Part 1

The big three

1

The organisation of chemistry in nineteenth-century France

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The organisation of science and all education in France was profoundly affected by the revolution of 1789. Although the short-term effects of the revolution were negative, in the long term the revolution can be seen as providing a boost for most branches of science. The work of Lavoisier and his colleagues shows that before the political revolution chemistry had reached a high standard, helped by such institutions as the Paris Academy of Sciences. Although many institutions were suppressed during the revolutionary period they were often replaced and on the educational front there was a vast expansion. The Enlightenment philosophy gave special importance to science and, when the major academies of the *ancien regime* were reorganised as the National Institute, science was given the most prestigious place as the First Class of the Institute.

Science lost its preeminence under the Bourbon Restoration (1815) but the royalist government accepted the scientific institutions founded under the revolutionary and Napoleonic regimes. Moreover, there was a conscious desire to catch up with Britain's industrial revolution and there was, therefore, a strong case for the encouragement of applied science. Science provided a career open to all, including young men of humble origins, and it is generally accepted in France that equality of opportunity was one of the permanent legacies of the French Revolution. The centralisation of intellectual life and education in Paris, which had been reinforced by the revolution, was to become even stronger in the nineteenth-century. The fact that the 'chemical revolution' associated with the name of Lavoisier had taken place in France gave that country a central place in the new chemistry. The specialist journal founded in 1789 by Lavoisier and his colleagues, the *Annales de chimie*, continued to flourish in the nineteenth-century and in many ways served as a European journal of chemistry with a French focus.[1] The continuing importance of France in scientific publication was

[1] M. Crosland, *In the Shadow of Lavoisier. The 'Annales de chimie' and the Establishment of a New Science* (Stanford in the Vale, Oxon: BSHS Monograph No 9, 1994).

reinforced by the foundation of the weekly *Comptes rendus*, published by the Academy from 1835, although this was also the period when the primacy of French science was beginning to be challenged by the growing importance of German science. This was particularly true of chemistry. The French defeat in the Franco-Prussian war of 1870–1 was used by scientists as a justification for greater government investment in scientific education and the high standard reached by many German universities was pointed to as a model.[2] Such arguments helped to obtain funds for the construction of more laboratories in French institutions of higher education.

Chemical education[3]

Science played an important part in the many educational institutions established in the more constructive period which followed after the Terror of 1793–4. The fact that scientists (and particularly chemists) had played a prominent part in the war effort, when France was threatened with invasion helped to give science an important place in the new state educational system. In the new secondary schools (*écoles centrales*) established in 1796, mathematics, natural history, physics and chemistry were included in the curriculum. In 1802, however, these schools were replaced by the *lycées* with a more traditional curriculum. In the short-lived Ecole Normale of 1795 chemistry was one of the subjects taught. When the school was re-established by Napoleon in 1808 science was present but less prominent in the curriculum. Only in the mid nineteenth-century under the patronage of Sainte-Claire Deville and Louis Pasteur did the Ecole Normale regain and exceed its previous position as a centre for chemical education.[4] From the very beginning in 1794–5 the Ecole Polytechnique constituted a major centre for education in mathematics and chemistry. The students, chosen by competitive examination, constituted an elite. Although many were later to become engineers, it was chemistry rather than physics that was taught as a major subject. The Polytechnique is notable for the early construction of several teaching laboratories where selected students could carry out experiments described in lectures.[5]

[2] H. Sainte-Claire Deville, *Comptes rendus*, (1871), **72**, 237–9. See also A. Wurtz, *Les Hautes études dans les universités allemandes* (Paris, 1870).

[3] There are many sources of information on scientific education in France since the French Revolution. See, e.g., M. Crosland, Scientific institutions for teaching and research, Ch. 3 of *The Society of Arcueil. A View of French Science at the Time of Napoleon* 1, (London: Heinemann 1967). R. Fox and G. Weisz (eds.) *The organisation of science and technology in France, 1808–1914* (Cambridge: Cambridge University Press, 1980). F. Leprieur, La formation des chimistes français au 19e siècle, *La Recherche*, (1979), **10**, 732–40.

[4] Craig Zwerling, The emergence of the Ecole Normale Supérieure as a centre of scientific education in the nineteenth century, in R. Fox and G. Weisz, eds., *loc. cit.* (3).

[5] Margaret Bradley, The facilities for practical instruction in science during the early years of the Ecole Polytechnique, *Annals of Science* (1976), **33**, 425–46.

Under Napoleon a new university system was established which for the first time included Faculties of Science. Professors of chemistry and physics were appointed in Paris and several provincial centres. In the first half of the nineteenth-century in the Faculty of Science in Paris and those in the provinces the level of chemistry taught was held back in the first place by a dilution of the student body by an interested public, which, in Paris at least, far outnumbered the registered students. The chemistry course tended to attract larger numbers than any other scientific subject. It was also held back by poor laboratory facilities, about which J. B. Dumas was to complain in a report of 1837.[6]

One institution going back to the *ancien régime* was the *Athénée*: originally founded for the popularisation of science, it continued into the nineteenth-century to make a useful contribution to scientific education.[7] Chemistry was one of the sciences taught and lectures were given in the evening to allow working people to attend. It provided an ideal introduction for mature students or those who for one reason or another had missed the foundation stone of French higher education, the *baccalauréat*. The chemist J. B. Dumas owed much to it. He was eventually appointed as professor of chemistry there and he taught a course on applied chemistry. He believed that industrialists could gain much by consideration of general chemical principles and in 1829 he was one of three co-founders of the Ecole Centrale des Arts et Manufactures, where courses were given on general chemistry, analytical chemistry and industrial chemistry.[8] The school was unusual in being a private initiative yet very successful and fully competitive with such elite institutions as the Ecole Polytechnique. Under Napoleon III it was taken over by the state.

Another place where chemistry was taught was the Museum of Natural History which originally in its seventeenth-century foundation had interpreted chemistry largely in relation to pharmacy. In 1793 Fourcroy succeeded to the chair of general chemistry while Louis Brongniart was appointed to the chair of applied chemistry.[9] By 1850 their respective chairs were devoted to inorganic and organic chemistry. The burgeoning subject of organic chemistry was recognised by a chair of organic chemistry at the Ecole de Pharmacie (1859) and another at the Collège de France (1865), both entrusted to one man, Marcellin Berthelot. Meanwhile in 1819 Clément had been appointed to a chair of applied chemistry

[6] O. Gréard, *Education et Instruction* (Paris, 1889), pp. 236–55.
[7] For the Athenée (originally called the Musée, then the Lycée) see W. A. Smeaton, The early years of the Lycée and the Lycée des Arts, *Annals of Science* (1955), **11**, 257–67, 309–19, also Leo Klosterman, *Studies in the Life and Work of J. B. Dumas (1800–1884), The Period up to 1850*, University of Kent PhD thesis, 1976, pp. 97–101.
[8] Leon Guillet, *Cent ans de la vie de l'Ecole des Arts et Manufactures, 1829–1929* (Paris, 1929). See also Klosterman, *op. cit.* (7), pp. 195–226.
[9] Paul Lemoine, Le Muséum National d'Histoire Naturelle, *Archives du Muséum d'Histoire Naturelle*, 6e série (1935), **12**, 3–79.

at the Conservatoire des Arts et Métiers. The links of the institution with industry made it appropriate that chemistry should be taught in an applied context and many of the students were working men.[10] They provided a contrast with the increasingly elitist Ecole Polytechnique, which emphasised theory rather than practice. From the 1830s the Conservatoire, together with the Ecole Centrale, provided the two main training grounds for industrial chemists.

The foundation of the Ecole Pratique des Hautes Etudes in 1868 was an indication that the French government was taking higher education even more seriously. In theory it increased the number of posts available in Paris for scientists but in practice most of the positions were given to people already holding other positions in higher education.[11] This was one example of the well-established French practice known as the *cumul* which enabled some senior scientists to live very comfortably while depriving others of positions they might otherwise have expected. It meant that a chemistry professor at one Parisian institution might well have a second (or even a third) university-type post, thus reducing the variety of possible approaches to the subject. This helped to reinforce a uniformity in chemical education which was already subject to excessive centralisation and bureaucratic control. Thus until the 1890s all important decisions about the provincial Faculties of Science were taken in Paris. The position of Marcellin Berthelot as inspector general of higher education (1876) and his even more powerful position as secretary of the Academy of Sciences (1889) ensured that his hostility to the atomic theory in chemistry acted as a brake on the development of chemical theory in France in the final decades of the nineteenth-century.[12]

An important step in the training of top-level researchers was the introduction in 1846 of research fellowships at the Ecole Normale. The title of the post was *agrégé préparateur* and one of the first holders of the position was Louis Pasteur.[13] In 1870 E. Fremy, professor at the Museum, agitated for the expansion of chemical training. He was particularly concerned with the basic training of chemists for industry. This cause was taken up in 1882 by the foundation of the Ecole de physique et de chimie industrielle de la ville de Paris.[14] It should be noted that this was a municipal and not a state foundation. It had none of the privileges of the *grandes ecoles* but, thanks to the devotion of its first director,

[10] Ministre de l'Education Nationale, *Cent-cinquante ans de haut enseignement au Conservatoire National des Arts et Metiers* (Paris, 1970), p. 10. R. Fox, Education for a new age. The Conservatoire des Arts et Métiers, 1815–30, in D. S. L. Cardwell, ed., *Artisan to Graduate*, (Manchester: Manchester University Press 1974), pp. 23–38.
[11] R. Fox and E. Weisz, eds., *op. cit.* (3), p. 98.
[12] Jean Jacques, *Berthelot, autopsie d'un mythe* (Paris, 1987), Ch. 23.
[13] M. Crosland, The development of a professional career in science in France, *Minerva*, (1975), **13**, 38–57 (55), reprinted in M. Crosland, *Studies in the Culture of Science in France and Britain since the Enlightenment* (Aldershot: Variorum, 1995).
[14] H. Copaux, ed., *Cinquante années de science appliquée à l'industrie, 1882–1932* (Paris: n.d.).

P. Schutzenberger and, more famously, of Pierre and Marie Curie, it was later to make its mark, not only in France, but on the international stage.

Some characteristics

In France chemistry enjoyed special prestige throughout the nineteenth-century, a prestige probably only exceeded by that of mathematics. This was not the case before the 'chemical revolution' associated with the name of Lavoisier and the political revolution of 1789. The special place of chemistry can be illustrated by looking at two major institutions. At the Ecole Polytechnique chemistry occupied an extraordinarily important place in the curriculum in the early years, being taught to students in their first, second and third years. This is partly explained by the prominent part played by chemists in the foundation of the school, notably Fourcroy and Guyton de Morveau with Berthollet joining them on the teaching staff. However, a better index of the important place of chemistry among the sciences is provided by the situation in the Academy of Sciences.[15] Each of the sciences were represented by six members, constituting a national elite for that subject, but the advances made in chemistry in the early nineteenth-century made this limitation particularly restrictive for chemistry. So we find chemists applying for membership of other sections having some connection with chemistry. The section of agriculture seemed particularly appropriate for some people who had worked on applied chemistry. It was an obvious place for the agricultural chemist Boussingault (elected 1839) and, once this precedent had been created, it helped to introduce candidates who were less obviously qualified as agricultural chemists. Although Pasteur was clearly identified with chemistry in the early part of his career, his work on crystals qualified him for membership of the mineralogy section (1862). Indeed by the 1860s so many chemists had managed to enter the Academy in one guise or another that one critic could claim that 'the Academy of Sciences was being transformed into an Academy of Chemistry'.[16] Of course this was a gross exaggeration. Yet in the second half of the nineteenth-century two permanent secretaries who were particularly influential were chemists: J. B. Dumas and Berthelot. Each in turn exercised considerable influence over the cause of science and scientific education in France.

When I speak of the prominence of chemistry in nineteenth-century France it was often at the expense of physics which was placed uncomfortably in Comte's hierarchy between mathematics and chemistry. From the secondary school onwards boys with exceptional mathematical ability were given special treatment,

[15] From 1795 to 1816 the Academy of Sciences was known as the First Class of the National Institute.
[16] J. Marcou, see M. Crosland, *Science under Control, The French Academy of Sciences, 1795–1914* (Cambridge: Cambridge University Press, 1992), p. 74.

sometimes at the expense of those who otherwise might have been physicists. Those interested in experimental science were often attracted to chemistry. The greatest prestige was attached to academic research and the greatest prize for the few was membership of the Academy of Sciences. At a lower level of prestige than the academic chemists, although often with higher salaries, were the industrial chemists. An early consultant to chemical industry was Gay-Lussac who was employed by the famous glass and chemical works of Saint Gobain in addition to his position at the Paris Mint.[17] The holder of several professorships, Gay-Lussac became one of the wealthier scientists of the 1830s and 1840s. An exact contemporary of Gay-Lussac was Nicolas Clément, who in collaboration with Desormes, had published a paper in 1806 explaining the role of nitre in the lead chamber process for the manufacture of sulphuric acid.[18] Clément's good theoretical and practical knowledge of chemistry led to his employment also at the Saint Gobain factory.[19]

One of the French contributions to chemistry often neglected by historians was the development of volumetric analysis. Gay-Lussac was able to take further the earlier work of Descroizilles who had been concerned with estimating the strength of alkalis used in bleaching.[20] Apart from the estimation of the strength of acids and alkalis, the method was soon applied to the estimation of silver in coinage. Here then was a new method of analysis which was capable of wide applications and which did not require a great deal of skill to carry out. Whereas it needed a scientist of considerable distinction and originality to work out the principles of the preparation of standard solutions and the invention of appropriate apparatus (notably the burette and the pipette), one did not need an advanced knowledge of chemistry to follow fairly simple instructions. In the period 1818–35 Gay-Lussac published various instructions on the use of volumetric analysis which made this method known in France. Only in 1855 did Friedrich Mohr publish a comprehensive book on volumetric analysis which superseded the French work and represented the beginning of a more general international recognition of the value of volumetric analysis in industry.[21]

In France chemistry has had a particularly close association with pharmacy. G.-F. Rouelle was the teacher of Lavoisier, and Baumé was one of his colleagues in the Paris Royal Academy of Sciences. When this was replaced by the National Institute in 1795, although the first few of the new chemists to be elected were

[17] M. Crosland, *Gay-Lussac, scientist and bourgeois* (Cambridge: Cambridge University Press, 1978), p. 230.
[18] N. Clément and C. B. Desormes, Théorie de la fabrication de l'acide sulfurique, *Annales de chimie* (1806), **59**, 329–39.
[19] Jacques Payen, art. Clément, *Dictionary of Scientific Biography*, (New York: Scribners, 16 vols., 1970–80) ed. C. Gillispie, Vol.3, pp. 315–17.
[20] Crosland, *op. cit.* (17), pp. 205–22.
[21] 'The narrow circle of chemists using these methods was originally comprised of Frenchmen.' F. Szabadváry, *History of analytical chemistry* (Oxford: Pergamon Press, 1966), pp. 237ff.

not pharmacists, the old tradition was soon resumed, as illustrated by the election of Vauquelin and Deyeux. One of Vauquelin's students was Chevreul, best known as an organic chemist. It may be pointed out that two important chemists of the late nineteenth-century who made their respective names in organic and inorganic chemistry were Berthelot and the Nobel laureate, Moissan, both originally trained as pharmacists. Thus at least up to 1900 pharmacy continued to be an important training ground for chemists.

We must, therefore, look briefly at the Ecole de Pharmacie, founded in 1803 with Vauquelin as director.[22] In fact three pharmacy schools were founded (in Paris, Montpellier and Strasbourg), parallelling the three large national medical schools.[23] Each school was required to provide four courses, of which only one was strictly pharmacy. There were also courses in botany and chemistry. In the original buildings of the Paris school very much more space was given to growing medicinal plants than to laboratories. From the 1860s there were discussions about finding a new much larger site for the school but it was not until 1881 that the new buildings were in use. Several large laboratories were built for the students. In the course of the 1880s several research laboratories were built for organic chemistry and analysis. In 1897 a special inorganic laboratory was built for Moissan. In fact students had been engaged in practical work since 1830. Chemistry was a subject taught to all students in their first year. From 1803 there had been a professor of chemistry (Bouillon Lagrange, succeeded by Bussy in 1830). Later further chairs of chemistry were added, for example a chair of organic chemistry in 1859. A chair of analytical chemistry had to wait until 1895, although the subject had been taught previously.

This is not the place for a full discussion of French chemical industry but it might be appropriate here merely to mention France's early contributions. One thinks particularly of the Leblanc soda process, Berthollet's method of bleaching using chlorine and the manufacture of sugar from sugar beet in Napoleonic France. The pioneering position of France in the chemical industry was matched by action in the accompanying area of chemical pollution. In France the prefect of each department was able to introduce regulations which in Britain would have involved many years of debate followed by an appropriate act of Parliament. Rouen and Marseilles were two towns with flourishing local chemical industries producing fumes causing much local complaint.[24] In 1809 we find the local prefects of each of these towns taking action, not restricting the existing factories, but prohibiting any further chemical factories being built. There were also com-

[22] There had been a *Collège de pharmacie* in 1777 but it had been abolished during the Revolution with other educational institutions, reappearing briefly in 1797 under the name Ecole gratuite de pharmacie.
[23] *Centenaire de l'Ecole supérieure de pharmacie de l'Université de Paris, 1803–1903*, (Paris: n.d.).
[24] *Recueil des textes officiels concernant la protection de la santé publique*, ed. G. Ichok, Vol. 1 (1790–1830) (Paris: 1938) pp.165–8.

plaints in Paris and the chemists of the First Class of the Institute were consulted. The growing scale of soda manufacture created troublesome atmospheric pollution and forced action on a national scale. By an imperial decree of 1810 all works emitting unpleasant odours were classified according to the seriousness of the nuisance caused.[25] The manufacture of soda was considered to be one of the worst offenders and special authorisation would be needed for the siting of any new factory. The main solution advised by the Institute was that such factories should be only built in the country at a certain minimum distance from human habitation. This was the main French solution to the problem of dealing with large amounts of hydrochloric acid gas emitted from the Leblanc soda process as opposed to the later British method of absorption by the Gossage process.

Chemistry as a profession

Science emerged as a profession (a full-time career following formal training) after the French Revolution. Up to this time future chemists had usually acquired a knowledge of their subject informally and by methods not very different from apprenticeship. A knowledge of chemistry could not be expected to lead to employment and France's greatest chemist of the eighteenth century, Lavoisier, earned a living as a tax official, doing chemistry only in his spare time. The constructive aftermath of the Revolution of 1789 was to provide both a system of higher education (in which science was prominent) and employment. From the early 1800s we find a group of men emerging in France who had benefitted from the new system of higher education, were self-consciously men of science and were subsequently able to practice science on a full-time basis as a career.[26] The Academy of Sciences exercised control at the highest level over French science, establishing standards and rewarding what it considered to be good science.[27]

In nineteenth-century France anyone hoping to enter a profession would first be expected in the final school year to have passed the *baccalauréat*, administered by the 'University' (Ministry of Education) established by Napoleon in 1808. From 1821 there was a special *baccalauréat* in science. After the *baccalauréat* anyone wishing to enter a well-established profession, such as law, would then undertake a period of higher education. A similar career pattern might be expected of the new professional scientist, particularly if he contemplated employment within the educational system. For a teaching position in a state

[25] John Graham Smith, *The Origins and Early Development of the Heavy Chemical Industry in France* (Oxford: Oxford University Press, 1979), pp. 285–93.
[26] Crosland, *op. cit.* (17), p. 4.
[27] Crosland, *op. cit.* (16), Ch. 7.

school, he would need a degree (*license*) and, for a university post, a doctorate. The vast majority of well-known French scientists of the nineteenth-century had a university qualification or alternatively they were graduates of one of the *grandes écoles*. What has been written in these two paragraphs is true of science in general but it is now necessary to return to the subject of chemistry, which was particularly prominent in early professionalisation since it provided many avenues for employment.

A French dictionary of professions published in 1842 devotes some ten pages to the profession of 'chemist' (*chimiste*).[28] One could make a start by attending one of the public courses in chemistry, such as that given at the Faculty of Sciences in Paris. If, at the end of the academic year, a young man was determined to make chemistry his career, he should then begin a period of training by working under the supervision of senior chemist who would give him practical guidance in analysis and research. The young man might hope sooner or later to be admitted into the laboratory of a professer of chemistry. We know that the young Liebig had been exceptionally fortunate in the 1820s to be admitted into Gay-Lussac's laboratory and even to carry out collaborative research with him.[29] By 1838 Dumas had set up a small private laboratory in Paris, where a number of French and foreign students studied under his direction and began to undertake research.[30] By the 1840s there were several such private laboratories in Paris which complemented the many public institutions where chemistry was taught. Both provided opportunities for practical experience for the junior chemist, who might even gain employment as a *préparateur* or a *répétiteur*.

The editor of the dictionary of professions warns the aspirant that the career of science as a profession is only open to a small number of persons and one needed both talent and luck to be successful. Thus, if one could gain the position of *préparateur* for the courses at the Ecole Polytechnique, this would provide access to a laboratory which could be used in one's spare time to undertake private research that might lead on to further advancement in the academic field. However, an alternative career path lay in applied chemistry. Industry, it was said, could provide a lucrative career. Chemical experts were sometimes required in connection with the law or with patents. The growth of chemical industry had been accompanied by growing pollution which often required adjudication and here the expertise of chemists was becoming increasingly recognised. Chemistry, therefore, with its well-developed theoretical basis, was already established as an

[28] E. Charton, *Guide pour le choix d'un état ou Dictionnaire des professions*, (Paris: 1842), pp. 104–15.
[29] Crosland, *op. cit.* (17), pp. 252–3.
[30] Leo Klosterman, A research school of chemistry in the nineteenth century: Jean-Baptiste Dumas and his research students, Part 1, *Annals of Science* (1985), **42**, 1–40 (9).