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Lavoisier; Discovery, Interpretation and Revolution (**)

In August 1812, the young Michael Faraday wrote in great exitement[1] that «I would wish you not to be surprised if the old theory of Phlogiston should be again adopted as the true one tho I do not think it will entirely set aside Lavoisiers». It did not: there was no chemical counter-revolution. Although imperfections in Lavoisier's theory had become evident, he remained on his pedestal as the founder of modern chemistry. If in the late twentieth century we accept that all knowledge is somewhat unstable, we may wonder at this longevity.

Preamble

Lavoisier[2] was indeed extraordinarily successful. He got his interpretation of acidity and combustion accepted, and with it his list of simple substances or elements, so completely that we are apt to see his work simply as discovery in the literal sense. Like his contemporary Captain James Cook actually landing on what had been «Terra Australis Incognita», Lavoisier seems to have taken the lid off the phenomena of chemistry, seeing what was really there for the first time. Australia, and its plants and kangaroos, had always been there: so, we accept, had oxygen and hydrogen, but not phlogiston. When Lavoisier died, two hundred years ago, many chemists were converts to his views; but not all were. We wonder why; and tend to compare Joseph Priestley and others with the reactionary professors who refused to look through Galileo's telescope and see what the Moon was really like. We look back at the chemistry of the late eighteenth

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(**) Comunicazione presentata il 20 ottobre 1994 al Seminario internazionale per il bicentenario della scomparsa di Antoine Laurent Lavoisier (1743-1794).

[1] F.A.J.L. James (ed.), *The Correspondence of Michael Faraday*, vol. 1, London, 1991, p. 17.

[2] B. Bensaude-Vincent, *Lavoisier*, Paris, 1993; A. Donovan, *Antoine Lavoisier: Science, Administration, and Revolution*, Oxford, 1993.

century through Lavoisier's eyes; and see the work of chemical, electrical and pneumatic philosophers as leading inevitably to his labours and interpretation.

Science may be a more-or-less steady advance in knowledge, a progressive business in which each generation sees more than its predecessor; but even then, we would have to admit that in the excitement of new discovery older truths have sometimes been forgotten or neglected. If, on the other hand, science is the imposition of paradigms upon booming, buzzing confusion, then Lavoisier's new order will have prevailed because it seemed to those active in the science to be the best available: we should have to see how he and his associates propagated it, rather as a political party promulgates its views, or a church wins converts. Either way, then, it is worth exploring what other interpretations of nature were available, which seemed to some able contemporaries to be both convincing, and fertile in suggesting experiment.

This is more difficult because Lavoisier self-consciously promoted a scientific revolution. He lived through, supported, and was in the end the victim of, the French Revolution. The English Revolution of 1688 had seemed a return to the Good Old Days before the Norman Yoke had been imposed in 1066; but the French looked forward rather than back. With his fashionable interest in language, Lavoisier (as Linnaeus had done) changed the terms used in his science so that they became more definite. Older chemists had used a language rich in overtones and suggestions, where the names of discoverers, the appearance of substances, or their geographical whereabouts determined how things were referred to; and where terms came from a variety of European and exotic tongues. The new language was systematic;[3] and Lavoisier and his associates launched a new journal[4] in which it was used exclusively. Once it became accepted, with some modifications in different countries,[5] it was hard to understand what users of the old nomenclature were talking about. This is another reason why they seem obscurantists. George Orwell in his novel *Nineteen Eighty Four* imagined a language, Newspeak, in which it was not possible to think old thoughts; Lavoisier had already achieved it.

In 1814 the Bourbons were restored to power in France; and much earlier than that Napoleon had declared that the Revolution was over. Political revolutions can be reversed, the wheel of fortune can revolve, though of course one can never go back to the past and start again. Even the language of revolutions,

[3] Guyton de Morveau et al., *Methode de Nomenclature chimique [1787]*, intr. A.M. Nunes dos Santos, Lisbon, 1992; D. Knight, *Chemistry and Metaphors*, «Chemistry and Industry», *24*, 996-9 (1993).

[4] M.P. Crosland, *In the Shadow of Lavoisier: the Annales de Chimie and the Establishment of a New Science*, Faringdon, 1994.

[5] A conference on the new language was held in Paris in May 1994, organized by Dr Bernadette Bensaude-Vincent; it will be published.

as we saw when Leningrad reverted to being St Petersburg, can be dropped in favour of the old nomenclature. What is striking about Lavoisier's intellectual revolution is that there was no serious counter-revolution; despite the work of the next generation demonstrating that some of his interpretations were false, it is upon Lavoisier's labours that modern chemistry has been built. We do not have to go all the way with Adolphe Wurtz and his «Chemistry is a French science: it was founded by Lavoisier of immortal fame»,[6] but he had a point. Let us now look at what might have been a counter-revolutionary tradition, with its origins in Britain and in Italy.

Chemical Philosophy

Lavoisier quantified chemistry in terms of weights. Chemists in the narrow sense, concerned with pharmacy or metallurgy and involved in doing analyses for the most part, may have found this a straightforward way to proceed: but it was not the most obvious, or what contemporaries would have called the most philosophical, route for all those involved in what came to be called chemical philosophy.[7] Joseph Priestley wrote about the impact of electricity and optics, his own route into science:[8]

> 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.

Priestley like Lavoisier drew upon what came to be called experimental physics; but unlike Lavoisier, who believed that theories of matter must be metaphysical and indefinite,[9] Priestley hoped for real understanding of its internal structure, with point atoms that were centres of force.[10] In the Newtonian

[6] W.H. Brock, *The Fontana History of Chemistry*, London, 1992, p. 87.

[7] M.J. Nye, *From Chemical Philosophy to Theoretical Chemistry: Dynamics of Matter and Dynamics of Disciplines, 1800-1950*, Berkeley, 1993, ch. 3.

[8] J. Priestley, *The History and Present State of Electricity [1775]*, intr. R. Schofield, New York, 1966, I, pp. xiv-xv.

[9] A.L. Lavoisier, *Elements of Chemistry [1790]*, trans. R. Kerr, intr. D. McKie, New York, 1965, p. xxiv.

[10] J. Priestley, *Disquisitions Relating to Matter and Spirit*, 2nd ed., London, 1782, vol. 1, pp. 34 ff. See also F. James, *Reality or Rhetoric? Boscovichianism in Britain: the cases of Davy, Herschel and Faraday*, in P. Bursill-Hall (ed.), *R.J. Boscovich: Vita e Attività scientifica*, Rome, 1993, pp. 577-85.

tradition, a quantified chemistry would for Priestley have been based upon particles and forces. Not with ordinary inanimate brute matter was the natural philosopher primarily concerned, but rather with forces and powers; and in particular with the «imponderables», light, heat and electricity. The weights of things were by contrast banal; the balance was not the only or obvious route into chemical understanding. We shall take these three imponderables as our guide.

Colour, or colour-blindness, was one of John Dalton's ways into science; and the young Humphry Davy's[11] first chemical speculations had to do with the role of light, via the supposed compound *phosoxygen*. Although *light* came at the top of Lavoisier's list of elements or simple substances,[12] Davy believed that he had failed to appreciate the part combined light plays in chemistry: Davy connected light closely with electricity, as others had who noticed that transparent bodies, fullest of light, were «electrics», capable of accepting charge. Thomas Young, the Newtonian heretic who proposed a wave theory of light, was also one of the last to publish a numerical table of elective affinities.[13] William Hyde Wollaston, the chemical analyst called by his friends «The Pope» because he was infallible, invented the optical «reflective goniometer» for measuring the angles of crystals;[14] but spectroscopy lay far in the future, so that investigating light and colours did not, for Priestley's and the next generation, much illuminate chemistry.

On the other hand, the study of electricity, and of Priestley's later favourite, gases (those compounds of heat), proved extremely fruitful; opening doors into new territories, and leading to a vision qualitative as well as partly quantitative which was rather different from that of Lavoisier. For Davy at the end of his life in 1829:[15]

> *Chemistry relates to those operations by which the intimate nature of bodies is changed, or by which they acquire new properties.* This definition will not only apply to the effects of mixture, but to the phenomena of electricity, and in short to all the changes which do not merely depend upon the motion or division of masses of matter.

Chemistry was thus the fundamental science, while Mechanics (which Romantics always despised) was of minor significance: we might note that in Britain, Davy's protégé Michael Faraday counted as a chemist. The study of both gases and electricity have the further advantage for us that they had a strong input from both Italy and England. The serious physical study of the atmosphere had begun with Evangelista Torricelli, and had been carried on in

[11] D.M. Knight, *Humphry Davy: Science and Power*, Oxford, 1992, p. 23.
[12] Lavoisier, *Elements of Chemistry*, p. 175.
[13] «Philosophical Transactions», 99, 148-160 (1809).
[14] «Philosophical Transactions», 99, 253-8 (1809).
[15] H. Davy, *Consolations in Travel; or, The Last Days of a Philosopher*, 5th ed., London, 1851, p. 262, (italics original).

the laboratory by the Accademia del Cimento in the 1650s;[16] and their work was then taken up by Robert Boyle. In the eighteenth century came the realization that the air involved or evolved in chemical changes was not just good or bad, but belonged to distinct kinds: fixed air, then vital air and inflammable air and other sorts were collected and identified, notably by Priestley,[17] another great admirer of the French Revolution.

Just two hundred years ago, in the Dissenting Academy at Hackney (near London), whither he had gone after a mob had sacked his house in Birmingham, Priestley delivered a course of lectures on chemistry.[18] They were full of phlogiston: and indeed Priestley invoked Newton in his support against the latest French ideas:

> It is one of the principal rules of philosophizing to admit no more causes than are necessary to account for the effects. Thus, if the power of gravity, by which heavy bodies fall to the earth, be sufficient to retain the planets in their orbits, we are authorized to reject the *Cartesian Vortices*. In other words, we must make no more general propositions than are necessary to comprehend all the particulars contained in them. Thus, after having observed that iron consists of a particular kind of earth united to phlogiston, and that it is soluble in acids; and that the same is true of all other metallic substances, we say, universally, that all metals consist of a peculiar earth and phlogiston, and that they are all soluble in some acid.

Later, he reported that «alkaline air», or ammonia, «consists chiefly of phlogiston»; and discussed at some length the composition of water, where his views conflicted with those of the recently-executed «Mr. Lavoisier and most of the French chemists». For Priestley, the new theory was both unnecessary, and inconsistent with facts. We are apt to see Lavoisier's quantitative argument, that phlogiston would have to have negative weight, as crucial; but Priestley did not — his chemistry was qualitative. His suggestion was that:

> it seems probable, that water united to the principle of heat, constitutes atmospherical air; and if so, it must consist of the elements of both dephlogisticated and phlogisticated air; which is a supposition very different from that of the French chemists.

It is indeed; and Priestley's lectures also included a remark about a «wise provision in nature»; though unorthodox, he belonged in the tradition of natural theology. His interpretations both of chemical changes, and of the world generally, thus differed from Lavoisier's — and indeed most of ours.

Nevertheless, Priestley's attempts to save the interpretation he had grown

[16] *Essayes of Natural Experiments [1684]*, tr. R. Waller, intr. A.R. Hall, New York, 1964.

[17] J. Priestley, *Experiments and Observations on Different Kinds of Air [1790]*, 3 vols., reprinted New York, 1970.

[18] J. Priestley, *Heads of Lectures on a Course of Experimental Philosophy, particularly including Chemistry [1794]*, reprinted New York, 1970; quotations from pp. 3f, 38, 128, 132, 134 and 142.

up with was unsuccessful. Henry Cavendish, whose experiments on inflammable air had led Lavoisier to the view that water was a compound, gave up chemistry. In Priestley's circle, the Lunar Society of Birmingham,[19] Josiah Wedgwood provided financial support for a Pneumatic Institution in Bristol where Thomas Beddoes with James Watt treated the sick with factitious airs such as oxygen — for they and their young protégé, Davy, used the new terms. There, Davy took up Priestley's work, his first major publication[20] (in 1800) being on «nitrous oxide», its chemistry and its effects as laughing gas; and this led to his appointment at the newly-founded Royal Institution in London.

Priestley's friend Benjamin Franklin had shown the electrical character of thunder and lightening; and Priestley was a great user of electrical discharges to set off chemical reactions in airs — especially to test for the «goodness» or respirability of samples of air, in a eudiometer.[21] By 1800 he had lost his battle to keep phlogiston at the centre of chemistry in Britain;[22] the new language had been generally adopted (despite quibbles about details), and although authors of textbooks tried to keep theory and facts apart, language and theory went hand in hand. But we might note that when Davy was ill in the 1820s, he was given antiphlogistic remedies (to reduce fever) — and phlogiston in medicine had quite a long run after that time. But Priestley's advocacy of electricity did bear fruit in a dynamical chemistry.

Tiberius Cavallo had been another of those working where chemistry and electricity met; but it was Luigi Galvani and his adversary Alessandro Volta[23] who made electricity central to chemical philosophy. Volta's «pile» of metallic discs in water was indeed as Davy put it, an alarm-bell to the experimenters of Europe. Chemical affinity had been a mystery; and the science awaited its Newton who would explain the phenomena in terms of forces. A polar force was required, unlike gravity which is always attractive; and electricity looked as if it might be the answer. Lavoisier had been reluctant to enter into questions of particles and forces, believing that these led only to metaphysics and would set chemistry back; but a disciple of Priestley's, sharing his Newtonian dream and feeling for natural theology, was well-placed to set chemistry in a new direction. This was Davy.

[19] R. Schofield, *The Lunar Society of Birmingham*, Oxford, 1963, pt. 5.

[20] H. Davy, *Researches, Chemical and Philosophical, chiefly concerning Nitrous Oxide or dephlogisticated Nitrous Air and its Respiration [1800]*, reprinted, London [1972].

[21] J. Golinski, *Science as Public Culture: Chemistry and Enlightenment in Britain, 1760-1820*, Cambridge, 1992, chapter 4.

[22] D.M. Knight, *Ideas in Chemistry: a History of the Science*, London, 1992, chapter 6.

[23] M. Pera, *Radical Theory Change and Empirical Equivalence: the Galvani-Volta Controversy*, in W. Shea (ed.), *Revolutions in Science: their Meaning and Relevance*, Canton, Mass., 1988.

Counter-revolution or Synthesis?

Using a giant Voltaic battery, Davy[24] isolated the new and anomalous metals sodium and potassium; and went on to infer that the «oxymuriatic acid» of Lavoisier and C.L. Berthollet was in fact an element, which he called *chlorine*. Davy thus illuminated the faults in Lavoisier's theory of acidity, demonstrating that the caustic alkalis soda and potash contain large amounts of oxygen, the acid-maker; whereas the acid from sea-salt contains none. In his papers about the new metals, there is a footnote indicating that the discoveries might be explained using the phlogiston theory.[25] Faraday, who as a bookbinder's apprentice attended Davy's later triumphant lectures on chlorine, took this occasion to write[26] to his friend Benjamin Abbott that Lavoisier's chemistry might be set aside and phlogiston might come back again. But although Davy delighted in having proved that chemistry was not a French science, and rebuked Berthollet and his associates for their dogmatism, and the baseless fabric of a vision[27] that they had erected, he did not achieve, or even seriously attempt a counter-revolution.

Like Napoleon dismissing the Holy Roman Empire, Davy remarked of chlorine that[28] «to call a body which is not known to contain oxygen, and which cannot contain muriatic acid, oxymuriatic acid, is contrary to the principles of that nomenclature in which it is adopted». He added his conviction that names «should be made independant of all speculative views, and that new names will be derived from some simple and invariable property». One of the terms which Lavoisier did not replace was *acid*: but (like *mass* in physics) it changed its meaning, from a sour substance, to a basis or radical combined with oxygen; and then through Davy's puzzlement, to Auguste Laurent's idea[29] of a compound in which hydrogen is replaceable by a metal, to G.N. Lewis' *proton donor or electron acceptor*; the reference is much the same, but some substances are acids according to one account, but not another. Davy knew[30] that «hydrogene is disengaged from its oxymuriatic combination, by a metal, in the same manner as one metal is disengaged by another» but he had not got a theory to replace Lavoisier's. He seems to have felt that acidity was the outcome of a particular balance of forces or powers.

[24] D. KNIGHT, *Humphry Davy: Science and Power*, Oxford, 1992, chap. 5 & 6.

[25] H. DAVY, *Collected Works*, ed. J. Davy, vol. 5, London, 1840, p. 89n.

[26] See above; F.A.J.L. JAMES (ed.), *The Correspondence of Michael Faraday*, vol. 1, London, 1991, p . 17 — see also following pages.

[27] This is a quotation from Shakespeare's *Tempest*.

[28] H. DAVY, *Experiments ... on Oxymuriatic Gas*, «Philosophical Transactions», *101*, 32, 35 (1811).

[29] A. LAURENT, *Chemical method*, tr. W. Odling, London, 1855.

[30] H. DAVY, *Muriatic Acid in its different States*, «Philosophical Transactions», *100*, 240 (1810).

Oxygen, which had occupied a privileged position in Lavoisier's chemistry, had to share its throne with chlorine; and acidity, which had seemed to be explained, became once again problematic. Sulphuric acid, supposed by Lavoisier and by Davy and his contemporaries to be composed of sulphur and oxygen only, and the acid made of hydrogen and chlorine only, had no element in common: and for Davy this vindicated the belief that forces rather than material components were crucial in chemistry — a belief that went back to his work on the oxides of nitrogen, which had very different properties, though composed of the same two elements. Davy had also long rejected the idea that heat was a substance — like light, it came as «caloric» on Lavoisier's list of Simple Bodies — because with Count Rumford he believed that it was the motion of particles. During the 1820s belief in the substance of heat waned generally in the scientific community; but this again led to modification of Lavoisier's schema, and not to its abandonment.

Dalton, Davy's contemporary, hit upon his chemical atomic theory when thinking about the composition of the atmosphere in the light of caloric theory — questioning why it was uniform, and not a sandwich with the densest gases at the bottom. He thus adopted Lavoisier's view of heat, but believed that atoms were a part of science rather than metaphysics. His atomism and Davy's more Romantic electrochemistry were synthesized by J.J. Berzelius[31] in a way that consolidated Lavoisier's revolution, and also gave us in time our modern chemical notation and equations.

Dalton's beliefs about atoms have almost all been falsified, and yet our chemical atomism is the direct descendant of his, rather than that of Lucretius, Galileo, Gassendi or Boyle which was indeed not testable chemically. In the same way, although many of Lavoisier's crucial ideas have been proved wrong, the foundation for the science which he laid have proved capable of bearing the load of later discoveries and interpretations. Physical chemistry does have its debts to the dynamical tradition associated with Priestley, Volta and Davy; and perhaps even with phlogiston;[32] but it developed within Lavoisier's structure, or perhaps we should say «paradigm». Modern chemistry incorporates a number of traditions, and yet we can see that it was with Lavoisier that the science took perhaps its most important change of direction; and the critical feature was probably the new language. Language and leadership in chemistry have gone together throughout its modern history.[33] Those who described chemistry in

[31] E.M. Melhado and T. Frängsmyr (ed.), *Enlightenment Science in the Romantic Era: the Chemistry of Berzelius and its Cultural Setting*, Cambridge, 1992, chaps 3 and 4 (by G. Eriksson and A. Lundgren).

[32] W. Odling, *The Revived Theory of Phlogiston*, «Proceedings of the Royal Institution», 6, 315-25 (1870-2).

[33] M.J. Nye, *From Chemical Philosophy to Theoretical Chemistry*, Berkeley , 1993, p. 270.

Lavoisier's terminology had to see nature as he did. When willy-nilly Beddoes and Davy adopted Lavoisier's language, they had to translate into it the discoveries of Priestley and others; and the Italian proverb tells us that translation is treason. The new language was not just a matter of new names for old things, like rechristening Van Diemen's Land as Tasmania; it involved interpretations, which like discoveries were all bound up in Lavoisier's revolutionary insight.