,' notably by Priestley, a new range of chemical substances became available to the sick, or to those looking for new sensations. Thomas Beddoes, with money from the wealthy potter Josiah Wedgwood and equipment designed by James Watt, in 1798 set up in Bristol a Pneumatic Institution to treat disease with gases. Both Wedgwood and Watt (prominent members of the Lunar Society of Birmingham, with Priestley and Erasmus Darwin (10)), had sons suffering from tuberculosis, and oxygen seemed a promising treatment. Health, comfort and wealth would flow from chemistry.

In the event, these medical hopes which had focused attention on the latest chemistry were not fulfilled at that time, and before Beddoes' death in 1808 it was said that people were having to be paid to undergo the experimental treatments. But in 1799 young Davy (11), employed as Beddoes' assistant, discovered that nitrous oxide, feared by some (notably the American, Samuel Mitchill) as a deadly poison, a very 'septon,' was instead laughing gas. His subjective accounts of anesthesia remain classics; and this gas offered the pleasures of alcoholic indulgence without a subsequent hangover. Davy met the poet Samuel Taylor Coleridge, who was experimenting with drugs (having taken opium for pain relief on the suggestion of Beddoes (12)), and he and others tried the gas. In 1800 Davy published his first book, *Researches Chemical and Philosophical, Chiefly Concerning Nitrous Oxide,* in which part was devoted to the chemistry of the oxides of nitrogen, and part to the effects of laughing gas. It made his reputation, and made the breathing of nitrous oxide a craze. In 1801 Davy was appointed (by Benjamin Thompson, Count Rumford) to a position at the Royal Institution in London, and there is a celebrated cartoon by James Gillray showing the public administration of laughing gas there in the course of one of the fashionable lectures for which the Institution was celebrated (13).

Those watching this and other lectures could follow the lecturer's thought as he manipulated the apparatus in order to illustrate his exposition. And some of them at least were tempted to do the experiments themselves. In his last posthumously published book, *Consolations in Travel* (14), Davy commented upon the way in which chemists had in his lifetime come to deal with much smaller quantities, replacing furnaces by spirit lamps so that experiments could now be done in the drawing room. He also remarked that few chemists had retained through life a steady hand and a quick eye, for the laboratory was a dangerous place; but neophytes might perhaps be expected to avoid this spice of danger which made chemistry macho, and work with apparatus which might easily be contained in a small trunk or traveling carriage, and cost only a few pounds. Davy had himself, when visiting Napoleon's France to collect his prize for electrochemistry from the Academy of Sciences (accompanied by young Michael Faraday as assistant and servant), used such a box of apparatus in the preliminary work of elucidating the nature of iodine, in a race with Joseph Louis Gay-Lussac, though the research was completed in a fully equipped Parisian laboratory (15).

When he and William Wordsworth were settled in the Lake District, Coleridge had written earlier to Davy asking for advice in setting up a laboratory. Nothing seems to have come of the proposal, though Davy did punctuate some of Wordsworth's poems for the printer in London, stay with the Wordsworths at Dove Cottage, and subsequently climb Helvellyn with Wordsworth and Walter Scott. But at that time there were chests of apparatus, chemistry sets, commercially available and known as 'portable laboratories;' Brian Gee describes their development (16). They had begun as equipment for mineral surveyors or doctors testing mineral waters (doctors were already accustomed to carrying medical chests in their carriage as they visited patients, or on shipboard); but by 1800 they were being assembled by instrument makers for recreational purposes also. Thus William Henry in Manchester sold portable laboratories of different sizes at fifteen, eleven, or six and a half guineas (17). James Watt junior bought one of the top-price models, although Henry was soon grumbling at the trouble involved in assembling all the components in the provinces. London-made portable laboratories were bought by Davy's friend and physician William Babington (to whom Davy's fishing dialogues, *Salmonia* (1828) were dedicated), and by Bryan Higgins. Frederick Accum and then John Newman sold standard sets, with Accum asking £80 in his catalogue of 1817 for one suitable for 'a general course of chemical experiments.'

This would be a huge price, an investment for a would-be itinerant lecturer or an institution, at a time when Davy at the peak of his career was earning about £1,000 annually. Soon cheaper sets came onto the market, often accompanying a popular book, for texts at this time, such as Samuel Parkes' *Chemical Catechism* and Colin Mackenzie's *Thousand Experiments in Chemistry* listed many experiments to be performed, as did Michael Faraday's only book, *Chemical Manipulation* (18), which describes how to carry out processes such as weighing and bending glass tubes in ways that might still be helpful to the practical chemist. Chemistry after all could not be learned in a meaningful way from books or lectures alone. Thus Gee tells us that in 1835 R. B. Ede sold small trunks of apparatus at one and a half or two guineas (superior grade, with stoppered bottles and French-polished box) to accompany J. J. Griffin's *Chemical Recreations.* By the middle of the century, forward looking schools were beginning to teach chemistry and used portable laboratories because they did not have a purpose-built room. Jane Marcet's famous *Conversations on Chemistry* (1807), was written to help those who had heard lectures by Davy (or someone less exalted), really understand what was going on. Those dialogues, written for girls, contain experiments with illustrations of apparatus (including hands, indicating how to manipulate it) and perhaps real governesses followed the example of 'Mrs. B' in the book and used a portable laboratory with their charges (19).

Fifty years ago I learned chemistry in a school laboratory built at the end of the nineteenth century, and the experiments with which we began went back to the time of Priestley and Lavoisier. We collected gases over water, we weighed, we bored corks, then we titrated and heated as we progressed towards about the time of Robert Bunsen. The sheer sensual pleasures of chemistry enthralled us (as it did Oliver Sacks, where he vividly describes it as saving him from childhood miseries (20)); and we also (though forbidden) dissolved pennies in nitric acid and squirted each other with wash bottles. Later, doing ether distillations and handling concentrated acids and other unpleasant or poisonous substances gave that spice of danger which Davy and his contemporaries had relished. In the nineteenth century, chemistry had led the way in hands-on practice—physicists might think of it as mere advanced cookery, but chemists knew better—and anyway, cookery is not to be despised, nor are manual skills and bodily satisfactions. But we may wonder how readily available these things were in the early nineteenth century, to those who were not well-off supporters of literary and philosophical societies, athenaeums, or academies.

In 1824, when William Nicholson's informal *Journal of Natural Philosophy* had long ago been taken over by *The Philosophical Magazine* (which was also soon to swallow *Annals of Philosophy)*, a new journal, *The Chemist*, was launched, coming out weekly in octavo parts of sixteen pages, and costing 3d (about 8c), so that 80 issues would have cost a pound. It was illustrated with woodcuts in the text, rather than expensive copper-plates, many of them showing apparatus, and was aimed at working men—skilled artisans rather than laborers. It was a part of the 'march of mind,' going with Mechanics' Institutes and the Society for the Diffusion of Useful Knowledge, as more people learned to read in the Sunday Schools, and in the weekday 'monitorial' schools, founded by the churches in educationally backward England, when political reform was at last on the agenda. In his opening editorial the editor, looking for a chemical hero, was therefore critical of Davy, who as figurehead (21):

> …professes a sort of royal science. If in its pursuit he makes any discoveries which are useful to the multitude, they may, and welcome, have the benefit of them. But he has no appearance of labouring for the people. He brings not the science which he pursues down to their level; he stands aloof amidst dignitaries, nobles, and philosophers; and apparently takes no concern in the improvement of those classes for whom our labours are intended, and to whom we look for support. Amidst all the great efforts which have been lately made to promote scientific instruction among the working classes, and amidst all the patronage which these efforts have found among opulent and clever men, it has been with regret that we have sought in vain to trace one exertion or smile of encouragement bestowed on such efforts by the President of the Royal Society.

The use of the term 'working classes' was unusually early, but the message was that elite chemistry was not popular. Instead *The Chemist* recognized the difficulty working men would have in assembling apparatus. Faraday in his book was to advocate the use of ordinary household equipment wherever possible, and to advise on making a cheap and ingenious balance for those who had no access to a proper one. He also urged the reader to contrive things out of glass tubing and pieces of wood. On the first page of the first number of *The Chemist*, we find the reassuring message that many experiments may be carried on with 'a simple and cheap apparatus,' and that 'experiments conducted on a small scale have led to most of the brilliant discoveries of our times,' and noting that the galvanic battery and the blowpipe will only work on small quantities. Heat may be supplied by an ordinary fireplace and bellows, while for other operations 'a few glass retorts and phials, a small lamp and a common bason' are all that is needed. The editors promised to make a point of describing cheap and easy experiments for readers to perform and included sensible advice on cleanliness and labeling. Each number of *The Chemist* did indeed include a description of one or more pieces of equipment and gave advice on manipulation and on the recycling of damaged glassware. The journal was high-minded in rejecting advertising (many chemistry books also functioned as trade catalogues) and in paying authors, and therefore did not last very long. But it did point to the delight in chemical experiment that working men shared with the more leisured; whether their daughters got much of a look is doubtful. Chemistry was a science in which manual skills had to be developed to give bodily dexterity and sensual pleasure.

Chemistry and the Mind

What then about the mind? All science should give intellectual satisfaction, but with chemistry at this time the relatively undeveloped state of theory made it particularly exciting and approachable. Lavoisier had described his own work as a revolution, akin to what was happening at just the same time in French political life. And 'revolution,' which had meant in Britain in 1688 and in America in 1776 a return to the supposed lost liberties of Merrie England before the Norman yoke was imposed, came with the French revolution of 1789 to mean instead a new departure, an escape from the past rather than a restoration of it. Thus the new language of Lavoisier and his associates (22) was a fresh start, making the task of learning chemistry much easier for the neophyte. With its basis in the logic of Condorcet and Condillac, and thus ultimately of Locke, this new language (seen by Thomas Kuhn as a crucial feature of scientific revolutions (23)) was to be a kind of algebra, clear and free from personal, adventitious, or historical associations, incapable of metaphor or flights of fancy. With Priestley and Lavoisier, chemistry had expanded to include all three phases of matter: it was no longer a branch of cookery or pharmacy, and indeed Davy could define it as a wide-ranging and fundamental activity (24):

> Chemistry relates to those operations by which the intimate nature of bodies is changed, or by which they acquire new properties.

Chemical theory was also controversial, something which always attracts outsiders far more than calm certainty. There was argument over whether the science needed to be theory-laden, should have an international language, should be seen as static or dynamic (based upon weights or forces), and how it should relate to other sciences.

Priestley had interpreted his work in the context of the phlogiston theory; and in the lectures he delivered in Hackney (to which he fled after his house in Birmingham was sacked by rioters in 1791), he compared Lavoisier's theory of oxygen (25) to the vortices by which Descartes had sought to account for planetary orbits. This was a classic put-down for the French, because the vortices had been magisterially shown to be false by Isaac Newton in his *Principia* (1687). But to Nicholson, author and translator of textbooks, author of a dictionary of chemistry, and editor of a journal important in its day, both Priestley and Lavoisier over emphasized theory. His ideal was the sober presentation of facts, and for him theory was an add-on. He indicated this devotion to the inductive philosophy of Francis Bacon by putting theories at the end of chapters and treating them as more or less probable aids to memory and organization—generalizations rather than serious guides to the structure of the world. He explained them (26):

> In such a way, as to create in the chemical student an habit of steadily and calmly attending to the operations of nature; instead of indulging that hasty disposition for theorizing, which indeed might pass, on account of its evident impropriety, without any earnest censure, if we had not had the mortification to see it too much practiced by men entitled to the best thanks of the scientific world, and on that account possessing greater power to mislead.

Nicholson evenhandedly put down Priestley and Lavoisier and found no trouble translating between the phlogistic and antiphlogistic languages of chemistry.

Lavoisier and his team had hoped that by choosing names like 'oxygen' and 'hydrogen,' based upon ancient Greek words, they would (as Linnaeus had with his botanical Latin (27)) create an international language, used by everyone. In this they were disappointed (28), for in Germany, Russia, the Netherlands, and elsewhere the terms were translated; so the Germans have Sauerstoff for oxygen, for example. For them, Lavoisier's error in thinking that oxygen was the generator of acids is constantly before their eyes; while for English speakers, who adopted the French forms and who no longer mostly have a classical education, the words convey nothing but chemistry. It is curious that although Britain was at war with France for much of the eighteenth century, and then for over twenty years after the 1789 revolution, there should have been no trouble in taking over the language. Although the French worry about *Franglais*, English has been for centuries very permeable to French, as we see with café, restaurant, government, and many other ordinary words. 'Oxygen' was theory-laden; but when convinced that his greenish choking gas was an element, and not oxymuriatic acid, Davy named it 'chlorine' for its color, and the avoidance of theory (except that metals normally end in 'um') has become general. Similarly, the French 'azote,' (deadly), was replaced in English by 'nitrogen,' since it was a faulty description. When Berzelius eventually told his housekeeper Anna to say 'chlorine' because that was better, he was signaling that he had changed his theory of acidity from Lavoisier's to Davy's.

Lavoisier's chemistry was based upon weights and careful bookkeeping, as in his job in the tax farm where the accounts had to balance (29). Priestley had another vision, of a science based upon forces (30):

> Hitherto philosophy has been chiefly conversant about the more sensible properties of bodies; electricity, together with chymistry and the doctrine of light and colours, seems to be giving us an inlet into their internal structure, on which all their sensible properties depend. By pursuing this new light, therefore, the bounds of natural science may possibly be extended, beyond what we can now form an idea of. New worlds may open to our view, and the glory of the great Sir Isaac Newton himself, and all his contemporaries, be eclipsed, by a new set of philosophers, in quite a new field of speculation.

In his laws of motion and of gravity, Newton had gone beyond the facts of astronomy to disclose the underlying forces and the ultimate simplicity, order, and beauty of the world. But mechanics went less deeply than chemistry, if allied with electricity, could do. With the publication in 1800 of Alessandro Volta's paper on the electric pile, this alliance was cemented. Different metals immersed in water, or better in dilute acid, generated electricity; and the subsequent researches of Nicholson and then in 1806 onwards of Davy established electricity as a chemical science. The conclusion for which Davy was awarded his prize by the Parisian Academy of Sciences was that electricity and chemistry were manifestations of one power. Berzelius was to build this insight into his account of chemical affinity, as 'dualism:' every compound had its positive and negative pole. Even before Davy's great papers Friedrich Schelling (31), Johann Ritter, and others in the German tradition of Naturphilosophie had sought a dynamical chemistry in which combination was a true synthesis of opposites in a world of flux and process. Chemical logic lay behind the romantic publication of 'fragments' by Friedrich Schlegel (32). There could be many candidates standing as 'the Newton of Chemistry,' and much exciting discussion about matter and force, especially as chemists explained respiration and photosynthesis and seemed to be casting light on the vital principle itself. Here was excitement, but where the speculation was allied to and controlled by experiment.

Chemistry and Spirit

There is less to be said about chemistry and spirituality than would be the case with astronomy or natural history, where popularization was very generally in the form of praise for the Creator, and William Paley's famous *Natural Theology* was published in 1802. Joseph Priestley (who was by profession a minister) had in his *Disquisitions Concerning Matter and Spirit* (1777) put across his view that matter was active, its point atoms being centers of force. There was no reason why some suitable arrangements of such matter could not think, and Priestley therefore embraced a Christian materialism bringing together his Unitarian faith and his dynamic idea of matter. He believed that the doctrine of immortal souls had drifted into true 'primitive' Christianity from pagan Platonists; and that we were material beings, who at death came to an end. Death was not a family reunion. We did not survive it as disembodied souls. The promised resurrection of the dead would happen as in medieval wagon plays or on the wall of the Sistine Chapel: when the angel blew the trumpet, the 'sleeping' dead would by a miracle be revived and face judgment. Contemporaries frightened by the French Revolution of 1789 were alarmed by Priestley's embracing of democracy and heresy; and, except among Unitarians, whose faith according to the Darwin and Wedgwood families was a feather bed to catch a falling Christian (33), his particular form of scientific religion did not catch on. Materialism remained very much a term of abuse through the nineteenth century.

Lecturers alluded in a general way to design; and when the Earl of Bridgewater died in 1829, bequeathing £8,000 to the Royal Society to commission treatises demonstrating the goodness and wisdom of God in the creation, the eminent physician and chemist William Prout was one of the eight authors selected (34). Whereas astronomy, physiology, geology, zoology, psychology, and even the human hand all received a treatise of their own, however, chemistry was shoehorned in with meteorology and the function of digestion (35). Prout, who had identified hydrochloric acid in the stomach, used the chemical part of the book to present a version of his famous hypothesis about the nature of matter and the complexity of the chemical elements; but apart from that, the arguments for a wise creator are conventional, and the work rather dull. Although the series as a whole was a great success, his was not much commented on and never became a classic as some did.

In 1838 Mrs Hannah Acton gave £1,000 to the Royal Institution for a prize to be awarded every seven years for a work of natural theology. The first in 1844 went to a chemist at the Middlesex Hospital in London, George Fownes, whose essay was published that year. He believed that (36):

> …recent discoveries in chemistry, more especially in its relations to animal and vegetable physiology, lead to the hope that it may be possible to draw an inference of design from the chemical constitution of the earth and its inhabitants, hardly inferior in value to that derived from their physical study, although not always so obvious and striking.

Thus he was able to popularize the recent advances in organic chemistry, even what we would call biochemistry, and indicate the potential for chemical explanations of biological phenomena. There are discussions of chemical mechanisms and of organic analyses, giving a good snapshot of how things stood at this time. Justus von Liebig was the great man in this work, and the first two of his *Familiar Letters on Chemistry* (37) take up the same points: chemical natural theology was possible, indeed unavoidable. Awe and wonder at the extent and complexity of the creation and of the processes which sustain life were inevitable consequences of the serious (as opposed to the merely empirical) study of chemistry.

Those who dilate upon the wisdom and goodness of God have tended to be healthy and comfortably off. Another chemical perspective, further from easy optimism, is found in the *Religio Chemici* (38) of George Wilson, the first Professor of Technology (39) in the University of Edinburgh and a lifelong invalid. He had long hoped to write it, but it was incomplete at his death and was published posthumously by his sister. He was prepared to face up to the evil and pain in the world and was perplexed by the way in which, although we exist through the continual flux of our material components, repairs after injury or aging are never complete. The new materials reform the scars and wrinkles. The book, a collection of essays originally conceived on the model of Sir Thomas Browne's *Religio Medici* (1642) (40), also contains biographical essays valuable to the historian, reminding us that the lives of chemists then and since make the science interesting and perhaps popular.

We do not therefore need to marvel that chemistry should have been popular in those years after the French and Chemical Revolutions of 1789; it had everything, appealing to body, mind, and spirit. Whether the chemistry of our time can be made as attractive remains to be seen; but a great deal of specialization, unhappy experience of reluctant students with examinations to pass, and scientific disasters lie between us and the cheerful childhood of the science.

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