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HISTORY OF SCIENCE IN A NATIONAL CONTEXT

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THE history of science can be approached in several different ways. It may be studied, as in the classification once favoured in the long-established Department of History and Philosophy of Science at University College London, by considering separately the history of individual sciences: physics, chemistry, biology, etc.—Partington's monumental *History of chemistry* is a good example of the cross-section of history of science obtained by considering a single discipline. This approach is understandable when history of science is the work of retired specialists in a particular science. On the other hand, many of those who have approached the history of science from a training in general history have tended to favour a study of a particular period as an alternative to an orientation by subject. This is particularly valuable before the nineteenth century, when subject boundaries were not so tightly drawn as some of the old science historians tended to assume. A third possibility is area studies, usually the history of science within a particular country. Sometimes this is done unconsciously, as when historians claim that they are dealing with a general theme, such as science and religion or scientific institutions, but do so with special reference to their own country. French historians of 'the Enlightenment' often study French authors exclusively. Language as much as country is a limiting factor here.

There are advantages and disadvantages in all of these approaches. Let me make a brief criticism of the subject approach. Partington too easily rejected as irrelevant, ideas in what he saw as 'physics' or 'biology' even though such ideas might have been pertinent to chemistry. The subject classification itself is something of an anachronism in, say, the sixteenth century, when vitalistic ideas permeated proto-chemistry, and even astronomy or astrology had connexions with it. But if I mention Partington, it is not to deride him. His massive though hardly imaginative scholarship is of permanent value to us, his successors, whose linguistic ability and sheer *Sitzfleisch* may hardly be on the same level. The period approach may be less open to objections than the subject orientation, though if the period chosen is very restricted, or is very early, or very modern, other historians might feel the work too narrow.

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In keeping with the circumstances in which this talk was given, footnotes have been confined to a few basic references. I hope to have a later opportunity to develop more fully some aspects of this survey.

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If we think of history of science in relation to a country, we may consider the evidence for national characteristics. The British, for example, have often been associated with empiricism.[1] I quote the nineteenth-century astronomer G. B. Airy, who claimed that

> In England an observer conceives that he has done everything when he has made an observation . . . In the foreign observatories on the contrary, an observation is considered as a lump of ore . . . and without value until it has been smelted.[2]

It can happen that in one country astronomy is seen as largely an observational science, whereas in a neighbouring country the major advances may be in mathematical astronomy: it is interesting to remember that William Herschel and Laplace were contemporaries. Was it by chance that all the basic experimental work in pneumatic chemistry was done in Britain? One thinks of Boyle, Hales, Black, Cavendish, and Priestley, who might collectively be described as a British school. However, we should not exaggerate the concept of a national style. There is always the danger of caricature, and I prefer to discuss wider and less intangible questions of a social and institutional context. This approach can be valuable, particularly if one can manage eventually to look at more than one country.

Most contributions to the understanding of the natural world from the seventeenth to the early twentieth century were made within a local or national context. Most men of science wrote in the vernacular, primarily for their friends and compatriots, and it is only comparatively recently, with wonderful improvements of communication, that we have been able to think of science on an international stage. After the collapse of the medieval world, where Latin had provided a medium of communication that was understood by educated men from one side of Europe to the other, linguistic barriers were added to other barriers between communities: geographical, political, and religious. The English Channel and the Alps were probably two of the most effective physical barriers in western Europe. Of course, it was always possible for any *savant* to strive to reach beyond his local context. The publication of Volta's famous paper on the pile in the *Philosophical transactions* and of Avogadro's memoir in the *Journal de physique* were attempts by the authors to obtain wider recognition than would have been possible in their own country in the early nineteenth century. Nevertheless, Volta and Avogadro must be understood in the context of the Italian states in which they lived. Similarly, many Swedish men of science felt that they lived on the edge of the civilized world and made great efforts to overcome isolation. The European tour of Berzelius, and particularly his year in Paris, brought him out of that isolation. Yet he remains a Swedish scientist, and we must make some attempts to understand the Swedish scene if we are to understand Berze-

lius. We must know something of the structure of intellectual life within a country. In brief, we must study institutions.

Science has an important institutional dimension. This is most obvious in the case of experimental science, but even the theoretician usually has institutional support. The isolated thinker may work outside any university or academy, but, even for him, publication and the reception of his ideas involve institutional factors. The formulation of ideas is usually influenced by education, reading, and discusssion, and these in turn presuppose schools, channels of publication, and associations whether informal or in a scientific society.

The institutional dimension can, of course, be examined in relation to a specific branch of science. It is possible to consider the provision of university posts and laboratories for the study of one science without considering others. In some cases, however, this will impose a rather artificial division. Again, it is possible to consider institutions in a particular period. Martha Ornstein's book *The role of scientific societies in the seventeenth century* has shown that such a general survey on a European scale is possible for that period; but, as the number of scientific societies has grown, it becomes increasingly difficult to make such a survey at more than a superficial level. Finally, one can consider institutions within a particular city or country. In so far as different scientific subjects are often studied within the same institution, it is convenient to look at science in general. But if the overlap of source materials is one reason why one might study science in a national context, it is hardly the ultimate justification. This must be an appreciation that science is a part of the intellectual life of a country and cannot be divorced from social, political, and religious history. One may need to examine attitudes towards science—for example, an evaluation of its utility in the economic life of the country or its implications for established religion. Government policy has sometimes encouraged particular kinds of science, such as astronomy as an aid to navigation, or mineralogy as a guide to the exploitation of natural resources. Appropriate facilities have then been provided. The absence of financial support, on the other hand, may rule out the pursuit of certain types of experimental work involving expensive instruments, and may encourage the development of a cheaper branch of experimental science or even desk science. Local conditions have also had a decisive influence on specimens available for the study of the various branches of natural history. Thus even when scientists in different countries have begun with similar interests, their achievements have often been significantly different.

The idea of studying the science of a particular country has sometimes been criticized on the grounds that science is international. There is a sense, of course, in which science does transcend both time and place. But the historian of science, being concerned with the development of

ideas about the natural world, is committed to the study of science in a perspective that does not transcend time. Equally he might consider those aspects of science that do not transcend place.

In the reception of scientific theories, national factors are of major importance. Thus German reactions to Lavoisier's oxygen-centred theory and nomenclature were influenced by factors that were frankly nationalistic. Some German chemists took a patriotic pride in the large part played by their fellow-countrymen Becher and Stahl in the early formulation of the phlogiston theory which was now threatened by the new oxygen theory. The theory was sometimes known in Britain and Germany as the French theory—much to the annoyance of Lavoisier, who sought credit for himself. During the Revolutionary and Napoleonic wars the use of such a phrase as 'the French theory' hardly helped objective study, and there can be little doubt that Humphry Davy was stimulated to criticize the new theory as an act of patriotism as well as of science.

But the thesis that there is a national context for scientific work does not always depend on the crudest feelings of nationalism. The reception of Darwin's theories in France, for example, did not depend simply on a patriotic preference for Lamarck. Yet Lamarck and Geoffroy Saint-Hilaire had discussed evolution and the evidence for it half a century before Darwin published his *Origin of species*, and French biologists could not help but see evolution through Lamarckian spectacles. If the publication of the *Origin of species* in 1859 began a drama that was to dominate British thought for several decades, the situation in France was different. As a recent writer has remarked, the French stage was not empty and waiting;[3] the evolutionary plot had already been explored and driven off the stage, for example in a number of skirmishes which took place in the Académie des Sciences in the spring of 1830, when attempts by Etienne Geoffroy Saint-Hilaire to defend the mutability of species had been attacked by Cuvier. Hence discussion of evolution in France in the nineteenth century was a much longer-drawn-out affair, in which, for the first two acts of the play, Darwin did not even come on the stage. When he did appear to the French public, it was in the translation of Clémence Royer, who gave her own twist to Darwin's ideas. If some French biologists saw Darwin as the successor of Lamarck, she saw him as the successor of Condorcet and even incorporated the idea of progress into the French title.[4] Darwin's disappointment that his book caused little excitement in France is suggested by his comment about 'horrid unbelieving Frenchmen'.[5] In considering the reception of the ideas of a scientist in another country, therefore, the prejudices of his translators may be all-important. Heinrich Bronn, the Heidelberg palaeontologist who translated Darwin's *Origin* into German, did not accept the theory;[6] he added notes criticizing the text and omitted the controversial sentence of Darwin that 'light will be thrown on the origin of man'. I think I have said enough to suggest

some of the differences between the reception of Darwinism in Britain, where strong traditions of natural theology made Darwin's ideas particularly controversial, and in different European countries, where a different religious, social, and intellectual history, not to mention the accident of the translator, could make a major difference to the reception of the idea. Darwin himself mused: 'It is curious how nationality influences opinion.'[7]

Before leaving the general discussion of science in a national context, I should refer to one or two complexities. But if they are difficulties, they do not invalidate the concept of national scientific patterns. The first objection is the complication caused by migration. In the understanding of American science in the twentieth century, one often has a picture that is unusually complex in so far as it involves people from different European countries crossing the Atlantic to begin a new life. A full biography of any such scientist must obviously examine both the old world and the new. It is only those concerned with scoring in the Nobel prize game who feel they need to assign scientists to one country only. Nor is a brain drain a purely modern phenomenon. Although Huygens came from the Netherlands and Roemer was a Dane, some of their work comes within the orbit of French science in so far as it was done in Louis XIV's Académie Royale des Sciences. Similarly a large part of the work of Lagrange comes within the context of French science despite his birth in Turin as the son of Guiseppe Francesco Lodovico Lagrangia. Most scientists, however, do not change their names, nor do they move from one wealthy patron to another.

Nor does the existence of border areas invalidate the approach to a national context for science. Obviously the north of England has been more influenced by the products of Scottish education than, say, the west of England. On the Continent, Alsace provided a fertile meeting ground for French and German ideas. Often a language helped both to erect an external barrier and to provide some internal coherence before political unity existed; Germany is an obvious case in point. We do not have to wait until Bismarck before we make generalizations about German science or German universities.

Early colonial or expeditionary science may, in another sense, be a border area in so far as it combines the education and ethos of the mother country with the influence of the local environment. In Bonaparte's expedition to Egypt in 1798 and the establishment of the Institut d'Egypte,[8] Berthollet's study of chemical reaction suddenly found a new meaning in the trona deposits, Malus was encouraged to consider optical phenomena, and it has been suggested that Fourier became obsessed with the problem of heat when he returned to the colder climate of France.[9] Despite such strong environmental influence, the Institut d'Egypte was strongly French in character, a microcosm of the French

National Institute in Paris. Similarly the British transported their civilization to India. In the early nineteenth century the Asiatic Society of Bengal made some attempts to study science; a specifically scientific periodical was published in Calcutta from 1829 called *Gleanings in science*. The editor spoke of 'the scientific community of India',[10] but in his list of subscribers, all but one were British names. The editor felt that science would help to counteract 'the apathy and indolence which are the bane of our Indian clime'.[11] The pursuit of science, therefore, had a moral dimension, and the journal was printed, significantly, in Calcutta by the Baptist Mission Press. It not only kept expatriates in touch with work carried out in Europe but it encouraged local research: the growing of indigo, the analysis of Indian woods, meteorology.

In north America British cultural patterns persisted in the nineteenth century in Canada even more than in the United States. A Canadian writer in 1852 deplored the meagre contributions which had been made to science in North America, attributing their meagreness to 'the great vice of Society in America, that eternal sabbathless pursuit of a man's fortune . . . which leaves to the mind neither leisure, taste or capacity' for the cultivation of such pursuits as science.[12] He considered that Canadian science should not try simply to imitate science in Britain but should try to harness the 'fund of practical knowledge and thought, the wisdom of the workshop, the field and the loom' which was present in every community. Here, then, is the view that colonial science should be more practical in character or at least in inspiration.

In discussing science in a regional way, the country is not, of course, the only unit. In some cases one needs to take a larger cultural area and consider, say, science in Western Europe or Islamic science. At the other extreme, useful information may sometimes be provided by the local historian, and the study of a city, or of one institution within it, may produce valuable results. Finally, it hardly needs to be said that the study of science within a particular area does not preclude a study of a period or of a subject; for a short-term study, they can often be combined most effectively.

French science

For a case-history of a national context of science, I shall turn to France. A uniform national structure of education makes it a clearer case for study than Britain, with its traditions of local initiative and independence. But although in some ways it is easier to speak of French science than British science, there is a sense in which it is perhaps even more urgent to grasp the character of the British activity. In so far as scientists in France were trained as such and fulfilled the role of scientists, they came closer to an ideal trans-national science. The British man of science, who was not at all a specialist, was to a greater extent immersed

in the culture of his country.[13] There were many features of British science at the time of the Industrial Revolution that were not shared by other countries. It might be misleading if the student of science in this country were to generalize and to assume that what was true of the England of George III was true for the Austria of Joseph II or the Russia of Catherine II.

So I turn to France as a country which for the past 350 years at least has been a major contributor to the scientific endeavour. My aim will be neither to bestow extravagant praise on French science nor to attempt a systematic exposure of its weaknesses. I want simply to suggest that science in France had certain features not present in science in other countries and that national educational patterns and institutions in France provided a general encouragement for the pursuit of science, but in certain directions rather than others. Prizes offered by the Académie des Sciences for research on particular topics were only one way in which latent genius was encouraged to express itself. Within such a system valuable scientific work was done. The intellectual, religious, and political environment of the French was different from other countries. Methods of teaching,[14] social support, and economic stimulus were different. Science in France was highly structured, with career patterns[15] marked out and membership of the Académie an unbelievably important goal.

The founding of the two major seventeenth-century scientific societies, the Royal Society and the Académie des Sciences, represented two contrasting approaches to the patronage of science by the state, and since that time science has flourished or languished in Britain and France in different ways, for different reasons, and at different times. Science in France, of course, was not only different from her northern neighbour, but also from those on the other side of the Rhine and of the Alps.

The absolutism of the French monarchy after Louis XIV remained unrestrained by anything which in England would be called a Parliament. In the eighteenth century the nobility continued to enjoy privileges at the expense of the bourgeois and the peasants. Paris was the only large city. France remained an essentially agricultural country, influenced very little by the industrial changes taking place in Britain. In so far as science was thought of at all, it was studied by a handful of people as an intellectual exercise, and by rather more, as amusement. A smattering of science was a part of the conversation of the enlightened man. Voltaire and the Encylopaedists had more influence on the educated than the Catholic church, although nearly all education was in Church hands. A series of mounting crises in the 1780s finally led to the Revolution, which is a watershed in French history, education, and science.

In the creation of the new society, education was thought to be fundamental, and science had an important part in that education, partly for ideological reasons and partly because of the utility it had shown in

the Revolutionary wars. After the Terror a constructive period followed, which saw the establishment of the first Ecole Normale and the Ecole Polytechnique.[16] The Jardin du Roi was transformed and expanded into the Museum of Natural History, and under Napoleon the first faculties of science were established. Science could now become not a hobby but a full-time job, after training and the acquisition of the appropriate qualifications. Positions in academic life or the civil service depended on the *concours*. If we are to understand the conditions under which science was done in France in the nineteenth century, we must take into account the examination-orientated system, in which certain skills were at a premium.

Although some of my general remarks about French science will range more widely, I shall concentrate on the period of the early nineteenth century, not only as a period of great achievement, but as a key to understanding all of subsequent science in France. The foundations laid in 1794-5 and in the succeeding quarter of a century coincided with the greatest period in the history of science in France. They represented a national investment in science unparalleled in any other country at the time.

Two important features of the French educational system and the organization of science were centralization and integration. They are both perhaps symbolized by the establishment of the Museum of Natural History,[17] formed from the Royal botanical garden and the transfer of animals from the Royal menagerie at Versailles to Paris. The Museum was a national institution with the duty of supplying specimens for the whole of the country when required. The menagerie was not simply in juxtaposition to the botanical garden but was integrated as a department of the Museum. To give an example: on the death of an animal it was immediately taken to the anatomy laboratory, where the skin was removed and given to a taxidermist to prepare for exhibition. The skeleton was preserved and became invaluable material for the study of comparative anatomy. Sceptics who doubt the contribution of institutions to the pursuit of science might ponder the context of Cuvier's work on comparative anatomy.

The centralization of French science struck visitors forcibly. Charles Lyell, writing on a visit to France in 1823, commented: 'If a man is thought to display talent, he is hurried to Paris, as the only soil where it can be nourished or admired.'[18] The claim that French science was centralized requires some qualification according to the period under discussion. Although centralization was part of the policy of Louis XIV, the eighteenth century witnessed much important intellectual activity in the provinces, particularly in the Academies. With the Revolution, however, centralization was greatly increased. The Académie des Sciences in Paris was replaced by a National Institute, all full members of which

were required to reside in the capital. When the university system was set up, no provincial universities were established, but only provincial faculties, which were local branches of a system based on Paris, where the decisions were made. It was only at the end of the nineteenth century that real provincial universities were re-established, although they naturally suffered from lack of prestige. With this concept of centralization I associate integration. The Napoleonic University of France was really a Ministry of Education concerned with national education from infancy onwards. All examinations and grades were carefully specified, and science had to fit within this structure. Although Church schools were re-established in the nineteenth century to form a parallel system of education, their teaching was very much influenced by state examinations.

The centralization of French science was largely achieved by a concentration of major institutions in Paris. The Collège de France was itself a university in miniature. The Museum of Natural History was a centre both for teaching and research, the latter encouraged by the living-quarters provided for the staff and their families, who lived in proximity to their collections. With its many galleries and gardens, therefore, the Museum constituted an enclave of major importance in the history of the biological sciences. Then there was the Ecole Polytechnique, which impressed foreign visitors not only because of the standard of the students and the eminence of the staff but also because of the facilities provided for practical work. There were also higher educational establishments concerned with civil engineering, mining, and, of course, medicine. Finally, there was the Paris Faculty of Science and the Ecole Normale, which later in the nineteenth century was to rival the Ecole Polytechnique as a national establishment training mathematicians and scientists. All these institutions attracted the leading French scientists, who nearly all worked and lived in Paris. To list the staff of the respective schools would be to give a roll-call not only of the most distinguished French men of science but, in many fields in the early nineteenth century, of many of the most distinguished anywhere in the world. Even after the founding of the Universities of Berlin and London, no other capital city could provide such a concentration of leading scientists. Perhaps centralization tended to impose a certain uniformity of attitude towards any particular issue. Perhaps there would have been greater opportunity for critical examination of scientific theories if there had been competing centres of excellence.

Another characteristic of French science was specialization. In the late eighteenth century one might have expected to find in a country which took science seriously, chairs in mathematics, natural philosophy, and natural history. But in the Ecole Polytechnique there were chairs not merely of mathematics but of analysis, mechanics, descriptive geometry, physics, and chemistry. The Paris Faculty of Science, established

in 1808, had similar subjects, though astronomy replaced descriptive geometry, and mineralogy and zoology were added. Mathematics was represented by three chairs: calculus, higher algebra, and mechanics. It was understandably at the Museum of Natural History that the biological sciences received their most specialized treatment. Thus zoology was subdivided, having three chairs, the first concerned with mammals and birds, the second with reptiles and fish, and the third with insects, worms, and microscopic creatures. Lamarck held this third chair, and at his death in 1829 a further subdivision was introduced. To many a British naturalist in the early nineteenth century such specialization must have seemed very narrow; but it did enable the professors at the Museum to make significant advances in their respective fields, and daily contact with colleagues in related studies prevented the sterility of isolation.

Research in depth rather than in breadth was also encouraged by specialized journals. The *Annales de chimie*, first published in 1789, is the oldest surviving journal devoted specifically to chemistry. The first journal in the world specially concerned with mathematics was Gergonne's *Annales de mathématiques*, which first appeared in 1810; and when it ceased publication in 1831, it was soon succeeded by Liouville's *Journal de mathématiques pures et appliquées*. The new institutions also had their journals. Although here the glory of the establishment took precedence over any one subject, the journals did tend to cover a particular area. The *Journal de l'Ecole Polytechnique* was very mathematical, and the *Annales* of the Museum of Natural History covered the whole range of subjects studied in that institution.

The charge of extreme conservatism has been levelled against science in nineteenth-century France. There may have been a rigidity in French institutions which, with the passage of time, came increasingly to impose constraints on new developments. I want to consider particularly the flexibility of the institutional framework to enable it to incorporate new branches of science. The establishment of a chair in a new subject could have major implications for the development of that subject. The recognition of organic chemistry by the establishment of a chair in 1837[19] marks an important advance in one of the major sciences and is typical of the specialization which is a necessary part of the growth of science.

What were the possibilities for innovation within French science? In the eighteenth century most developments were of a comparatively minor nature, and the same may be true for much of the nineteenth century; but between the two there was one epoch-making generation in which recent changes in science could be encapsulated in an institutional framework. It is almost as if the French Revolution not only had to make up for the slow rate of development under the Ancien Régime but had also to anticipate the emergence of new sciences, since there were to be few opportunities in the nineteenth century. As schools such as the Ecole

Polytechnique had been far in advance of other countries and had achieved so much in the early years, it was easy for the French to be complacent and to assume in the mid-nineteenth century that they still led the field. Research was given a boost under the Second Empire by the foundation of the Ecole Pratique des Hautes Etudes, but it took the major catastrophe of defeat in the Franco-Prussian war to bring the French government to a fundamental reappraisal of the organization and financial support of science.

The Académie des Sciences, founded in 1666, was given a detailed list of regulations in 1699, which governed the major body of French science until its suppression in 1793. There were minor changes of title and sections, but the hierarchical organization and the clear delineation of the rights and duties of academicians remained. The Revolution threw all this into the melting pot, and the Académie that emerged under the title of the First Class of the Institute was quite different in its approach. Its recognition of a section for mineralogy was a reflexion of the work of the late eighteenth century, in particular of the crystallography of the abbé Haüy. The Académie in 1795 could not have foreseen the emergence of geology as a major branch of science. Because of the historical accident of the date of foundation, geology remained unrecognized throughout the nineteenth century in the premier scientific body of France as a major branch of science. One or two geologists like Elie de Beaumont were eventually rewarded by election to the mineralogy section of the Académie but, as long as the section was called mineralogy, it could largely ignore geology. Fortunately the inflexibility of the Académie did not prevent the introduction of geology in the Museum nor the later foundation of chairs of geology at the Ecole des Mines and at the Paris Faculty of Science.

The Collège de France is of some importance in the process of innovation, since it combined prestige with a certain independence of action.[20] Its status was such that the participation of one of its professors in a new activity constituted a stimulus to the legitimation of that activity. Founded in the sixteenth century as the Collège Royal and a bastion of Renaissance culture independent of the Sorbonne, it took pride in its independence. It pioneered many new subjects by the agreement of its professors to change the subject of chairs as they fell vacant. It was in this way that several science chairs were introduced in the 1770s: for example, a chair of physics was established to replace a chair of Greek and Latin philosophy. A century later, in 1888, a chair of experimental psychology was created by the transformation of a chair of law.

How was the actual science done in France affected by the social and institutional context in which the scientists worked? After all, it could be argued that, if the difference between science in Britain and France was that scientists had to carry out their research in their spare time in Britain, whereas many were able to do so as part of their employ-

ment in France, the results would be similar but more rapid on a full-time basis. But the differences between countries are usually more complex and subtle than this. In this discussion I shall touch on three specific areas: the question of standards, education, and the general intellectual climate. In fact, all three are related, but it is convenient to look at them in turn.

If French science reached a high standard in the early nineteenth century, it was not purely through native genius. One must think rather of ability guided in certain directions and benefiting not only from the education received early in a career but from the stimulus and direction of a highly competent and expert body, the Académie des Sciences. The Académie was the inner circle of the scientific community, but although its membership was severely restricted, its professional expertise was not. Any literate person could submit a memoir to the Académie for its judgement, and, if it was competent, the memoir would probably receive encouragement. John Herschel, in 1830, considered that the reports drawn up by commissions of the Académie 'contributed, perhaps more than anything, to the high scientific tone of the French savans'.[21] Pursuing this theme with some enthusiasm, Herschel continued:

> What author indeed but will write his best, when he knows that his work, if it have merit, will immediately be reported on by a committee, who will enter into all its meaning; understand it, however profound: and, not content with *merely* understanding it, pursue the trains of thought to which it leads; place its discoveries and principles in new and unexpected lights; and bring the whole of their knowledge of collateral subjects to bear upon it.

Of course, Herschel is too uncritical. Reports in the Académie were by no means always immediate; nor were they all works of art. However, they did constitute a kind of superior referee's report and one that authors were proud to have and that they sometimes published as an appendix to their own work. However, a system in which the approval of the Académie was so important encouraged the perpetuation of current orthodoxies rather than the introduction of new ideas.

Turning to education, one observes mathematics becoming an increasingly prominent part of school education in the eighteenth century (by 'mathematics' I mean rather more than just arithmetic and simple geometry.) The tradition may be found in the Ancien Régime in the schools conducted by the Jesuits and Oratorians, but it found its most advanced expression in the military academies. When, with the Revolution, education became the responsibility of the state, any special feature of education was likely to have the widest possible influence. In the écoles centrales, planned in 1795, mathematics and science had a prominent place and several future scientists were to benefit from this training. In 1802 the écoles centrales were replaced by the lycées and, because these

reverted to the traditional classical education and drastically reduced the time spent on science, it has sometimes been thought that this marked a serious reversal for the whole cause of science. In fact, it marked a decision to postpone the study of all but elementary science to university level.[22] But the main point I want to make is that in the lycées, mathematics, as opposed to science, was by no means restricted. Mathematics constituted a prominent part of the later classes of the lycée curriculum, and, from the very beginning, the lycées had two distinct mathematics appointments, often with assistants, in elementary mathematics and special mathematics.

So for one *professeur* who was responsible for the teaching of physics, chemistry, and natural history, there would be two or three to teach mathematics. When the Napoleonic lycées became the collèges of the Bourbon Restoration, mathematics continued to play a prominent part. Historians hardly seem to have appreciated the significance of the special *baccalauréat* in sciences mathématiques, which encouraged boys to specialize in mathematics. This was introduced in 1821 when Poisson joined the Council of Public Instruction. Those boys interested primarily in *experimental* science (or who were not good enough at mathematics to specialize) might take the *baccalauréat* in sciences physiques, which still involved a mathematics examination but only at the same level as that for students who had opted not to study science. After following courses in the faculties, a student could take a *licence* or first degree in sciences mathématiques, or sciences physiques, or sciences naturelles, and there was a similar division for the doctorate. There was a steady stream of students taking the *licence* in mathematics from 1811 onwards, and throughout the nineteenth century there were as many students taking this *licence* as those in the physical and biological sciences together.[23] The majority of those graduating would go on to teach, so strengthening the French mathematical tradition in the schools. This growing tradition was not without its critics among experimental scientists: in 1847, for example, J. B. Dumas as Dean of the Paris Faculty of Science presented a report in which he attacked 'the minute and sterile study of pure mathematics' and called for a broader scientific curriculum.[24]

If mathematics had a prominent place in the faculties, it had an even more important place in the prestigeous Ecole Polytechnique. Entry to the Polytechnique was on a national basis in which the applicants' ability and knowledge of mathematics were the controlling factors. As the Polytechnique in its early years provided free education, and was the gateway to a wide variety of careers, the requirements of the entrance examination had an important effect on French education. The ambition to enter was widespread enough to extend numeracy in the population as well as to stimulate mathematical talent at the highest level.

The importance of entry to the Polytechnique soon led to the estab-

lishment of special preparatory schools in the capital which gave a good grounding in mathematics. By 1800, candidates for entrance were examined on quadratic equations, progressions, logarithms, trigonometry, conic sections, and elementary statics, and further requirements were added in later years. The lycées and collèges sometimes gave special training in mathematics to senior pupils. Richard, professor of 'special mathematics' at the Collège Louis-le-Grand from 1821, built up a reputation for his preparation of young men for entry to the Polytechnique, and he could boast among his former pupils Galois, Le Verrier, and Hermite.[25]

At the beginning of the nineteenth century the encouragement of mathematical education and the establishment of teaching posts was of great benefit to physics, as is evident from the biographies and the work of Ampère and Fresnel. Over-specialization, however, had a drastic effect on physics. To the extent that mathematics provided both a training and a career parallel to but separate from physical science, this valuable dimension was lost to physics. The very separation of mathematics from the practical aspects of experimental science tended to increase its prestige, and the mathematics class was something of an élite. Nor was the pursuit of mathematics at a disadvantage in the later nineteenth century, when governments failed to provide adequate laboratory facilities.

The encouragement of mathematical talent and its syphoning off into a specialized group had, therefore, two important effects. First, it fostered the study of mathematics on a national scale, so that any boy with mathematical ability, wherever he lived in France, would be likely to find encouragement within the educational system. On the debit side, however, was an impoverishment of physics. Those who were experimentally minded often followed the French tradition of chemistry, which looked back to Lavoisier and included such men of the first rank as Gay-Lussac, Dumas, Wurtz, and Berthelot.[26]

While paying tribute to French scientific education, it is tempting to ask if it was not sometimes over-intensive. The problem of what constitutes an ideal scientific education and how to avoid indoctrination is a subject in itself, and I shall content myself with a passing reference to the problem and to one instance when the accusation was made. The fact that the testimony comes from a student who had been expelled from the Ecole Normale for political activity may make us view it with some caution, but as the student was Evariste Galois, who was to show in his short and tragic life that he did have important and original contributions to make, his remarks can be given more weight. In an article on the teaching of science,[27] Galois argued that mathematics was taught in a way that stifled the creative talents of students. He likened the teaching of mathematics to the teaching of Latin. Perhaps the problems set, which helped consolidate a mathematical technique for ordinary students, were too many for a mathematical genius. He felt that scientific education had

become a game in which one prepared to please the particular prejudices of the examiners.

Here, then, was an attack against the system. It was partly political, in so far as it represented the antagonism of a young republican to a system supported by a monarchy; but it also had serious educational implications. The implications of Galois's remarks are that within a generation the examination system, intended to create a meritocracy, had ossified as a test of conformity. Inevitably the French educational system did produce a certain uniformity. There was less room for the eccentric or the rare genius. This was one of the weaknesses of French science in the nineteenth century when it is compared with the diversity of the German or the British universities. In this way, the comparative uniformity of the French system and the stress that it laid on conformity had important implications for science.

Those who, in the nineteenth century, argued against government support for science were often exercised by misgivings about political control. There were a few cases of political interference—for example, the expulsion of Lazare Carnot from the Académie under the Directory and the expulsion of Monge under the Restoration—but such events were very much the exception. Holders of state appointments, including members of the Académie, were required to take an oath of loyalty to the government. Such a requirement can, perhaps, be defended, but for those who lacked the flexibility of a Laplace it could make life difficult in a fluctuating political situation. After the July Revolution of 1830 the legitimist Cauchy left France, but it was a self-imposed exile. Under the government of Napoleon III both the royalist Cauchy and the republican Arago were exempted from the oath of allegiance.

Government support of science could take many forms. Most obviously it provided institutions in which scientists could work, and it paid their salaries and some expenses. One area which has not been examined by historians is that of publication, something that was particularly costly in the case of the biological sciences where many illustrations were required. The state was able to help by taking out multiple subscriptions. To give a specific example: in 1805 the government was subscribing for 36 copies of the *Annales* of the Museum of Natural History.[28] It was also taking out a few subscriptions to the *Annales de chimie*, but in the case of the latter publication the Minister of the Interior intervened in a far more effective way: in 1806, at the behest of Fourcroy, he sent a circular to the prefects in all the departments of France urging them to encourage local subscriptions to the journal as one of public utility.[29] Not many scientific journals have been able to benefit from such government pressure. Indeed, the incident reminds us of the political dangers of a close association of government and science. It would have been sad if support had led to control of publication. A long-standing accusation

that the Napoleonic government intervened to prevent the publication of an alternative scientific theory has been refuted.[30]

In the last twenty years the history of French science has gradually gained greater recognition as a field of study. With greater professional support in the United States and Britain than in France for history of science, more has in fact been done in this field by 'les Anglo-Saxons' than the French,[31] but I do not think this is necessarily a bad thing. Since the 1950s, studies have widened from exclusive concentration on the Revolutionary period, and scholars have looked back to the Ancien Régime as well as forward to the early twentieth century. The greatest task ahead for historians probably lies in the nineteenth century. There is still much to learn about scientific education and scientific societies as well as about the science actually done. For many institutions, the principal source available is a centenary study, possibly published in the 1890s and with the editorial or financial assistance of alumni. The personal reminiscences contained in some of these histories hardly qualify as history, and we urgently need more scholarly studies.

Even the general public now recognizes that scientists are human beings and that we need to know more about them. Biographical studies of scientists can provide insight into the whole scientific endeavour in a national context. The French tradition of *éloges* has hardly fulfilled this purpose. It is seemly to praise the dead, but the historian usually wants greater freedom to analyse and criticize. Government support of science must be studied by looking at the records of the different ministries which contributed in some way to the support of science, as well as by studying parliamentary debates and statements of government policy. Influential scientists such as Laplace, Cuvier, Dumas, Pasteur, and Berthelot were able to exert important influence on government support of science. We are still awaiting a detailed study of laboratory facilities in nineteenth-century France.[32] We know that by twentieth-century standards they were inadequate, but we should beware of exaggeration—the shed with the leaking roof where Marie Curie toiled over her extraction of radium from pitchblende (as in the film) can hardly have been typical for scientists after they had gained recognition.

Apart from language, there are certain technical difficulties in pursuing the study of French science. For the benefit of foreign scholars there is now a specialized American company based in Paris, which in its advertisements claims to 'cut through the lack of co-ordination and bureaucratic difficulties which plague French research facilities'.[33] I think such remarks are a little unkind. In many instances the researcher is met with friendly co-operation, and there is a French tradition of documentation which goes back to the Revolution and which means that valuable information is recorded in archives. All this should encourage the potential student.

I am well aware that in this general talk I have been guilty of indulging in generalizations, some of which are only partly true—that is inevitable if one is to cover a broad canvas and not continually to insert tedious qualifications. I have also omitted many aspects of French science in this rapid and impressionistic survey. I should like to have had time to discuss other peculiarly French contributions to the history of ideas, such as positivism, or aspects of the organization of science, such as the *cumul*, but these would need separate articles; and to give even a superficial survey of French science over one century would require a book. But it seems to me that a prior need is for detailed studies of certain key figures in science, of the scientific community, and of institutions. When these have been published, we shall have a clearer idea of what is meant by French science.

I have tried to convey something of the atmosphere of science in France. I spoke earlier about some of the difficulties and limitations, but I cannot end without acknowledging a real danger in the study of science in a national context. Such history could easily degenerate into flag-waving, perhaps even encouraged by government grants. If governments became obsessed with the history (including history of science) of their own countries in order to bolster nationalism, a dangerous situation would result. Some past history of science has been too nationalistic. I think one achieves a greater objectivity if one decides to study a country other than one's own. The multi-volume *History of the English people in the nineteenth century* by the French historian Halévy is an example of a history written from the outside. Such a history can gain in perspective what it might lose in intimate local knowledge. But inevitably most history in a national context is likely to be written by natives and so with the dangers I have suggested.

I conclude, therefore, with the suggestion that a study of history of science in a national context should not preclude a wider frame of reference. In such history one is always implicitly making comparisons; but an explicit comparative study should be encouraged. Not only are we being less parochial if we know something about science in more than one country but we can learn more about science. It is so easy to take particular attitudes and institutions for granted. If we look at these in more than one country, we may gain a valuable perspective. We are finding at Canterbury that a study of the transmission of scientific ideas from one country to another can be an enlightening and, I hope, useful exercise.[34] The diffusion of science can often be profitably studied in terms of country, and studies of the reception of the ideas of Descartes, Newton, Lavoisier, and Darwin have been followed in this framework. But although nations have provided geographical, political, and linguistic constraints, they have never managed to imprison science. Much experimental, observational, and even theoretical science can be usefully thought of as arising

within a national context, but it finally becomes international. International co-operation in science has been growing in the past 300 years. In the end we must understand the development of science not only in its national but also its international context.

NOTES

[1] See M. B. Hall, 'Science in the early Royal Society', in M. P. Crosland (ed.), *The emergence of science in western Europe* (London, 1975), pp. 57–77.

[2] *Second Report of the British Association for the Advancement of Science; Cambridge, 1832* (London, 1833), p. 184.

[3] R. E. Stebbins, in Thomas F. Glick (ed.), *The comparative reception of Darwinism* (Austin, Texas, 1974), p. 122.

[4] *De l'origine des espèces ou des lois du progrès chez les êtres organisés . . .*, traduit . . . sur la troisième édition . . . par Mlle Clémence Auguste Royer. Avec une préface et notes du traducteur (Paris, 1862).

[5] Darwin to Lyell, 22 August [1867], in *Life and letters of Charles Darwin*, ed. F. Darwin (3 vols., London, 1888), iii. 72.

[6] O. Chadwick, *The secularisation of the European mind in the nineteenth century* (Cambridge, 1975), p. 176.

[7] Darwin, op. cit. (5), iii. 118.

[8] M. P. Crosland, *The Society of Arcueil. A view of French science at the time of Napoleon I* (London, 1967), pp. 14–16.

[9] J. W. Herivel, *Joseph Fourier. The man and the physicist* (Oxford, 1975), p. 235.

[10] *Gleanings in science*, i (1829), pp. xi-xii.

[11] Ibid., p. vii.

[12] *The Canadian journal. A repertory of industry, science and art and a record of the proceedings of the Canadian Institute*, ed. H. Y. Hind, i (1852–3), Introduction, pp. 2–3.

[13] S. A. Shapin and A. W. Thackray, 'Prosopography as a research tool in history of science: the British scientific community, 1700–1900', *History of science*, xii (1974), 4.

[14] For an excellent characterization of a certain style of teaching science in Paris in the nineteenth century, see R. Fox, 'Scientific enterprise and the patronage of research in France, 1800–70', *Minerva*, xi (1973), 442–73.

[15] Some information on nineteenth-century career structures is given in M. P. Crosland, 'The development of a professional career in science in France', op. cit. (1), pp. 139–59.

[16] An introduction to Revolutionary institutions is provided in M. P. Crosland (ed.), *Science in France in the Revolutionary era described by Thomas Bugge* (Cambridge, Mass., 1969).

[17] For the history of the Museum in the Revolutionary period, see M. Deleuze, *Histoire et description du Muséum royal d'histoire naturelle* (2 vols., Paris, 1823), i. 67–158.

[18] *Life, letters and journals of Sir Charles Lyell, Bart.*, ed. [Mrs] K. M. Lyell (2 vols., London, 1881), i. 150.

[19] A ministerial decree of 14 July 1837 retitled the chair of pharmacology at the Paris Faculty of Medicine: it was henceforth the 'chaire de chimie organique et de pharmacie'. It was given to J. B. Dumas. A further chair of organic chemistry was established in 1865 at the Collège de France for Marcellin Berthelot.

[20] *Le Collège de France 1530–1930. Livre jubilaire* (Paris, 1932). See also T. N. Clark, *Prophets and patrons. The French university and the emergence of the social sciences* (Cambridge, Mass., 1973).

[21] J. F. W. Herschel, in *Encyclopaedia metropolitana* (London, 1845), iv. art. 'Sound' [1830], 810 n.

[22] The time devoted to science in the lycées was a contentious issue; there were frequent changes which it would be tedious to list.

[23] O. Gréard. *Éducation et instruction. Enseignement supérieur* (2nd edn., Paris, 1889).

[24] Report quoted by R. D. Anderson, *Education in France, 1848–1870* (Oxford, 1975), p. 61.

[25] A. Dalmas, *Evariste Galois, révolutionnaire et géomètre* (Paris, 1956), p. 27.

[26] Although the major work of all four was in chemistry, Gay-Lussac and Berthelot had gained election to the Académie in the less fiercely contested physics section.

[27] 'Lettre sur l'enseignement des sciences', *Gazette des écoles* (2 January 1831).

[28] The cost was 3,120 francs for the year, the equivalent of a modest salary. Archives nationales, F[17] 1023, dossier 12.

[29] Ibid., dossier 13. The full text of the letter will be given in a forthcoming article by the present author on the history of the *Annales de chimie*.

[30] M. P. Crosland, 'Humphry Davy—an alleged case of suppressed publication', *The British journal for the history of science*, vi (1973), 304–10.

[31] See, for example, R. Taton, 'Sur quelques ouvrages récents concernant l'histoire de la science française', *Revue d'histoire des sciences*, xxvi (1973), 69–90.

[32] For a recent contribution in this area, see, however, Margaret Bradley, 'The facilities for practical instruction in science during the early years of the *École Polytechnique*', *Annals of science*, xxxiii (1976), 425–46.

[33] *History of science society newsletter*, vol. v, no. 1 (January 1976), p. 14.

[34] For example, R. G. A. Dolby, 'The transmission of science', *History of science*, xv (1977), 1-43, and M. P. Crosland and C. W. Smith, 'The transmission of physics from France to Britain: 1800–1840', *Historical studies in the physical sciences* (in press).