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THE ORGANIZATION OF SCIENCE:
A HISTORICAL OUTLINE OF SCIENCE AS A SOCIAL ACTIVITY

It is the purpose of this essay to provide some historical background to the contemporary discussion on the organization of science in Britain, and to show that our present difficulties have their roots in the past. The history of the organization of science has received little attention from historians of science, most of whom, in the West, are dominated by idealist or positivist philosophies. Their tendency is to stress the contributions of individual scientists, rather than the group activity and the interplay of science with industry and other human activities. This essay deals with the group activity: for the other aspects the reader should consult Bernal (1) and Mason (2).

THE BEGINNING OF MODERN SCIENCE

There has, of course, always been some element of collaboration between scientists, even in the remote past long before science had separated from the amalgam of religion, philosophy and technology of the early civilizations. In antiquity the organization of intellectual work reached its acme in the Alexandrie of the Ptolemies, with the foundation of the Museum. Closer to our time, the Middle Ages produced that remarkable institution, the university, which still plays a fundamental part in our intellectual life.

Nevertheless, until the seventeenth century, science was still in an embryo state, a minor part of philosophy, and its organization was rudimentary and haphazard. The seventeenth century saw a real change in quality, a change which occurred in Western Europe, and only there. This point is conceded by such a staunch champion of Chinese science as Joseph Needham (3)* Until the present century, the major development of science took place within a very few countries of the West, among which Britain has played a leading part.

(1) Bernal, J.D. Science in History. Watts. 3rd edition

(2) Mason, S.F. A History of the Sciences. Routledge & Kegan Paul. 1953.

(3) Crombie, A.C. (editor) Scientific Change. Heinemann. 1963 p. 118.

The characteristics of the science of the seventeenth century which distinguish it from the proto-science of the earlier period are: l) a rejection of _a priori_ philosophical systems; 2) the paramount importance of systematic experiment and observation; 3) the solution of relatively small problems within the scope of the experimental and intellectual capabilities of the time:; and 4) the explicit recognition that to understand the universe is a vast undertaking and requires the continuous and concerted action of the whole scientific community.

Nowhere are these points put more forcibly than in the writings of Francis Bacon, Lord Verulam. He intended his chief books to form a single integrated work under the title _Magna Instauratio_, a comprehensive plan for the reform of society (4). He contrasted the sterility of philosophic systems with the steady growth of technology and came to the conclusion that true knowledge can only be obtained by working with _things_, and that before theories can be correctly formulated empirical facts must be accumulated. He insisted that this work of acquiring knowledge could be so organized that,men of even moderate intellectual attainments could play their part in it.

Of particula interest in this respect is the unfinished _New Atlantis_ of l62y with its description of an island Utopia which possesses a scientific academy, provided with workshops, laboratories and other facilities. Bacon describes the duties of the staff: some collect information from abroad, summarize and interpret it, others carry out new experiments, while another group apply the findings to practical use. Administrators have not been forgotten, and, most important, neither have the novices, apprentices, servants and attendants. It was a remarkable forecast of the future.

It has been easy for the academics to jeer at Bacon. He was no scientist himself: his failure to appreciate the work of true experimentalists like Gilbert and Harvey is notorious, and he did not understand the importance of hypothesis and mathematics in scientific research. But the real stumbling block which he put in the way of his academic contemporaries and their modern counterparts is his insistence that science is not the preserve of a few great intellects. In spite of criticisms, his influence in the following generation was considerable. In his own words, he had rung 'the bell to call the Wits together'.

(4) For a Marxist analysis, of his philosophy see Farrington, B. _Francis Bacon_, _philosopher of industrial science_. Lawrence & Wishart. . 1951.

SCIENCE BEGINS TO ORGANIZE

How could the new type of scientific activity be co-ordinated in the way that Bacon and his followers desired?

Not through the universities which were generally committed to the Aristotelean philosophy, stagnating and reactionary. The Low Countries and Scotland showed a brighter picture and many English physicians were receiving their training at Leyden and Edinburgh, where the Dissenters were free from the proscriptions of Oxford and Cambridge. The foremost universities for science were in Italy, particularly Padua, which lay outside papal control. Galileo studied and taught at Padua, and important Englishmen like Thomas Lineacre, John Caius, and William Harvey received their medical training there. But they were essentially teaching institutions, and it would be some time before the new science could build up an accepted body of knowledge, systematised in the way required for a university course. The old authorities would form the basis of university teaching for some time to come. Besides, something was needed to bring scientists together, irrespective of university or lack of university.

The answer was the scientific academy or society.

THE ITALIAN ACADEMIES

Scientific academies first appeared in Italy, probably because the Italian city states were economically the most advanced, with a heightened interest in science-and technology; and Italy already had the precedent of the academies of the Humanists, although these were literary, not scientific.

As early as l560 a not very scientific Academia Secretorum Naturae was founded in Naples by Giovanni,Baptista Porta. At the beginning of the next century, the Accademia dei Lincei was founded in Rome in 1600 by the Duke Federigo Cesi. To a large e.,:tent a vehicle for Galilean science, it met for co-operative experimental work. After 1633 and the condemnation of Galileo, the Accademia dropped the study of physics as too dangerous, and finally dissolved in I657.

It was succeeded by the Accademia del Cimento, formed from a group of scientists gather round the Medici brothers, the Grand Duke Ferdinand II and Prince Leopold, but this, too, was disbanded in 1667.

After the Galileo affair, the Church re-asserted its supremacy in intellectual matters and Italy dropped to the rank of a minor scientific power. For the next century and a half the two leading countries in science were to be England and France.

THE ROYAL SOCIETY AND ENGLISH SCIENCE

In England the growing interest in science was mixed up with a strong movement of educational reform and criticism of the two Universities, and with the controversy of the Ancients against the Moderns. In all these trends Bacon's influence was very marked.

One of the early reformers was Sir Thomas Gresham, who as the wealthiest of the City merchants had the money to implement his plans. In spite of the denunciation of the University of Cambridge, his will (he died in 1575) endowing a college in the City of London was put into effect, and Gresham College was opened in 1598. Professorships of law, physic, rhetoric, mathematics, astronomy, geometry and music were provided for, and the Gresham professors, in constant contact with the merchants, sea-men and instrument-makers of London were among the leaders of the scientific movement.

The scientists of Elizabethan England were mainly outside the universities, including in their ranks physicians, schoolmasters and courtiers: men like Dr. John Dee, Thomas and Leonard Digges, Robert Recorde, Edward Wright and the groups round Sir Walter Raleigh and the Earl of Northumberland (the 'Wizard Earl') (5). The instrument-makers deserve special mention. A product of the need for navigational instruments as England grew to become a major naval power, they had acquired a fund of practical knowledge and a tradition-of craftsmanship which played an important part in providing the equipment for the growing body of experimental scientists. (6)

(5) When this essay was given as a lecture to the History Group, I remarked that these groups had been neglected in the history of ideas. But Christopher Hill's new book Intellectual Origins of the English Revolution, O.U.P. 1965, has devoted a chapter of over 100 pages to Raleigh. Although the book has appeared too late for me to take advantage of it, it is obviously a major contribution to the history of science in the period just prior to the Royal Society.

(6) Biographical information on these comparatively little-known men has been collected by Professor Eva Taylor in The Mathematical Practitioners of Tudor and Stuart England. C.U.P. 1954.

In face of the growing influence of the Moderns the universities made some small gesture of progress by the endowment of a few chairs and lectureships in science - the Savilean chairs of geometry and astronomy (l6l9) and the Sedley lectureship in Natural Philosophy (l62l) at Oxford and the Lucasian professorship at Cambridge (I663). But essentially science had little hold there.

Several representatives of the merchant class played a conspicuous part in the development of an organization for scientists, and were also prominent in schemes for educational reform and in philanthropic projects. Theodore Haak, a German merchant who came to England in 1625, was a friend of several English scientists, and through his Continental connexions, acted as 'corresponding secretary' for the group, keeping them in touch with scientists abroad. A member of Haak's group was another merchant, Samuel Hartlib, who came to be known as the 'great intelligencer', because of his activities as a go-between.

Haak seems to have been concerned in the formation of a group which met informally in London, including Dr. Wilkins, Dr. Jonathon Goddard, John Wallis, Francis Glisson, George Ent and Robert Boyle, and as it contained both Royalists and Parliamentarians, friction was avoided by barring all discussion of religion and politics, and confining the business to 'philosophical' (i.e. scientific) enquiries.

When the Cromwelliar, forces took control of Oxford, many of the professors, noted supporters of the King, were replaced by men of republican sympathies, including several from the London group. Wilkins, Goddard and Wallis became professors, and Boyle and Christopher 'Vren were persuaded to settle there for a time. As a result a brilliant group of scientists were formed, and for a short period, the centre of gravity of science in England shifted from London to Oxford.

In 1660, with Charles II on the throne, London again became the centre of activity and the group proposed to set up more formal meetings at Gresham College. A meeting of December 12th of that year narks the formal constitition of the Royal Society, with Lord Brouncker, an amateur mathematician of no mean ability, as its first President. It was not until July 15th 1662 that the Society received its Charter of incorporation from the King and in a Second Charter of I663 it was described as. 'The Royal Society of London for Improving Natural Knowledge'.

Many of the Fellows were not scientists by present-day standards, but were collectors of curios, dabblers in school-boyish chemical 'experiments', lovers of marvels, and the cranks who have always gathered on the fringes of science? these were subsequently to prove an embarrassment. The effective membership were high-ranking scientists like Hooke, Boyle, Sir William Petty, Wilkins, Wallis, and the professors of Gresham College. Much of the success of the Royal Society was due to its secretary, Henry Oldenbourg, and its Curator, Robert Hooks, although the two did not get on well together.

Oldenbourg was not a scientist, but a merchant and 'intelligencer' of the type of Haak and Hartlib, and was able to give invaluable aid to the Society through his foreign contacts. His extensive correspondence abroad brought him under suspicion and earned him on one occasion a short stay in the Tower.

Bacon's influence was very marked in the early days of the Society, many of its activities being of the fact-finding type. It based itself thoroughly on experimental science, and one of Hooke's duties was to carry out experiments at each meeting. Great interest was shown in industry and inventions; there were plans (which were not implemented) for making a survey of all the crafts and industries, and the Society examined inventions on behalf of the Government. Medicine ivas also discussed. It paid much attention to the newly opened territories and compiled a questionnaire for the use of travellers. It was not long, however, before the Society ceased to concern itself with these matters and restricted itself to 'pure' science, a state of affairs which has lasted until the present day. It is understood, though, that the possible extension of the scope of the Royal Society is now being discussed.

The Society ran into trouble immediately after its foundation. It had no financial support from the Crown, and subscriptions from the Fellows, its only source of income, were difficult to collect. The finances were a serious problem in its early years, but were not the only trouble.

A large body of opinion was hostile to the Society, particularly among the reactionary elements in the universities, where accusations, were rife that the activities of the Society were subversive of state and religion, and it was in refutation of these that one of the Fellows, Thomas Sprat - later Chaplain to Charles II and Bishop of Rochester - published his History of the Royal Society in 1667.

A heavy attack came from the physicians, who up till then had been the only body with any professional claim to scientific attainments. Kany of the early Fellows were, in fact, trained as physicians. Most of them, though, saw the Royal Society as a threat to the eminence of their own Royal College of Physicians and to their professional standing, as well as an attack on their Aristotelean-Galenic tradition. It was comparatively easy to win support against the Society from a populace with no understanding 01 science, and it was mercilessly lampooned, Samuel Butler's poem The Elephant in the Moon, Thomas Shadweil's play The Virtuoso and Aphra Behn's farce The Emperor in the Hoon, being among the more literary products of this type.

The Society survived its difficulties. Science Y?as now a movement which could not be stopped and the more far-sighted among those in high places were well aware that the new science was going to have a marked effect on the economic life of the country, and that in the trade war which was developing with France, the country which could raise its production and improve its manufactures would be at a great advantage.

Charles and his ministers were also very conscious of the need for improvements in navigation. A vexed problem was the determination of longitude at sea and until the invention of the chronometer this meant more accurate determinations of the position of the moon and stars "than were available. Accordingly in 1675 a Royal Warrant was issued authorizing the building of 'a small observatory within our Park at Greenwich', and John Flamstead was granted a salary of £100 a year as 'our astronomical observator' or Astronomer Royal.

This marks the beginning of official concern with scientific research in this country, although it was on a modest enough scale, and was typical of the British Government's niggardly attitude to science up to the present day. The sum allotted, £52O from the sale of spoilt gun¬powder, was only sufficient to provide a building but no instruments. Neither was any provision made for assistance, except 'a silly, surly labourer' for the rough work. Eking out his stipend with private tuition, and later, from 1684, enjoying the living of Burstow, Flamstead carried out a lengthy programme of observations, the most accurate to his day, with instruments made mainly by himself and at his own expense. He was only able to-engage an instrument-maker to help him when he inherited a little money in 1688. One outcome of this unsatisfactory state of affairs was that the instruments of the national observatory of '.norland were Flamstead's personal property,-with the exception of a few items from the Royal Society, and on his death, his executors insisted on selling them as part of his estate, so that his successor, Edmund Halley, found the Observatory practically stripped bare when he took over in 1720.

Even after this incident the Government made no attempt to put the Observatory on a proper footing. - By granting Halley half-pay as a Post-Captain in the Navy, a definite admission that the post of Astronomer Royal should carry an adequate salary was avoided. On the other hand the successive Astronomers Royal regarded the results of their labours as their private, not public, property and acrimonious squabbles broke out with the scientists who wished to use the observations recorded at Greenwich. 'hen Halley's successor, Bradley died in 1762, his executor took possession of all his astronomical observations as part of his estate: nor could the legal proceedings instituted by the Board of Longitude in 1767 regain them for the nation. It was not until the time of the Rev. Nevil Maskelyne (appointed Astronomer Royal 176$) that the Observatory began to implement those public services which we hfve now come to expect of it.

THE ACADEMIE DES SCIENCES

The other country to take a major part in the founding of modern scientific institutions was France. As in Italy and England, the representatives of science began to meet informally outside the universities, at first in the cell of the Minorite Friar, Marin Mersenne, and then in the salons of wealthy scientific amateurs: Dupuy, Peiresc, Montmort, (the Maitre des requites) and Thevenot. Progress was not steady, and by I664 the meetings had practically ceased. After several attempts- by private individuals to revive the meetings, the scientists turned to the government.

The time was just right. Colbert was in charge of finance, industry and the navy. Foreseeing the importance of manufactures as the foundation of French supremacy in commerce and war, he fostered the growth of State industries which have remained a feature of French life even under capitalism. He was quick to notice the interest which scientists were devoting to industry and trade, and was fully alive to the significance of Charles's patronage of the Royal Society in England. So when he was approached on the subject, he at once proposed to Louis XIV that the scientists then meeting at the home of Melchisedec Thevenot should be incorporated in an official academy, similar to the Academie Francaise (founded in 1635 as a literary academy), but restricted to mathematicians and physicists. The King's assent to the foundation of the Academie des Sciences was conveyed to the assembly on December 22nd 1668. The Acadd;mie was given the responsibility of organizing the national astronomical observatory. Pensions of 1,500 livres were allotted to the Academicians for their full-time services.

Colbert died in 1683. The narrow outlook of his successor, Louvois, had a bad effect on the Acad^mie; he made it quite clear that the scientists were not engaged for pure research but for 'recherche utile, celle qui peut avoir rapport au service du roi de l'Etat'. In l6$2 Louvois was succeeded by Pontchartrain, who placed his nephew Bignon in charge. Bignon's reorganization of the Academie, resulting in the constitution of 16$$ was to a large extent responsible for the flourishing of French science in the 18th century.

OTHfR ACADEMIES

In Prussia an Academy was set up in Berlin in 1700 by the Elector Frederick I of Prussia, based on suggestions made by Leibniz. The Elector insisted on the inclusion of history and the German language among its activities. Other European countries gradually set up Academies and following the Berlin example, they generally included the humanities among their interests.

Today the mopt influential sirgLe organization in the scientific world is the Academy of Sciences of the U.S.S.R. which plays a much greater part in the affairs of its own country than does any scientific institution in the capitalist countries. It began as an idea in the head of Peter I, somewhere about 1715? and was based on his acquaintance with events in the Western world, coupled with his desire to build up native Russian industry and trade. It was not till 1724, though, that he ratified the Statute of the Academy of Sciences, and the Academy of Sciences itself, did not, in fact, begin its activities till after his e'eath in 1725.

Peter's successors found little native scientific genius for the academy and so wore compelled to make up for the deficiency in its early years by inviting foreigners. The first members were for the most part young men without standing in the world of learning, but some of them later became internationally famous - Daniel Bernoulli, the mathematician, G.F. Miller, the historian, I.G. Gmelin, the naturalist, and the most famous of then all, the mathematician Leonhard Euler who came to Petersburg in 1727 at the age of 20.

Russia's greatest polymath, Mikhail Vasiliovich Lomonosov, became a professor of the Academy in 1742, at a time when German administrators were becoming such a powerful bureaucratic clique that the native Russians were beginning to chafe with resentment. The Academy itself was controlled by the Counsellor of the administration, Schumacher, who thought it dangerous to encourage Russians to study and progress in science, and in the course of his struggle against the German group, Lomonosov's hot temper earned him six months detention. Eventually Lomonosov's reputation at Court allowed him to overcome the German opposition. He was appointed Professor of Chemistry in 1740 \vhen the first chemical research laboratory in Russia was opened for him. Still later (1757) Lomonosov himself was appointed Counsellor and had much to do with subsequent reforms in the Academy.

The Academy was conceived by Petsr I as an institution to serve the needs of the state, and in fact throughout the eighteenth century much of its time was devoted to drawing up a survey of the natural resources of tiie country and to supervising technical education.

By the end of the seventeenth century the difference between the organization of science in England and abroad was already apparent. In England, where private enterprise had already attained a wide develop¬ment, state intervention was at a minimum, and the type of organization which evolved was a private society financed by the scientists themselves, With very few exceptions they were amateurs, men of independent means or aerning their livelihoods in some other field, often the church or medicine. This tradition of amateurism in science was later to become a brake on the progress of science in England and remnants of it still exist today. On the Continent money for science was provided by a despot who exerted a fair measure of control over science in return. Academies were formed rather than societies, and the academies served to a greater or lesser degree as organs of the state. In the case of seventeenth-century France it would not be far wrong to treat the Academie des Sciences as the scientific wing of Colbertism. Paradoxically, since the Academicians were paid officials, it was easier for a promising man of small means to become a scientist in aristocratic France than it was in more democratic England.

THE DOCUMENTATION OF SCIENCE

Science as a social activity requires that its achievements should be recorded for posterity and also made known as soon as possible both to the scientists themselves, and to those who may be able to adapt the new knowledge to practical use.

The first scientific periodical was the Journal des Scavans which appeared in Paris on January 5th 1665, publishing not original papers but scientific news. By the end of the eighteenth century there were several scores of journals publishing scientific research.

The Philosophical Transactions of the Royal Society began its long career in a typical haphazard British fashion. Henry Oldenburg, the Secretary, had considerable difficulty in collecting his salary from the Society. He had the idea of raising a little money by publishing a journal, which was to be better than the Journal des Scavans, based on the papers and observations presented to the Society. He was permitted to carry on with his plan as a private venture under the Society's license. The first issue of the Transactions appeared on March 16th, I665, but in the subsequent years was not the financial success Oldenburg had hoped. He continued as editor of the Philosophical Transactions until his death in 1677. The most important scientific periodical of its age continued under the private editorship of later secretaries, and it was not until halfway through the eighteenth century that the Society took over responsibility for its own publications.

The scientific periodical with its prompt publication catered for a comparatively new need in the intellectual world, the establishment of priority and property in a scientific discovery or theory.

Inventions, property in which involved material gain, were dealt with by the introduction of the patent system. The Statute of Monopolies (1624) was a milestone in the course of the struggle against the monarchy; it is also the foundation of our present system of industrial patents. Restricting the powers of the Crown, it laid down that monopolies could only be granted for new manufactures, and could only be granted to the 'true and first inventor and inventors of such manufactures', for a period not exceeding fourteen years. It was stipulated, too, that such a monopoly 'be not contrary to the lav; nor mischievous to the State by raising prices of commodities at home or hurt of trade or generally inconvenient'.

While all earlier Patent acts have now been superseded by the Patent act of 1949, the principles laid down in the Statute still remain the basis of our patent law. Although the patentee was required to make his process available to the public in return for the statutory protection, it was not until the middle of the eighteenth century that the patent specification became the usual moans of making the details of a process public. Prom then onwards the specification forms the most important item in the documentation of technology.

IN EIGHTEENTH CENTURY BRITAIN

Under the Presidency of Sir Isaac Newton (from 1703), the Royal Society entered on a period of stability, and following some reforms in the administration made by the next President, Sir Hans Sloane, from 1727, the finances improved and membership rose, reaching 301 in 1740. Scientists were in the minority, however, being outnumbered by two to one. Sloane retired in 1741 and was followed by half-a-dozen undistinguished successors, until 1778 saw the election of Sir Joseph Banks whose term of office lasted until 1820. Banks was a wealthy man of considerable social standing and an amateur scientist of no mean order. Right up to his death in 1820, if any question of a scientific nature required attention at a high level, Banks was the obvious man to approach, not only because of his contacts with the best scientific minds at home and abroad, but also because of his influence with the Government and even directly with George III. His big house in Soho Square became perhaps even more important than the premises of the Royal Society for conducting scientific business. It was the natural port of call for any foreign scientist visiting London, where he would be sure of a welcome and introductions to the scientists he wished to meet. The regular receptions Banks held at Soho Square were an important part of the scientific life of the country.

Banks had the interests of science firmly at heart and he performed his duties as President with the utmost regularity; yet he was content to leave the conduct of the Society in the hands of men of fashion. At the end of his long and autocratic presidency in 1820, the real scientists had no greater say in the affairs of the Society than they had at the beginning, in spite of some signs of revolt on their part, and no attempt was made to smarten up the extremely inefficient business methods. Banks did much to bring- the Royal Society closer to the Government and to gain recognition for science as a national institution; and yet scientifically the Royal Society stagnated and the stagnation lasted well into the nineteenth century.

This was the period of the Industrial Revolution, and the steam-engine. In spite of this the Royal Society, which had started off with such an interest in industrial processes and the applied sciences, showed no interest in these developments. Moreover, the main centres of this activity were not in London, but in Scotland and the provinces. Some of the most productive scientists, like Black and Priestley, had much more in common with the new industrialists than they had with the scientific gentry in London; and many of the industrialists, like Boulton, Roebuck and Josiah Wedgwood, took a very great interest in science and were pioneers in the introduction of scientific principles into manufacture. James Watt could lay considerable claim to fame as both scientist and industrialist.

It was obvious therefore that the Royal Society was totally inadequate to provide for the scientific and technical needs of the Industrial Revolution. One development was the founding of local societies based on the model of the Royal Society itself. In Dublin, the Royal Irish Academy was formed out of a society which began about 1782. In Edinburgh a society founded in 1731 was reorganized into the Royal Society of Edinburgh in 1783. It has included many famous scientists among its members and its Transactions contain much important work.

Another outcome was the formation of the provincial societies with much wider and more down-to-earth interests than the Royal Society. The two leading towns in the Industrial Revolution were Manchester and Birmingham, and it was in them that scientists and manufacturers came together in a way which made a strong impression on English intellectual life.

Birmingham had grown up without a charter or corporation and therefore, by one of those strange inconsistencies of English Law, the repressive Acts which made life uncomfortable for Dissenters in the towns did not apply there. Consequently a large number of the Dissenters who formed the backbone of the provincial manufacturing and commercial classes gravitated to Birmingham where an intellectual life sprang up which had little to do with the more aristocratic and conservative circles in London, Oxford and Cambridge. In the second half of the century, some of the most outstanding Birmingham manufacturers and scientists came together to form the Lunar Society, so called from its meetings on the Sunday of each month nearest to the full moon. Schofield (7) distinguishes between what he calls the Lunar circle which he dates 1765-75, and the Society proper from 1775. It began with small informal meetings at the house of Matthew Boulton, whose later partnership with James Watt had such momentous consequences for the development of the steam-engine. Otherwise the circle kept in touch by visiting and correspondence. It included Boulton, Dr. Small, Dr. Erasmus Darwin (of Lichfield), Josiah Wedgwood, Richard Lovell Edgeworth, Samuel Galton and one or two others less well-known. Subsequently James Watt and Joseph Priestley came into the group, which began more regular, though not much more formal, meetings in 1775.

Although the Society remained small and select (never more than about fourteen members); it had a considerable effect on the course of the Industrial Revolution, The unorthodox politics of some of its members brought suspicion upon the Society. In 1791, egged on by government agents, rioters attacked the homes of a number of Birmingham citizens who were noted as Nonconformists or supporters of the French Revolution, wrecking Priestley's home and destroying his library and apparatus. A little later he emigrated to America where he was received with enthusiasm. At the same time some other members moved from Birmingham,

(7) Schofield, E,R, The Lunar Society of Birmingham. O.U.P. 1963.

Besides being the best available book on the Lunar Society, it deserves to be read as an important contribution to social and industrial history.

and the Lunar Society gradually ceased to function.

In Manchester a club was founded which met weekly to discuss literature and science. In 1785 this became the Literary and Philosophical Society of Manchester. It had close connections with the Warrington Academy, one of the most progressive of the Dissenting Academies. It had a particular interest in chemistry in its early years, its most famous scientific member being John Dalton, the founder of the atomic theory of chemistry. Unlike the Royal Society, it did not object to the discussion of politics, although it had some difficulties during the time of the 'patriotic' riots. Nevertheless, it did not suffer as the Birmingham society did, and, after playing an important part in the science of the nineteenth century, has remained active to this day.

Many other local societies sprang up in the bigger provincial towns, as well as many amateur natural history and antiquarian societies.

Another development was the formation of societies devoted to a particular science. This was an indication of the increasing specialization of science. A short-lived Botanical Society was founded in London in 1721 and some societies for the study of entomology. The Important Linnaean Society was founded in 1788. A chemical society was founded in 1786 in Glasgow University, and another in 1798. An Edinburgh Chemical Society began in 1800. An interesting society was the Spitafields Mathematical Society founded in 1717. Said to have been formed at first of Spitafields weavers, it later seems to have been composed of local tradesmen and professional men. It could boast of no famous mathematicians, but it lasted until I846, when it was absorbed by the Royal Astronomical Society.

A society of a different kind from all these was founded halfway through the century, when a group of private individuals met in Rawthmell's Coffee-house in London and formed a Society for the Encouragement of Arts, Sciences and Commerce, which still flourishes, though in a restricted form as the Royal Society of Arts. It owed its inception to the enterprise of William Shipley, at the time a little-known drawing-master of Northampton, who, concerned about the sufferings of the poor of the district, thought the answer to their poverty lay in the rapid growth of industry and agriculture. This growth he proposed to foster by means of a society which would offer prizes to inventors, and would also indicate the areas in which improvements were most needed. He succeeded in bringing together eleven men, of whom the most important was Viscount Folkestone, in Rawthmell's on March 22nd, 1754. Shipley's schemes were agreed to, the Society was formed and money was raised from wealthy sympathizers. Two premiums were offered for the production of madder and of cobalt, and two more for drawings by children.

The Society was a success: its membership increased, money came in, and so did the inventions - so many that a number of separate committees had to be set up to deal with them in subject groups. The premium list for 1764 occupied $1 pages of text, with 380 classes. In the first twenty-two years, £l6,625 was disbursed in premiums. In addition it staged several exhibitions.

As for the influence of the Society, its historians (8) state: "Four claims can be asserted with confidence. First (the premiums) resulted in the afforestation of considerable areas of land. Secondly they played a predominant part in the earlier stages of the 'agricultural revolution', being the means of introducing several new crops to this country and to the colonies and of the invention of new agricultural implements. Thirdly, they fostered the skill of draughtsmanship. And, fourthly, by stimulating the invention of many mechanical devices contributed largely to the progress of the Industrial Revolution". So high was its reputation through the eighteenth century that a number of foreign societies were consciously modelled upon it, including the Free Oeconomical Society of St. Petersburg, 1766, and the still influential Society pour l'encouragemant de l'industrie nationale founded in Paris by Napoleon in 1801.

TRAINING IN SCIENCE

If science is to be properly integrated into the social structure, society must provide some means by which the scientific tradition can be handed down to the coming generations and by which new scientists can be trained. There was, in fact, no provision anywhere in England for the formal training of scientists as scientists until the nineteenth century.

For the most part the English scientists of the eighteenth century were self-trained in their specialities and their scientific work was carried out with private means, e.g. the Hon. Henry Cavendish; with the help of a wealthy patron - Priestley was companion to Lord Shelburne; or, more usually, they derived their incomes from some other activity - medicine, the Church, or teaching. Even Black at Glasgow University carried out his chemical research on his own initiative and not as part of his regular university duties. The most significant advances in this respect were to come outside England.

(8) Hudson, D., and Luckhurst, K.W. The Royal Society of Arts, 1754 - 1954. Murray. 1954.

By 1730; twenty-eight universities had been established in the Holy Roman Empire, but were not particularly effective. In Hanover, the Elector, George II of England, was advised to found a new university on different lines. The place chosen was Gottingen, then only a small and unimportant town. Teaching started as early as 1734, but the university was not officially opened until 1737. Compared with Oxford, Cambridge and Paris, the University of Gottingen possessed a strictly limited autonomy, the State controlling finances and the appointment of professors.

A major innovation was that the professors were required to combine teaching with research, and the. teaching was to be modem, practical and utilitarian,. Soon the system settled down to one in which the professors gave their regular teaching lectures open to all, and the so-called privatissima to groups of special students who paid for the privilege,* and in these lectures the professors taught the results of their own researches. The scientific subjects were divided between the faculties of Philosophy and Medicine. To Gottingen was due that tradition of research and scholarship which became such a hall-mark of German learning in the following century.

In franco the Academic des Sciences remained the focus of scientific activity, but unlike the British Government, the French actively fostered the training of scientists and engineers, chiefly for military purposes. At the suggestion of Marshal Vauban, a Corps of Engineers was set up in the French Army, and in 1716 a Corps of civil engineers was organized, the Corps des Ingenieurs des Fonts et Chaussies. In connection with this, an Ecole des Fonts et Chaussees was set up in 1748 to teach the background science required by the engineers. It had good teachers, and right into the nineteenth century turned out famous . scientists, industrialists and administrators, including the Montgolfier brothers,Lazarre Carnot and Gustavo Monge.

The French Revolution, had a profound effect on the place of science in French life. In spite of the execution of Lavoisier, the Revolution had great neel of its scientists, and the tragedy of Lavoisier's case was that he worked unstintingly for the Revolution as a scientist, among other things organizing the supply of gunpowder, hut under the Terror' his earlier connexions with the Ferme proved Lis downfall. Most other French scientists not only survived, but were strong supporters of the Revolution.

The Academic des Sciences was suppressed in 1793 in common with other institutions that were considered to be part of the ancien regime. In 1795 the Convention founded the Institut National to replace all academies, and finally in 1816 the Academie des Sciences was revived as part of the Institut de France, a state of affairs which still holds.

In 1791 Gustave Monge suggested the establishment of a science school to provide the men the country needed, and in 1794 founded the Ecole des Travaux Publiques which the following year was renamed the Ecole Polytechnique. With Monge as director it had a brilliant team of scientists as teachers, and its teaching was based on laboratory work and experiment. Together with the Ecole des Fonts et Chaussees and one or two similar but less important establishments founded at about the same time the Polytechnique had far more influence on the scientific life of France than the universities. The Polytechnique preserved its revolutionary traditions, long after the Restoration, and the Polytechniciens were usually mixed up in any radical disturbance in Paris.

Napoleon encouraged the sciences and played a large part in setting up scientific institutions in France. He allowed contact between French and English scientists, even when the countries were at war, and his Egyptian campaign was something of a research expedition in itself, particularly in the development of Egyptology. He reorganized the universities, but some writers maintain that he over-centralized science} which was taken from the provinces and became almost completely an affair of the capital. After the Restoration the reactionary, clerical government was not sympathetic with science, and French science was allowed to stagnate.

At the beginning of the nineteenth century, then, it is possible to see that science had developed certain national peculiarities. In England, Government gave no aid, to science or to the production of scientists and engineers. The favourable economic circumstances of the country seemed to show that no intervention was necessary, and it was left to the scientists themselves to get their education, set up their organizations, and finance their researches as best they could. Science in England was, in fact, an amateur pursuit, and the high reputation of so many of Britain's amateur scientists served to conceal the weaknesses in the situation.

In France science was cultivated actively by the Government for mainly military and administrative purposes, and through the medium of institutions outside the universities. In Germany Gottingen had already pointed to the nineteenth century, but this will become clearer in the next section. America made very little contribution to world science until the present century. Efforts at setting up scientific organizations were slow in getting under way, and as in Britain much was left to private initiative.

THE RISE OF GERMAN SCIENCE AND TECHNOLOGY

Germany began the nineteenth century as a conglomeration of semi-feudal states which did not present much of a challenge to the big powers; she finished it as a vigorously expanding, closely integrated industrial state, one of the great powers in science and industry and, as the Franco-Prussian War showed, a formidable military power.

This development was the result of a consistent policy applied over a long period, a policy in which the encouragement of science and technology formed an essential part.

Right at the beginning of the century, Wilhelm von Humboldt, the director of the Prussian Education Department, reorganized the education system, setting up the Gymnasia and Realschulen as the basis of state-controlled education. At his instigation Berlin University was founded in 1809 and this set the pattern for other universities in Germany. At Berlin even greater emphasis was placed on research than at Gottingen, and, with one or two exceptions, the Ph.D. by research thesis and oral examination was the only degree awarded. The university did not give a liberal education in the English sense, but did produce highly trained specialists, and since the sciences were well-catered for, this meant that a regular supply of trained scientists was assured.

Chemistry held a particularly high place in the sciences of the nineteenth century. The reasons are not far to seek. The Industrial Revolution in the western countries was to a large extent based on textiles and this produced a. rapidly expanding market for more and better bleaches and dyes. In fact the position is not much different today, when in spite of the enormous growth of industries based on physics since the War, chemistry employs a far greater number of scientists, and particularly in the dye and allied industries, than any other branch of science.

German chemistry became particularly important in the nineteenth century. . Justus von Liebig became assistant professor of chemistry at Giessen in 1824 and professor in 1825. There he set up, at first in a disused barracks, a chemical laboratory which became famous throughout the world. Students were trained in practical chemical research in a way which was not seen outside Germany. Other laboratories 'with a research school under a famous chemist were those at Gottingen under Wohler, and at Heidelberg under Leopold Gmelin and later Bunsen.

Similar laboratory instruction in physics did not appear till later in the century.

So began a period in which German universities became world-famous and students from all over Europe and the U.S.A. flocked to Germany to get the science teaching and training in research which their own countries did not provide.

Another aspect of Germany's determination to lead in technology was the foundation of many technical schools or colleges, many of them taking the Ecole Polytechnique as their model. There were some already in the previous century, but now the short period 1821-33, saw the foundation of the important technical schools of Berlin, Darmstadt, Munich, Nurnberg, Augsberg, Dresden, Kessel and Hanover, and in Switzerland a notable one was established in Zurich.

The technical schools evolved into a university type, and from I860 onwards were raised to Technische Hochschule status. It took another century to found the British CAT, the College of Advanced Technology. These German universities and technical colleges worked closely with industry, which soon had its own research laboratories, and laid the foundations of the efficient chemical and engineering industries which nearly won the First World War for Germany. Science in Germany had become a profession.

SCIENCE IN NINETEENTH CENTURY BRITAIN

Our present difficulties in the organization and financing of science and the provision of a sufficient number of scientists and engineers in an era of intense competition for foreign markets, have their roots in the past. The organization of science in Britain lagged far behind the achievements of our scientists. The story is of one long struggle to obtain the facilities for research in science and technology from a Government: committed to a policy of laissez-faire and from administrators brought up in the old traditions of a classical education.

By the beginning of the nineteenth century, the Royal Society was adequate neither to provide a forum for the different disciplines which had arisen as a result of the increasing specialization of science, nor to give a general direction to science. Falling away from, its original ideals, it had become more of a select London club than a scientific society. Both the English universities were in need of drastic reform, and not only from the point of view of the sciences, if they were to give the service the community needed. They were still essentially establishments for the training of the clergy.

There was a much healthier state of affairs in Scotland, probably due to the closenes of the Universities to the centres of industry in the North, and to the absence of control by the Church of England. The Royal Society of Edinburgh was flourishing, and the universities were more advanced. Chemical lectures were being given at Glasgow before the end of the eighteenth century, Joseph Black drawing large and appreciative audiences. Glasgow was the first place in these islands to set up a university laboratory for instruction in practical chemistry. It opened in 1817 under the professor of chemistry, Thomas Thomson. There, too, William Thomson (later Lord Kelvin) set up the first laboratory for teaching practical physics in 1846. It was no accident that Scottish scientists and engineers were outstanding in the nineteenth century. Without men like John Playfair, Clerk Maxwell, Lord Kelvin and David Brewster, Victorian science would have been much poorer.

The Scots were very critical of the management of science in England, but criticism was not lacking in the South. At Cambridge a number of undergraduates under the leadership of Charles Babbage and

John Herschel, dissatisfied with the antiquated teaching of mathematics, formed themselves into the Analytical Society "with the aim of agitating for the introduction of the more advanced Continental methods into the university. After leaving the university they formed the nucleus of a group actively campaigning for the improvement of British science on a wide front. Babbage wrote a very disturbing and influential book which appeared in 1830 with the title Reflections on the Decline of Science in England. He saw the root of the trouble in the tradition of amateurism in science. The individual sciences had now reached the point at which they had become full-time occupations. France and Germany, particularly the latter, had recognised this, but in Britain there was absolutely no provision for science as a profession. Babbage criticised the English universities and the Royal Society, calling for reforms in both, and advocated Government intervention.

THE DEVELOPMENT OF SCIENTIFIC SOCIETIES AND INSTITUTIONS

A promising development in London had been the foundation of the Royal Institution in 1799, sponsored in particular by Count Rumford. It was to be "a Public Institution for diffusing the knowledge and facilitating the general introduction of useful mechanical inventions and improvements, and for teaching by courses of philosophical lectures and experiments the application of science to the common purposes of life". Rumford, who was in the service of the Elector of Bavaria, returned to the Continent in 1802 and the character of the Institution was altered by the Managers: the interest in inventions was allowed to lapse and the lectures, at first intended for the education of artisans, were eventually given to quite a different clientele. They became a preserve of the upper classes, society events.

Under Humphry Davy and Michael Faraday, a fine research institution was built up, which has earned a lasting place in British science; but although it has provided opportunities for some of our best-known scientists, from Davy and Faraday to the Braggs to work full-time at their researches it has never been a large establishment and barely touched the fringe of the problem of professionalizing science.

The reform of the Royal Society took time.. At Sir Joseph Banks' death in 1820, William Wollaston, a remarkable experimental science, became President, to be followed after only a few months by Sir Humphrey Davy. For the first time the scientists managed to obtain a majority on the Council, and matters slowly improved. It was not until 1847, however, that it became possible to introduce a regulation limiting the number of new Fellows elected each year. From that time on it was possible to ensure that almost all the new Fellows were practising scientists, and as the number of non-scientists dwindled by death and resignation so the Royal Society became a real society of scientists.

Only the cream of the country's scientists were accepted, with the result that the Fellowship is now the greatest scientific honour which this country can bestow. The Society's influence has increased, and while it has carefully maintained its autonomy, it has a large influence with the Government on scientific matters. It does not hold any direct control over the country's scientific life, but nevertheless has a considerable indirect influence through the allocation of funds, and through its representation on many important committees. It is very much part of the scientific Establishment.

One result of the criticism of the Royal Society wa,s the foundation of the British Association. Ba,bbage, John Phillips (Secretary of the Yorkshire Philosophical Society), David Brewster, and some others, impatient with the slow progress in the Royal Society, decided to try to set up a different kind of society. They took as a model a German society founded by the 'Naturphilosoph', Lorenz Oken at Leipzig in 1822, under the name of the Deutsche Naturforscher Versammlung. Its meetings were to provide a forum where scientists of different disciplines, together with interested members of the lay public could review the advances in the different departments. Another of its interests was the encouragement of science in the provinces, and with that in view its chief activity was the Annual Meeting held successively in the main provincial towns, the capital being purposely avoided. The first meeting of the British Association was held at York in 1631, and then at Birmingham, Liverpool, Manchester, Newcastle and Southampton. Throughout the Victorian era, the British association meeting was the main scientific event of the year.

In addition to the organization of the meetings, it took an active part in the movement for science in the universities, and in ether matters affecting the conduct of science. It has done much useful work in spheres where co-operation between scientists was necessary, sometimes on an international scale. A major example of this was the standardization of electrical units.

At the foundation of the Royal Society, and for several decades afterwards, it was possible for a Fellow to be proficient in several branches of science, but specialization had now reached the stage where this was no longer possible. Scientists felt the need to meet in smaller, more specialized, societies, and also to draw in workers outside the Royal Society.

The first important specialist society was the Linnaean Society for the study of natural history, founded in 1778, with the approval of Sir Joseph Banks, to acquire the library and collections of Carl Linnaeus, the great Swedish naturalist. later Banks was not so kindly disposed towards the formation of new societies, seeing them as breakaway organizations (which they sometimes were) in opposition to the Royal Society and drawing off its active membership.

However, he could not prevent the formation of the Geological Society (1807), the Astronomical Society (about 1820) and the Microscopical Society (1819). He was able to prevent the formation of a chemical society in 1806, and it was not till 1841 that the Chemical Society came into being. By I836 a dozen new scientific organizations, including the British Associrtion, were recorded. Physics was a slow starter, the Physical Society not being formed till 1874.. Such societies are essentially paper-reading and publishing organizations and as such have continued to play an important part in scientific communication in all the major countries. Most of them have their own Journals, Proceedings or Transactions for the publication of research papers, and so rapidly did the journals proliferate that it was soon impossible for a scientist to read all the articles in his own field. The abstract journal, attempting to summarize all the papers in a given science became a necessity, first of all in chemistry where the Pharmaceutisches Centralblatt began in 1830 and still continues as the Chemisches Zentralblatt. This proliferation of sciences, societies, and journals proceeded at an ever-increasing pace all through the century and is still with us to such a degree that the 'crisis of communication' is one of the most talked-of topics in scientific circles today.

As science and technology became recognized professions, it was only natural that the practitioners should start to think about their material interests. Something other than a paper-reading society was required, and so a new type of organization concerned with professional status and educational standards arose. The engineers were the first to organize, the Institution of Civil Engineers being founded in 1818. Others followed during the century, including the loyal Institution of British Architects (1834)? the Institution of Mechanical Engineers (1847), the Institution of Naval Architects (1860), the Iron and Steel Institute (1869), the Institution of Electrical Engineers (1871), and the Institute of Chemistry(188l)

SCIENCE IN THE UNIVERSITIES

The struggle to reform the English universities, to secure adequate teaching of science and to set up research schools on the German model, was long and bitter. It is sufficient to state that it was not until the latter half of the nineteenth century that science courses were introduced at Oxford and Cambridge, and not till the end of the century that the research school became recognised as an essential part of the university's function.

London's University College set up in 1827 was based on German and Scottish models; it offered a syllabus including mathematics and theoretical physics (already taught at Oxford and Cambridge), but also chemistry, experimental physics, botany, economics, and geography.

It also gave professional education in law, medicine, and engineering. Not having a charter as a university, it could not award degrees, but gave certificates of proficiency.

London University was incorporated by Charter in 1836 as an examining body granting degrees and with powers affiliating approved colleges. By 1851 29 general colleges and nearly 60 medical schools were affiliated.

Other new universities generally began as local colleges, and then, as civic pride was touched, agitation would develop to endow them with university status. They were all greatly influenced by London in one way or another, and University College provided many of their professors. In all of them science was taught from the start, although post-graduate research work on the German model was not a feature. Nevertheless the increasing number of science professorships and lectureships provided the beginnings of a body of professional scientists, and the majority 01 the well,'-known British scientists of the Victorian era, were in fact in university faculties.

Durham (1837) was the first university to follow London; though essentially for training Anglican clergy it was thought expedient right from the start to provide engineering classes. Owens College, Manchester, 1851, had the best school of chemistry in England under H.E. Roscoe, and in 1874 was able to engage a second professor of chemistry, Carl Schorlemmer, who became a firm friend of Marx and Engels, and something of a scientific adviser to them.

Alongside the struggle for the reform of the universities Trent a struggle for a more definitely technological education. Reports from Germany had filled a number of more far-sighited people with fore-bodings about the ability of England to meet the challenge of German industrialization unless measures were quickly taken to ensure an adequate supply of trained technologists, and in this they received the influential backing of the Prince Consort.

He, and Sir James Clark, the Queen's physician, were the driving forces behind the foundation of the Royal College of Chemistry in Hanover Square. Such was the paucity of chemical talent that no suitable professor could be found in England, and recourse was had to Germany, from where A.W. von Hofmann was brought in on the advice of Liebig. Hofmann set up a very successful school, which at once produced a brilliant group of chemists which included de la Rue, Parkin, Frankland, Nicholson, and Odling. Its teaching was based firmly on laboratory work and research. It awarded no degrees, but a Testimonial of Proficiency, to obtain which they candidate must have completed original research worthy of publication.

The Prince had become President of the Society of Arts in 1843, and under him it re-awoke after a period of somnolence. It put on several exhibitions which were so successful that the Society undertook the organization of the Great Exhibition of 1851, which Marx described in the year before its opening as the bourgeoisie's rejoinder to the political revolutions on the Continent. In connexion with the Exhibition a series of lectures was staged by the Society, in which Lyon Playfair alarmed his audience with a comparison of German industrial enterprise and English apathy, and called for the foundation of an Industrial University.

Parliament was prodded into voting £150,000 to be added to the £186,000 profit from the Exhibition for the purchase of three estates in South Kensington as a site for a concentration of technical institutions. Six years later a Department of Science and Art under the control of the Education Department of the Privy Council was sat up there. So began the development of that complex of colleges and museums which has given South Kensington its own very special place in the world of learning. The culmination of the drive towards the technical university was the formation of Imperial College of Science and Technology by Charter in 1907 from an amalgamation of the Royal School of Pines (which was descended from the Royal College of Chemistry), the Royal School of Science and the City and Guilds Central Technical College.

The Museums have played an essential part in the scientific life of the country. The first was the Museum of Practical Geology, opened in 1851, and the Science Museum followed in 1857, being based on many objects that had been acquired for preservation from the Great Exhibition. In 1883 the Natural Science collection of the British Museum (itself founded in 1753) was moved to South Kensington to for;: the Natural History Museum, or more correctly the British Museum (Natural History).

In the provinces, the Newcastle College of Physical Science opened in 1871, and the Yorkshire College of Science, Leeds, in 1874. A College of Science was founded in Birmingham, while in Bristol a proposed College of Science for the West of England was given a wider scope and was incorporated as University College, Bristol, in 1876.

INDUSTRIAL RESEARCH

By the end of the century there was still no government organ with any responsibility for science and technology, and industrial research was almost non-existent. What little there was was confined to the chemical industry.

in 1856 W.H. Perkin, a pupil of Hofmann's at the loyal College of Chemistry discovered the synthesis of mauve, the first of the aniline dyes. The story has often been told of how Perkin, his father, and his brother began the commercial production of the new dye and how, in 1874, he sold up the business so as to return to research work. One of the reasons for this move was his difficulty in obtaining suitable research workers to follow up his discovery. Other firms, particularly those of Ivan Levinstein and Read Holliday took up the manufacture of the aniline dyes, these two firms becoming the largest manufacturers of synthetic dues in England by the end of the century. But the Carman chemical industry, with its scores of graduate chemists in research and many more in production, development and sales, had seized on Perkin's discovery and so outstripped this country that about 90% of the world production of aniline dyes was in its hands.

Now, a factory making dyes can be rapidly switched to making TNT and similar explosives, and a chemist versed in one branch of organic chemistry can readily turn his hand to another. Moreover, the German optical and electrical industries were more advanced than the British. So when war broke out in l914, in a matter of weeks the superiority of German industry was brought home to the British Government in the most unpleasant fashion. The situation was retrieved by a series of emergency measure deriving mainly from a committee under Lord Haldane. The Royal Society and other interested bodies took the opportunity in 1915 to urge the provision of government assistance for scientific research for industrial purposes. The result was the formation of the Department of Scientific and Industrial Research, constituted as a Committee of the Privy Council.

To take the story further would involve us in a discussion of science policy in the present-day world, which is not my purpose. However I hope I have been able to show that the situation we have to face today is a legacy from the past. Too many remnants of the 'gentleman amateur' tradition exist today: the government is reluctant to deal with the organisation of science as a national matter, and one to be taken out of the hands of private enterprise; science graduates form a small minority among industrial executives and the top civil servants; scientists are poorly remunerated in comparison with business executives and pop-singers - the pleasure of scientific work is supposed to be an adequate recompense in itself; and the scientists themselves are slow to achieve the effective Trade Union organization needed to improve their situation.

This country has produced many of the world's greatest scientists and enjoys a tradition of scientific discovery second to none. But the achievement of the British 'string and sealing-wax' school has always been in spite of, and not because of the inadequate recognition of science by successive governments.

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