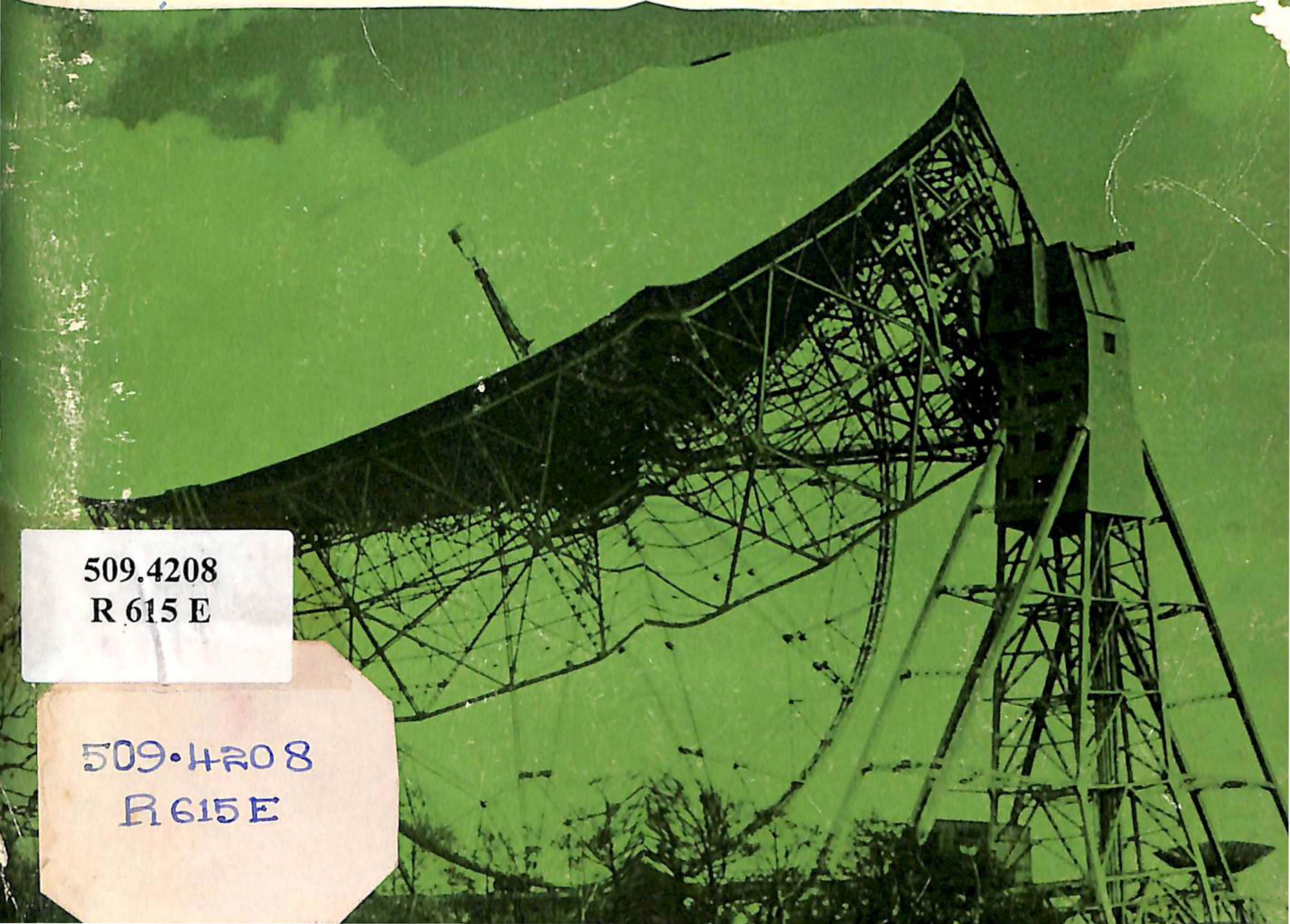
SOURCES OF HISTORY

The Emergence of a Scientific Society in England 1800-1965

Sol. 243

G. W. RODERICK

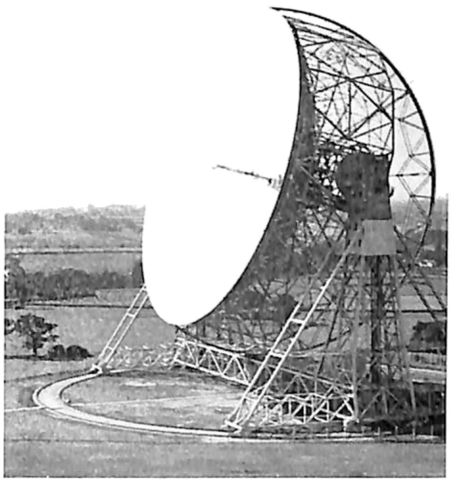


Other titles in the series include

Christopher Thorne: *Chartism*
E. K. Milliken: *Archery in the Middle Ages*
A. J. Bagley and J. J. Bagley: *The English Poor Law*
J. W. Derry: *Parliamentary Reform*
Owen Ashmore: *Development of Power*
M. W. Flinn: *Public Health Reform in Britain*
E. K. Milliken: *Chivalry in the Middle Ages*
A. J. Bagley and J. J. Bagley: *State Education in England*
John Gibson: *The Development of Surgery*

THE EMERGENCE OF A SCIENTIFIC SOCIETY

G. W. Roderick, Ph.D., B.Sc., A.Inst.P.



MACMILLAN
London · Melbourne · Toronto

ST MARTIN'S PRESS
New York
1967

MACMILLAN AND COMPANY LIMITED
Little Essex Street London WC2
Also Bombay Calcutta Madras Melbourne

THE MACMILLAN COMPANY OF CANADA LIMITED
70 Bond Street Toronto 2

ST MARTIN'S PRESS INC
175 Fifth Avenue New York NY 10010

PRINTED IN GREAT BRITAIN BY RICHARD CLAY (THE CHAUCER PRESS), LTD., BUNGAY, SUFFOLK

Contents

	Lists of Illustrations and Graphs	6
	Acknowledgements	6
	Preface	7
1	1800–30 Science in Decline	9
2	1830–70 Resurgence	19
3	1870–1914 Consolidation	39
4	1914–39 Stagnation	60
5	The War and After: A New Age for Science	69
	Appendix I	92
	Appendix II	104
	Further Reading List	109
	Reports	110
	Index	111

List of Illustrations

Jodrell Bank—the 250-foot reflector 3
Warrington Academy 12
Charles Babbage 14
An evening at the Royal Institution 17
Old Owens College 22
Berlin University 23
The Royal College of Chemistry 24
August Wilhelm von Hofmann 25
The Museum of Economic Geology 26
Thomas Henry Huxley 36
Sir Lyon Playfair 36
Sidney Gilchrist Thomas 40
Sir William Siemens 40
Sir Henry Bessemer 40
The Bessemer Works 41
Ferdinand Hurter 45
Smoke over Leblanc Widnes 46
Hurter's laboratory 47
James Clerk Maxwell 52
Lord Rayleigh 52
Finsbury Technical College 54
Charlottenberg Technical Institute 55
Thomson and Rutherford 64
Manchester University 76
The Mechanics Institute, Manchester 77
A Linear Accelerator 90

List of Graphs

1. Production of pig-iron and ferrous alloys in Great Britain and Germany, 1880–1965 42
2. Production of steel ingots and castings in Great Britain and Germany, 1880–1965 42
3. Production of sulphuric acid in Great Britain and Germany, 1870–1965 43
4. British and German exports of synthetic dye-stuffs, 1880–1965 43
5. Growth of the University population in: (*a*) England and Wales, and (*b*) Germany, 1875–1965 44
6. Students of science and technology at University: (*a*) England and Wales, and (*b*) Germany, 1870–1965 44
7. Students of science and technology in England and Wales, 1875–1965 73
8. Honours graduates in science and technology in England and Wales, 1875–1965 73
9. The rise of the professional in science and technology: membership of leading professional institutions, 1880–1965 84

Acknowledgements

The publishers wish to thank the following for their help in connection with the illustrations on the pages quoted:

Cambridge University Press: 64. The Central Office of Information: 3. *The Illustrated London News:* 26. Imperial Chemical Industries: 45, 46 and 47. Landesbildstelle, Berlin: 55. Manchester University: 76, 77. The Mansell Collection: 14, 52 (left). Radio Times Hulton Picture Library: 23, 25, 36 (both), 40 (all), 41 and 52 (right). The Royal Institution: 17. The United Kingdom Atomic Energy Authority: 90.

PREFACE

A PARADOX of British history in the last hundred years has been the juxtaposition of a remarkable growth in scientific institutions alongside a decline in the status of British technology. The pre-eminent status of this technology in the early part of the Industrial Revolution owed little to organised scientific research and when, after 1870, technological change became increasingly associated with pure and applied science, the absence of institutions devoted in part to scientific research held back industrial advance. Towards the end of the nineteenth and in the early part of the twentieth century the extent of scientific activity and research increased out of all proportion to previous precedent, but this development in England did not compare with that of her competitors and its slow rate of expansion continued to affect industrial progress.

The scientific advance of a nation is inevitably a dependent variable of its educational system. 'What you would put into the State, you must first put into the school', von Humboldt declared when he was put in charge of the reorganisation of education in Prussia following her defeat by Napoleon. Later, a German professor remarked:

> The forces which the nation require were nourished in the schools; in them the weapons were forged with which the battle for progress was fought.[1]

The Germans in building a scientific and industrial society began with their schools. In England, on the other hand, attempts to create higher institutions of scientific study foundered, for Primary and Secondary education had been neglected, and an integrated, cohesive educational programme did not evolve until the end of the century.

The distinctive features of the history of English[2] education are well known but perhaps what is less well known is the extent to which its slow growth conditioned the pace of scientific advance.

> We are not by nature revolutionary; confronted with new ideas, we handle them with care. In this educational revolution, we have a few whole-hoggers, enthusiasts quick to scrap the old and exploit the new with maximum intensity. But the great majority made their changes cautiously, seeking a synthesis of old and new.[3]
>
> We are reluctant to believe, even when struck by a new idea, that everything we have done in the past has been on wrong lines, and we hesitate to scrap well-worn modes of educational practice. Rather it is our genius to allow the new ideas to permeate the old, to keep what has been found of value in the past, adding to it what seems of value in the new.[4]

[1] *Education in the Nineteenth Century*, ed. R. D. Roberts (C.U.P., 1901), p. 246.

[2] Special factors play their part in determining educational attitudes in Scotland and Wales during the nineteenth century. Moreover Scotland had an educational system which was distinct from that of England. Hence it is necessary when referring to education to speak of England in the nineteenth century and not Britain.

[3] W. O. Lester-Smith, *Education* (Penguin Books, 1957), p. 36.

[4] J. S. Ross, *Groundwork of Educational Theory* (Harrap, 1952), pp. 34–35.

Preface

This genius for gradual adaptation, claimed as a virtue in English education, for it safeguarded certain cherished ideas, could be criticised as being the consequence of an inertia to change. In scientific education and in industry the effects of such an attitude were little short of disastrous. This, together with the failure to plan and organise, were to some extent responsible for the loss of English industrial prestige by the end of the nineteenth century. The legacies of these attitudes remain and have meant that Britain's position relative to others in the technological revolution has gradually worsened.

Nevertheless, the pace of scientific advance has, even in Britain, been rapid, and it is no more than a truism to say that we live in a scientific age. In his introduction to *Crisis in the Humanities*, J. H. Plumb says:

> The humanities are at the crossroads, at a crisis in their existence: they must either change the image that they present, adapt themselves to the needs of a society dominated by science and technology, or retreat into social triviality.[1]

His claim that

> society is dominated by science and technology

is one that is frequently heard and it is at least arguable that this is so.

In this country scientists and technologists might be excused for doubting this thesis for the time and space devoted to science by television, magazines and the 'respectable' Sunday newspapers compares most unfavourably with that given to the 'arts' and social sciences. As cultural or intellectual talking-points science and technology are non-starters. The scientist might well feel that he was a member of an esoteric coterie whose knowledge only entitles him to a position on the fringes of cultural society but whose activities are increasingly recognised as being of vital importance to the future well-being of society. It is in this respect that the present scientific society differs significantly from that of the seventeenth century. In those days the concepts and theories of science permeated the general climate of thought. It was an age when to be cultured implied that one had to be *au fait* with the frontiers of scientific knowledge.

The essential feature of the present society is that respect for science is firmly rooted in what science can do and not for any subtler values that are an integral part of scientific activity. This new-found respect for science was born more out of fear of being left behind in the race for national prosperity and material progress rather than from any positive admiration for science itself. Bacon's plea for men to believe in their power, through science, to advance their material conditions of life and to gather 'the fruit' of scientific activity has come home to roost, so much so that it is even claimed that this scientific age is one

> whose major social end is the development and application of scientific technology.[2]

G. W. R.

[1] *Crisis in the Humanities*, ed. J. H. Plumb (Penguin Books, 1964), p. 8.
[2] J. Macmurray, *Religion, Art and Science* (Liverpool U.P., 1961), p. 22.

Chapter One

1800–30 SCIENCE IN DECLINE

DURING the sixteenth and seventeenth centuries Europe witnessed a radical transformation in thought and outlook. Following the works of Copernicus, Kepler, Galileo and Newton the dogmatic, *a priori* approach to natural phenomena was replaced by the empirical, experimental method of science. No country was more greatly influenced by this scientific revolution than England. Partly owing to the advocacy of the experimental philosophy by no less influential a person than Sir Francis Bacon, Lord Chancellor of England, the scientific revolution had been readily embraced by Elizabethan England. The seventeenth century was characterised by unprecedented scientific ferment which culminated in the work of Newton and the formation of the Royal Society in 1660. By 1700 England was a leading scientific nation.

The Eighteenth-century Inheritance

The scientific achievements of individual Englishmen in the eighteenth century were substantial but it is nevertheless true that by 1800 organised science had made little progress since the days of Newton. Further, the factors which caused this stagnation continued to operate well into the nineteenth century. The consequences were seen later in the century as England's competitors, Germany in particular, established a technical and industrial supremacy which became increasingly noticeable as the century drew to a close.

At the beginning of the nineteenth century neither the institutions nor the corporate activity so necessary to national scientific advancement existed in England. When these were finally to emerge the absence of efficient Primary and Secondary School systems was belatedly discovered. Such systems were prerequisites for the creation of a corps of trained scientists and technologists. Their lack was a conspicuous cause of England's failure, for by 1800 France and Germany had established the foundations of a national system of education.

In France, state legislation in the first decade of the nineteenth century created a national, centrally controlled system of education in which a complete unification of administration, curricula and methods of instruction was achieved. The curriculum included mathematics and science. An important innovation was the establishment in 1793 of the École Polytechnique. Designed for scientists and engineers, the syllabus included mathematics, physics, chemistry and civil engineering. It was

> the first attempt at a college of applied science in the world and among its professors and students were numbered practically all the leading French savants of the early nineteenth century — Lagrange, Gay-Lussac, Fourier, Carnot, Fresnel and Ampère.[1]

[1] D. S. L. Cardwell, *The Organisation of Science in England* (Heinemann, 1957), pp. 20–21.

The Emergence of a Scientific Society

The exigencies of the Napoleonic Wars precipitated state aid in industry. Industrial invention was stimulated and encouraged by the State. A general climate of opinion favourable to science was engendered and as a result France became 'the mother of organised scientific research'. In addition:

> She was the first to encourage science on a large scale and to realise that scientific work must not only be organised but also summarised and propagated.[1]

In 1762, Pestalozzi and others founded the Helvetic Society for the

> furthering of universal education, scientific and undenominational.

Influenced by Pestalozzi's ideas, many German states had established by 1800 a system of popular schools with compulsory attendance. Among the German higher educational circles the dominating ideal was that of *wissenschaft*: the critical, objective and empirical approach to all knowledge. Thus the right attitude towards science was implicit in the general philosophy of higher education. The emphasis on universal education and the empirical approach to knowledge created the right conditions for scientific advance.

> The scientific spirit . . . found in Germany a uniquely appropriate intellectual climate. The social prerequisites for the survival of science are finance, leisure, and freedom to pursue research, coupled with opportunities for scholars to associate together and to transmit ideas and techniques to their successors. All these were already present in Germany in the early nineteenth century.[2]

Scotland, in the eighteenth century, had developed a distinctive educational system of her own. At the age of fifteen students entered university for four years of a general education which included philosophy, classics and science. After this general education students undertook their specialist training. The universities were conceived as appendages to the school system—higher schools to the rest of the educational system rather than separate, specialised seats of learning. Further, the Scottish universities were more democratic, being intimately connected with the life of their districts, than the English universities of Oxford and Cambridge. Thomas Huxley was later to refer, in an address at Aberdeen University, to the contrast between Scottish universities and Oxford and Cambridge.

> Your little bursaries of £10 and £20 a year enable any boy who has shown ability in the course of his education in those remarkable primary schools, which have made Scotland the power she is, to obtain the highest culture the country can give him. . . . When I think of the host of pleasant, monied, well-bred young gentlemen, who do a little learning and much boating by Cam and Isis . . . I turn from this picture to the vision of many a frugal Scotch boy wending his way to this University, with a bag of oatmeal, and ten pounds in his pocket . . . determined to wring knowledge from the hard hands of penury I cannot but think that the spirit of reform

[1] Sir Eric Ashby, *Technology and the Academics* (Macmillan, 1958), p. 19.
[2] Ashby, op. cit., pp. 20–21.

has much to do on the other side of the barrier.[1]

In Scotland all eminent men of science were university professors, whereas in England men of science were, in the main, found outside the university walls. England was to owe much to the products of the Scottish universities in the fields of science and medicine during the nineteenth century.

Professor Morgan, in an address entitled *Medical Education at the Universities 1875*, pointed out that of 3,241 graduates in medicine practising in England in 1875 no less than 2,829 graduated at the Scottish universities (i.e. 87%). Those graduating at Oxford, Cambridge and Durham numbered 230 (i.e. 7%).[2]

Edward Turner, first Professor of Chemistry at University College, London, was trained at Edinburgh. So was his successor, Thomas Graham (father of colloid chemistry).

Among other distinguished alumni of the Scottish universities (who emigrated south) were:

- David Brewster — experimental work on polarised light
- Clerk Maxwell — electromagnetic wave theory
- Lord Kelvin — physicist
- W. J. Rankine — engineer, founder of thermodynamics
- John Percy — lecturer in metallurgy at Royal School of Mines and pioneer of metallurgy as a scientific subject
- Charles Bell — discoverer of the nervous system.

Hale Bellot in his *History of University College, London, 1826–1926*, says that Edinburgh University was the 'single most important intellectual influence in the creation of University College'. It imitated Edinburgh in its lecture system, range of subjects and absence of religious tests.

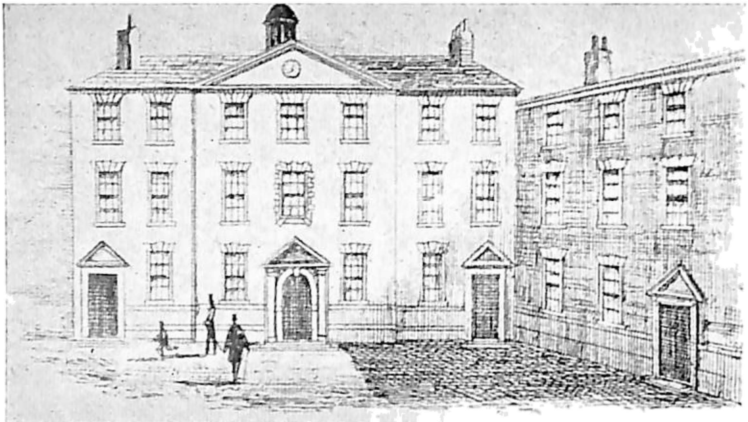
While science flourished in the higher institutions of the Continent and Scotland, Oxford and Cambridge remained scientifically moribund. The Test Acts excluded all but Anglicans from graduating and opportunity of entry was restricted in the main to the nobility and opulent gentry. The intellectual life of England was not to be found inside the walls of Oxford and Cambridge but in the Dissenting Academies and in the various societies beginning to appear throughout the country.

Dissenters, having been ejected from Oxford and Cambridge in 1662, started their own higher institutions of learning. By the end of the eighteenth century these Dissenting Academies had reached their final phase. No religious tests were imposed at these Academies and in no sense were they narrowly sectarian institutions; Anglicans frequently sent their sons to them in preference to Oxford and Cambridge. Science was taught as well as theology, law and medicine. New subjects were introduced, new educational methods applied, and scientific apparatus extensively used.

Notable among the Academies was Warrington Academy, established in 1757. It achieved, before its demise in 1786, a far greater international reputation than Oxford

[1] T. H. Huxley, *Universities: Actual and Ideal.* Inaugural Address as Lord Rector of Aberdeen University, 1874. Reprinted in *Science and Culture* (Macmillan, 1881), pp. 24 ff.

[2] Quoted in Joseph Thompson, *The Owens College* (J. E. Cornish, 1886), p. 518.



Warrington Academy

The most celebrated of the Academies set up by the Dissenters. Founded in 1757, it became known as the 'Athens of the North'.

and Cambridge during the same period. It was to Warrington that Joseph Priestley came as Tutor in Languages and Belles-Lettres, only to become the outstanding English chemist of the eighteenth century. Priestley advocated 'observation and experience' as the only safe guides to learning. The influence of Warrington was far-reaching; former students were a seminal influence in the founding of the Manchester Literary and Philosophical Society and of Owens College, Manchester, which was to become Manchester University.

Towards the end of the eighteenth century groups of individuals of all denominations and catholicity of backgrounds were uniting to create new institutions and organisations for the furtherance of science and education. At Manchester the Literary and Philosophical Society (founded 1781) was instrumental in founding two new colleges. The College of Arts and Sciences (1783) was established for liberal instruction in arts, sciences, law and commerce. Three years later the Manchester Academy was founded primarily for the education of Protestant dissenting ministers, but it also accepted laymen. John Dalton, who was at the time at Kendal Dissenting Academy, was invited to become a tutor at the Manchester Academy in mathematics and natural philosophy. It was here that he was given a basement room by the Manchester Literary and Philosophical Society in which the germinal experiments of his atomic theory were carried out. Liverpool, Leeds and Newcastle, too, had their Literary and Philosophical Societies.

At Birmingham there was the Lunar Society, a loose association of intellectuals, predominantly scientists and technologists, which included among its members Erasmus Darwin, James Watt, Matthew Boulton, Joseph Priestley and Josiah Wedgwood.

Such societies played an active part in supporting scientific activity and their members included most of the leading scientific savants. Nevertheless, they were no substitutes for large-scale organised science, but in the absence of state institutions for scientific research they became primary organisms of scientific research.

In addition, other societies with more limited objectives were soon to make their appearance. These were formed among those interested in a particular branch of science. Such were the Astronomical, Geological and Zoological Societies.

Charles Babbage: Reflections on the Decline of Science

Although Babbage's controversial work appeared in 1830 it referred to a state of affairs which had existed for over half a century. Publication of this work was precipitated by administrative malpractices in the Royal Society, ruled at that time by a coterie of dilettantes. Babbage gave no real indication of the state of science generally, but his book helped to air the grievances of those who were concerned at the absence of scientific institutions.

Babbage's main contention was that in England the pursuit of science did not constitute a distinct profession. Trained for the Law, the Church, and medicine, English scientists, with a few exceptions, were largely amateurs devoting the greater part of their time to their chosen professions. France and Germany on the other hand

> had recognised the professional status of science. This had provided science with a stimulus and it was advancing by leaps and bounds while its amateur status in England held it back. The Royal Society had become a club whose Council was dominated by amateurs and always elected an amateur President.[1]

Babbage's second major criticism was concerned with the relationship between government and science. The Government in his view had not 'encouraged the authors of useful discoveries'. He cited the honouring of leading French and German scientists by their respective governments. Napoleon had even awarded prizes to leading English scientists. Babbage calculated that the six leading French scientists earned, on average, £1,200 a year. By comparison the remuneration of those English scientists who were able to obtain posts was a mere pittance.

> In England, those who have hitherto pursued science have in general no reasonable grounds of complaint; they knew, or should have known, that there was no demand for it, that it led to little honour, and to less profit.[2]

To overcome this Babbage demanded institutions for the support of science and for active interference by the Government, despite what he perceived to be an obvious difficulty — the scientific ignorance of the Government 'class'.

> Supposing science were thought of some importance by an administration it would be difficult in the present state of things to do much in its favour because the higher

[1] L. Pierce Williams, 'The Royal Society and the Founding of the British Association', in *Notes & Records of the Royal Society* (1962–3).

[2] Charles Babbage, *Reflections on the Decline of Science* (B. Fellowes, 1820), p. 24.

Charles Babbage (1792–1871)

The Cambridge mathematician who invented the principle of the automatic computer. He was instrumental in founding the British Association and other scientific societies.

> classes in general have no profound knowledge of science.[1]

In advocating direct government participation Babbage was far in advance of the generally held views of the time in England.

Babbage reserved his most caustic criticisms for scientific societies, at that time thirteen in number. Such were the Geological Society of London (1807), The Zoological Society of London (1826) and the Royal Astronomical Society. Election to membership did not necessarily involve any serious interest in science, and was entered into more from a desire for a status symbol than from a genuine concern for science.

> . . . those who are ambitious for scientific distinction may, according to their fancy, render their name a kind of comet, carrying with it a tail of upwards of 40 letters, at the average cost of £10. 9. 9¼ per letter . . .[2]

As to the Royal Society, very few of its members ever published any scientific work and the Society was

> managed by a party or coterie. The object of this has been to maintain itself in power and to divide, as far as it could, all the good things amongst its members.[3]

Babbage called for a reform that

> shall rescue the Royal Society from contempt in our own country, from ridicule in others.[4]

Babbage's book contained an appendix in which an unnamed foreign critic wrote in defence of English science.

The critic argued that the two major mathematical works of the time were written by Frenchmen rather than by Englishmen not because of

> any deficiency of genius in the English but because of the extreme specialisation of French science.

In England on the other hand

> great minds applied themselves to many different branches of science.

The critic favoured the English approach. Babbage in favouring specialisation was again in advance of the prevailing view in

[1] Babbage, op. cit., p. 24. [2] Ibid., pp. 43–44.
[3] Ibid., p. 45. [4] Ibid.

England. Support for Babbage's central thesis that science lacked recognition and was poorly organised came from other scientists. Sir Humphry Davy shortly before his death considered writing a work along the same lines as that of Babbage. England, said John Herschel, had fallen out of the race in mathematics and chemistry and whole fields of continental discoveries remained unknown.

Paradoxically, in 1831, the year following publication of Babbage's work, Faraday published his *First Series of Experimental Researches in Electricity*. These described the experiments underlying the discovery of electromagnetic induction which led to such practical consequences as the transformer and dynamo. Indeed, during the previous fifty years England had enjoyed an enviable reputation in the scientific world. This had been earned by the contributions of a few brilliant individuals — Priestley, Cavendish, Davy and Young — around none of whom had developed a 'school' or centre of research:

> England can show individual men who hold their own against the world . . . For the want of organisations of research and teaching, these ideas of English thinkers have frequently lain dormant or been elaborated by foreign talent; this want of a recognised system, and of a standard course of study, has forced original minds into a closer communion with nature and with life, whence they have frequently returned to the laboratory with quite novel revelations.[1]

The same was true in technology, in which the discoveries of Nasmyth, Newcomen, Arkwright and Watt contributed much to the Industrial Revolution.

> Individual as opposed to corporate effort was rewarded with a succession of brilliant discoveries which have revolutionised practical life or opened out new views into the hidden recesses of nature.[2]

Oxford and Cambridge

Towards the end of the first decade of the nineteenth century the *Edinburgh Review* began a sustained campaign of criticism directed at Oxford and Cambridge. In 1810 it published a virulent attack on the concept of 'scholar' as envisaged by Oxford, Cambridge and the Public Schools.

> A learned man! A scholar! A man of erudition! Upon whom are these epithets bestowed? . . . Are they given to men who know the properties of bodies and their action upon each other. No! This is not learning. The epithet of scholar is reserved for him who writes on the Aeolic reduplication, and is familiar with Sylburgius's method of arranging defectives in ω . . . His object is not to reason, to imagine, to invent but to conjugate, decline and derive . . . Would he ever dream that such men as Lavoisier were equal in dignity of understanding to, or of the same utility as Bentley and Heyne. The feeling excited would be a good deal like that expressed by Dr. George about the praises of the King of Prussia, who entertained considerable doubts whether the King, with all his victories, knew how to conjugate a Greek verb in μι.[3]

[1] J. T. Merz, *History of European Thought*, vol. i (Blackwood, 1896), p. 300.
[2] Ibid.
[3] Sydney Smith in the *Edinburgh Review*, vol. xv (1810), pp. 46–47.

The Emergence of a Scientific Society

At Oxford the subjects of the B.A. degree course were ancient history, Latin, Greek, poetry, philosophy, logic and mathematics. This was followed by a period of study — related to a chosen profession — in theology, or law, or medicine. Oxford, in 1800, had no chemistry, and while Cambridge included chemistry in its curriculum neither Oxford nor Cambridge had laboratories.

Oxford, Cambridge and the Public Schools were dominated by the concept of a 'liberal education' – an education designed to develop character as well as mind.

> The term 'liberal education' has acquired a peculiar significance in the history of English culture and thought. Whereas science is the product of French thought and Wissenschaft of German . . . In discussions on the work of high schools and universities the Germans always talk of Wissenschaft whereas the English talk of 'liberal education'.[1]

These institutions were in no position to further the cause of science. Designed for the training of the ruling class in a feudal society they were 'weighed down by the dead hand of tradition' and were a hindrance to the advancement of science, for they embraced an idealogy antagonistic to science.

The Royal Institution

The only institution of major importance to science in existence during the first quarter of the century was the Royal Institution of London. Founded in 1799 by Benjamin Thompson (Count Rumford) and others, its object was to

> diffuse the knowledge and facilitate 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.[2]

Thompson was a member of the Society for Bettering the Condition and Increasing the Comforts of the Poor and he had the support of the Society in founding the Institution. He further proposed that the Royal Institution ought to

> diffuse the knowledge of all new useful improvements in whatever quarter of the world they may originate and to teach the application of scientific discoveries to the improvement of arts and manufactures in the country . . . to the increase of domestic comfort and convenience.[3]

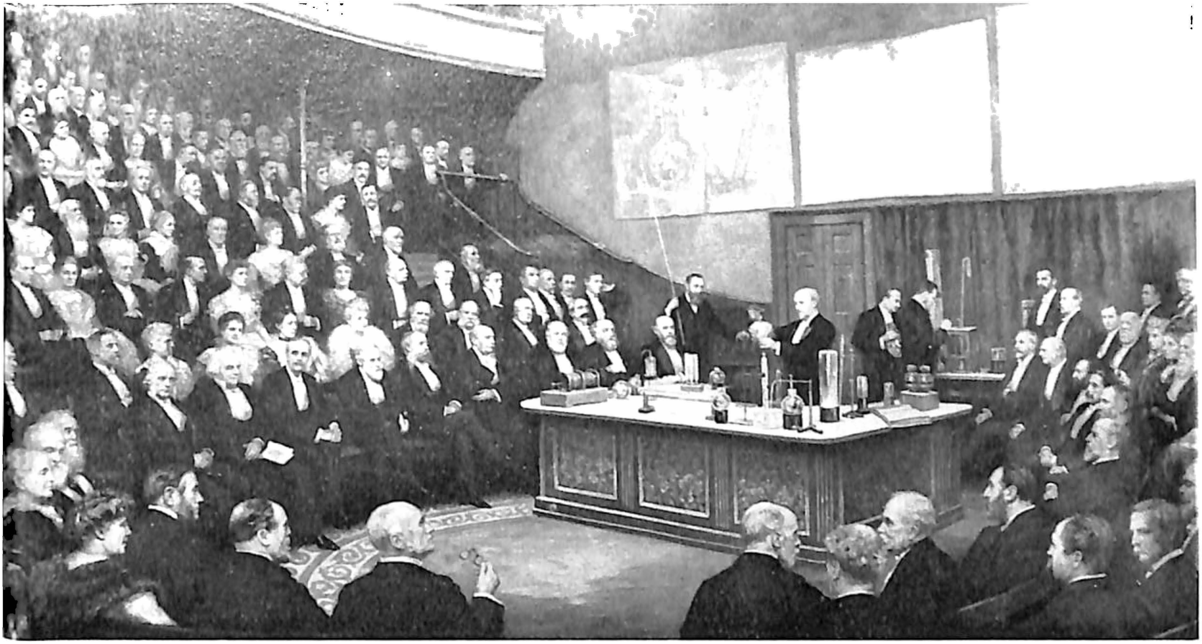
To these ends a model room, for the exhibition of mechanical inventions and improvements, and workshops and kitchens were installed. However, this emphasis on practical matters did not receive the support of the other sponsors and Thompson's aims were never fulfilled. Instead the Royal Institution became an outstanding centre of research in fundamental science.

One of the first to be appointed to the Royal Institution was the brilliant young chemist, Humphry Davy, who, in 1801, at

[1] Merz, op. cit., p. 260.

[2] Thomas Martin, *The Royal Institution* (Longmans, 1948), p. 4.

[3] W. H. G. Armytage, *Civic Universities* (E. Benn, 1955), p. 162.



An evening at the Royal Institution

Sir James Dewar (1842–1923) giving one of the Friday Evening Discourses which Michael Faraday (1791–1867) originated. For a scientist it became a distinction to be asked to deliver the Friday evening lecture to audiences that included men of the first rank in several fields.

the age of twenty-three, left the Pneumatic Institute at Bristol to become Lecturer in Chemistry and Director of the Laboratory.

> It was his devotion to experiment and his powers as a lecturer which first established what have ever since been the special characteristics of the work of the Royal Institution, its tradition of scientific investigation carried out in its own laboratories coupled with exposition and experimental illustration of the latest researches in its lecture room.[1]

Davy's audiences at the Royal Institution consisted of:

> Men of the first rank and talent, the literary and the scientific, the practical, the theoretical, blue-stockings, and women of fashion.[2]

His researches were instrumental in establishing the branch of science known as electrochemistry. Another to hold a Chair at this time was Dr. Thomas Young, who advocated the wave theory of light.

Davy's fame, both as researcher and lecturer, was later surpassed by his young protégé, Michael Faraday. Faraday,

> instead of being backed by a wealthy Academy and ample assistance, had during all the years when his great discoveries were being made, to keep alive, with an income scarcely exceeding £100 a year, an institution which but for him the memory even of such names as Rumford, Young and Davy would not have sufficed to preserve from utter ruin and collapse.[3]

[1] Martin, op. cit., pp. 9–10. [2] Ibid., p. 9.
[3] Merz, op. cit., p. 246.

Davy and Faraday were the first in a long line of eminent scientists to be appointed to the Royal Institution. These were to include John Tyndall, Thomas Huxley, Lord Rayleigh, James Dewar, J. J. Thomson and Ernest Rutherford. The Royal Institution was the only public research laboratory during the first quarter of the century, an Act of Parliament having converted it from a private to a public body. It remained a leading centre of research throughout the greater part of the nineteenth century.

The Status of 'Original Research'

Writing in the *Quarterly Review* of May 1810 Dr. Thomas Young advanced the view that

> the diffusion of a respectable share of instruction in literature and in the sciences among those classes which hold the highest situations and have the most extensive influence in the State is an object of more importance to the public than the discovery of new truths.

This opinion was held by the majority of English academics at the time, for research was not a recognisable function of a university. The idealogical struggle to establish the principle of 'original research', both in universities and in industry, was a key feature of the nineteenth century.

At the beginning of the century there was very little individual research carried out in English universities and there was a complete absence of organised 'schools of research' at university and elsewhere. On the other hand:

> The German universities were professional schools rather than places of liberal education . . . the only degree awarded was the Ph.D. The usual practice was to attend lectures for the first year or so and then in the remaining years to undertake, under the direction of the Professor, some original research.[1]

England, then, during the first quarter of the nineteenth century relied on individual effort and private benefaction. Educational and public institutions consisted of two outmoded universities and the Royal Institution. In addition there was an inefficient Royal Society and a multiplicity of scientific and learned societies. The organisation of science was fitful, unco-ordinated and haphazard and revealed a somewhat casual attitude to its importance.

[1] Cardwell, op. cit., pp. 20–21.

Chapter Two

1830–70 RESURGENCE

MAJOR technological discoveries allied to natural advantages in mineral resources had gained for England an early lead in the Industrial Revolution by the beginning of the nineteenth century. This success, it was reasoned, justified the individual effort on which it was partly based and thus conditioned the later industrial attitude to science. This complacent reliance on individual achievement was symptomatic of the philosophy of individualism which characterised the nineteenth century. Its consequences were perhaps not to be fully realised until the disastrous years 1914 to 1916. England's industrial lead was gradually whittled away as her main competitors strove to catch up with her, and eventually surpassed her. That they were enabled to do so can be partly attributed to their energetic pursuit of scientific research and to the efficiency of their science-based industries.

During the period under consideration in this chapter criticisms of the state of education and science increased in frequency and culminated in the intense propaganda and pamphleteering of the 1860s. Immediate results were the Education Act of 1870 and the legislation concerning technical education. While there was a decline in actual industrial achievement relative to the achievements of other nations, at the same time there was a resurgence of energy with regard to the organisation of science, and the foundations were laid for future progress. Although the importance of science and technology had largely been recognised by 1870 opposition to science has continued right down to the present day, when changing economic circumstances have again produced the appearance of a conflict in society between 'progressive' and 'reactionary' forces.

Britain's pre-eminence in the industrial world reached its zenith at the Great Exhibition of 1851. The loss of industrial supremacy was not immediately apparent but became manifest at the Paris Exhibition of 1867 where British industrial prestige fell well below its 1851 level. During the next three decades British industrial production in many fields was overtaken by that of her major competitor, Germany.

In Germany the State supported industrial research and fundamental research in pure science. The craft orientation of British industry as compared to German orientation towards scientific and technical research was the result not only of ingrained conservatism and a penchant for the 'practical mind' but also to the conspicuous absence of a corps of highly trained scientists and technologists — the 'officer class', as Huxley was to call them. The German 'schools' of research at university and polytechnic level were producing such a class whereas there were no comparable research schools in England.

Yet such 'schools' existed in embryo in England before mid-century. There were four institutions, apart from the Royal Institution, which could, given favourable conditions, have become academic centres devoted in part to the pursuit of scientific research along the lines of the German universities. These were University College, London; Owens College, Manchester; the Royal College of Chemistry; and the Royal School of Mines.

New Developments in Scientific Education

University College, London, was designed to provide higher education for those members of the middle class unable to enter Oxford or Cambridge and also to provide opportunities for the study of subjects not available at the older universities. Opened in 1826, it was modelled on the recently-founded University of Berlin. Its sponsors had taken note, too, of events on the other side of the Atlantic. Speaking at the inauguration of the University of Virginia in 1819 Thomas Jefferson had declared that its function was:

> To harmonise and promote the interests of agriculture, manufactures and commerce. To enlighten them with mathematical and physical sciences, which advance the arts and administer to the health, the subsistence and comforts of life.

Central influences behind the creation of University College were Whig, Dissenting and Utilitarian. Hostility to its founding came from several quarters. On 26 May 1825 Henry Brougham moved in the House of Commons for leave to bring in a Bill which would establish the College. On the same day Robert Peel, a member of the Cabinet, wrote to the Dean of Christ Church, Oxford, saying:

> This must be opposed and rejected, but I have hardly time to give to such an important matter the attention which it deserves . . . Can it be argued that because Westminster and the Charter House are as well conducted as Eton and Harrow, a London College would be as fit a place for the education of youth as Oxford and Cambridge?[1]

The forces ranged against the sponsors included the older universities and the Established Church. Opposed in principle to the foundation of the new college, they were further antagonised by the emphasis given to science and the neglect of theology.

Among the first Chairs created were those in Chemistry, Engineering and the Application of Mechanical Philosophy to the Arts. It was the intention of the College to appoint a Professor of Geology and Mineralogy, but this Chair remained unfilled. The professors were to depend mainly on students' fees. The contemporary attitude was

> no reputation, no students; no students, no income.

This had developed from Scottish experience, which was held to prove that men lectured best when they were hungry! In chemistry a laboratory for courses in practical work was provided from the start as well as a private laboratory for the Professor. A Chair of Practical Chemistry was founded in 1845 and an evening course in practical chemistry was instituted. This latter was for the convenience of persons engaged in manufactures. In 1859 the Chair of Practical Chemistry was filled by A. W. Williamson, who had studied at Giessen — then the foremost chemical research centre in Europe. Imbued with a keen desire for research he instituted research in chemistry and persuaded others to follow his

[1] H. H. Bellot, *A History of University College, London, 1826–1926* (University of London Press, 1929), pp. 216–17.

example. He was also partly responsible for inaugurating a Faculty of Science and establishing degrees in science. The London B.Sc. degree established in 1859 included the subjects of mathematics, physics and chemistry. This could be followed by a D.Sc. degree by examination or research.

In natural philosophy there were 'instruments for demonstration and research'. In this branch of science, too, University College was progressive and in 1867 set a new trend by being the first in England to appoint a Professor of Physics — T. A. Hirst. This was quickly followed in 1868 by the appointment of Carey Foster as the first Professor of Experimental Physics. But the appointment of professors in itself was not sufficient; for the conditions under which Foster had to work were in marked contrast to the splendid facilities offered in Germany.

> At first only two rooms were available, one his own private room. Afterwards a room in the basement, known as the Dungeon, was added in which a few research men could be accommodated along with a gas engine and a set of accumulators. Research apparatus had to be dismounted each week to make room for undergraduates, and then had to be built up again each following week.[1]

The great virtue of University College was that it kept an open mind and was prepared to welcome branches of learning which were not acceptable elsewhere. For example, the Senate were keen to make the College one of the chief places of scientific education for the engineer and succeeded in this by creating a Chair of Civil Engineering in 1874 and a Chair of Mechanical Technology in 1878.

Meanwhile, in Manchester, the Owens College was created in 1851. This came about as a result of the will of John Owens, a wealthy merchant of the city, who left £100,000 in trust for the express purpose of founding a college open to all, irrespective of creed. At the outset half of the Chairs created were in Science, being professorships in mathematics, chemistry and natural history. Practical chemistry was begun as early as 1851 and in 1854 a Chair of Commercial Science was created. Classes were begun in technological chemistry but in 1855 these had to be abandoned for lack of students. Following the institution of the B.Sc. degree by the University of London, in which natural philosophy was included as a special subject, the trustees of the College appointed R. B. Clifton as Professor of Natural Philosophy and he was to institute a course of lectures on experimental physics. It was at Owens College that J. J. Thomson (the discoverer of the electron), who entered the College as a student of engineering, had his first taste of experimental physics and this induced him to stay on at the College and change from engineering to physics.

In 1865 it was felt that a School of Civil Engineering should be set up but the scheme had to be dropped because it was a bad year for trade and there was a shortage of money. A year later Manchester engineers got together and concluded,

> it is expedient to establish a professorship of civil and mechanical engineering, together with a special library and a museum of models.[2]

[1] Bellot, op. cit., p. 312.
[2] Thompson, *The Owens College*, p. 295.

The Emergence of a Scientific Society

The practical effect of this was the appointment of Osborne Reynolds to a Chair of Engineering in 1868.

Between 1857 and 1866 the total number of honours graduates in chemistry amounted to eleven at University College, London, and fourteen at Owens College. While there were more science students at University College than at Oxford and Cambridge combined, the number at Owens College exceeded that of University College.

The original building which housed Owens College was Richard Cobden's former house which

> trembled when the heavily laden carts went by and delicate experiments had to be abandoned.[1]

Another site was obtained but this did not meet the needs of the expanding college and by 1865 things had got so bad that the Professor of Natural Philosophy was forced to complain that:

> The lecture rooms get very stuffy. Ventilation causes draughts so that students have to wear coats . . . The rooms get into a state not only destructive of efficient study but most injurious to health and students are compelled to leave the room fainting. No institution of the kind in the Kingdom has so many persons under instruction in so confined a space.[2]

[1] Thompson, op. cit., p. 210.
[2] Thompson, op. cit., pp. 247–9.

Old Owens College

Formerly the house of Richard Cobden, M.P., in Quarry Street, Manchester, the building was leased for an annual rent of £200.

Berlin University

Founded in 1809, it soon became the leading university in Germany, and in its timing and organisation directly influenced the founding of University College, London.

The project for building a new Owens College was first mooted in 1859; it was eventually accomplished in 1873. The above complaint was made in 1865 when the College housed 439 students. By 1873 this number had risen to 891.

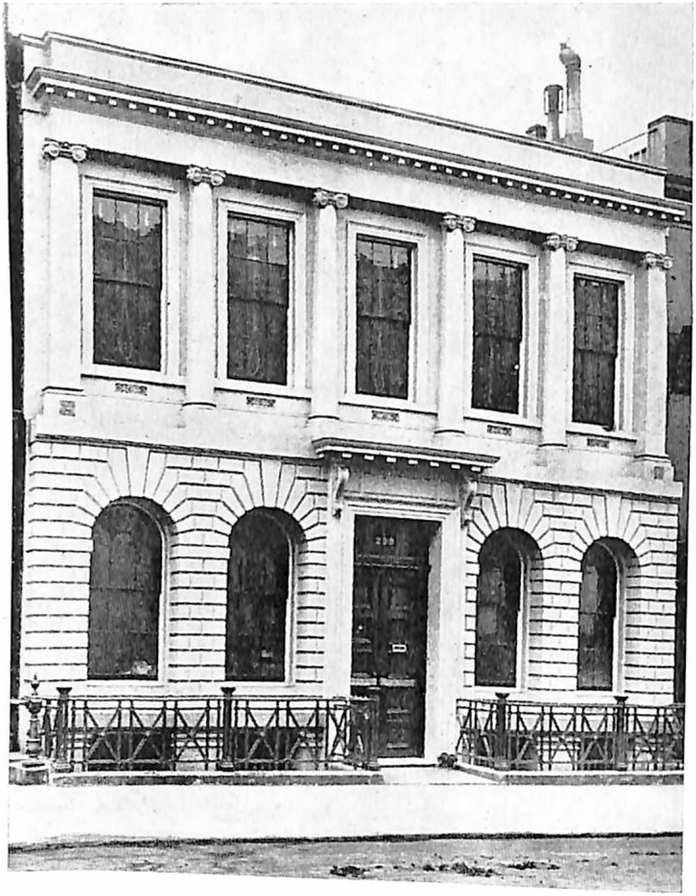
In 1868 Henry Roscoe and Greenwood, the Principal, undertook a comprehensive tour of German and Swiss universities and polytechnics. These included the Universities of Berlin, Leipzig and Bonn, and the Polytechnics of Hannover, Karlsruhe, Stuttgart and Zürich. These were taken as models for the new college.

Prior to the 1840s those who wished to pursue a systematic course of advanced study in chemistry were obliged to seek it abroad — at Göttingen or Giessen. Certain leading public figures came to the conclusion that a national college of chemistry was required in London. Thus was founded the Royal College of Chemistry. A provisional committee was elected and a prospectus issued. Originally called the Davy College of Practical Chemistry, it was

> mainly devoted to pure science; at the same time, to meet the exigencies of this country, and to adopt the latest improvements in the continental schools an appendage will be provided, devoted to the Economic Arts, where inquiries relating to Pharmacy, Agriculture and the other Arts may be pursued.[1]

By July 1845 a Council had been elected with H.R.H. Prince Albert as President. Their first task was to appoint a Professor of Chemistry. The post was successively offered to Dr. Fresenius of Wiesbaden and Dr. Will of Giessen, both of whom declined. Eventually, as a result of the personal intervention

[1] T. G. Chambers, *Royal College of Chemistry, Royal School of Mines and Royal College of Science* (Hazell, Watson & Viney, 1896), p. 37.



The Royal College of Chemistry

This began as the Davy College of Chemistry in 1845. Prince Albert, the Prince Consort, played a leading part in its foundation.

of the Prince Consort, Dr. August Wilhelm von Hofmann was enabled to take up the post as the result of the generous allowance of two years' leave of absence by Bonn University.

Under Hofmann's inspiration research flourished and he was soon to speak of the students in the following terms.

> Almost all classes of society have been represented in the laboratory — gentlemen following chemistry as a profession, or as an object of scientific taste, chemists and druggists, medical students, and medical men, agriculturists, manufacturers in almost all branches of the chemical arts, copper smelters, dyers, painters, varnish makers, soap boilers, brewers and sugar-makers have been working side by side.[1]

Although the venture had not been lacking in guaranteed support the College was in financial difficulties by 1847. Subscriptions had fallen off considerably,

[1] Chambers, op. cit., p. 31.

> partly owing to the disappointment of some of the contributors, who desired some more substantial return for their money in the form of lectures, soirées, analyses and the like — these, not receiving such return, withdrew their support.[1]

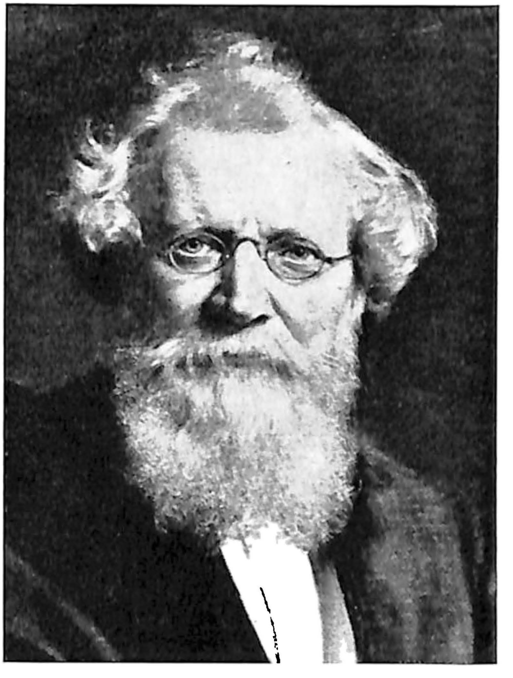
The debt was partly cleared by twenty-three members of the Council, contributing £50 apiece. In addition

> Dr. Hofmann voluntarily gave up in succession — first a portion of his salary, then his share of the students' fees and lastly his house; yet during this trying period he never in the slightest degree relaxed his efforts to establish the reputation of the College. He not only gave up the money which was his due, but, out of his extreme devotion to the educational objects of the College, abandoned for some years what to a German savant is of still greater importance, his original scientific investigation.[2]

Persuaded by the Prussian Government to return to his own country in 1864, Hofmann, in the same year, was appointed Professor of Chemistry in the University of Berlin and was replaced by Edward Frankland.

In 1853 the Royal College of Chemistry became the chemistry department of the Metropolitan School of Science and such it remained when that School was renamed the Royal College of Science and Royal School of Mines.[3]

The Royal School of Mines had its origins in the Museum of Economic Geology founded



August Wilhelm von Hofmann (1818–92)

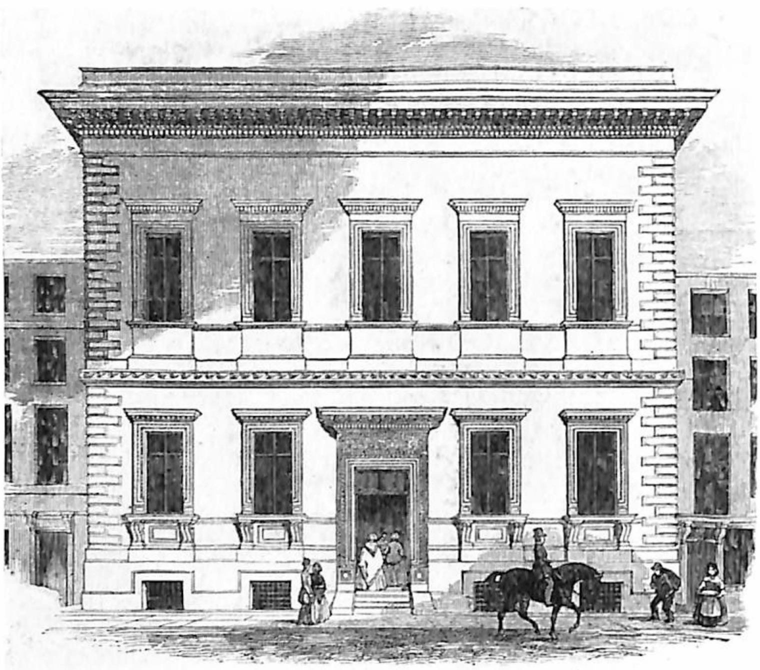
First Professor of Chemistry at the Royal College of Chemistry. Introduced German methods of research to the college, and helped to establish its reputation as a leading centre of chemical research.

[1] Chambers, op. cit., ibid.

[2] Warren de la Rue, *Farewell Banquet to Dr. Hofmann* (Chambers, 1864), 28 Apr. 1864.

[3] *Genealogy of Royal School of Mines*

1839	Museum of Economic Geology.
1851	This became part of a new Government School of Mines Applied to the Arts.
1853	Royal College of Chemistry incorporated as the chemistry department.
1857	Became Government School of Mines and of Science Applied to the Arts.
1881	Became Normal School of Science and Royal School of Mines.
1890	Became Royal College of Science and Royal School of Mines.



The Museum of Economic Geology

The museum was set up in Jermyn Street in 1837 with the object of providing in England an institution equivalent to the mining academies of the Continent. In 1851 its was renamed the Government School of Mines and of Science Applied to the Arts.

in 1839. Pupils received instruction in mineralogy, analytical chemistry, and meteorology. A report of a Committee of the House of Lords commented in 1849 that

> a want appears to be felt of facilities for acquiring mining education, such as are provided by the mining schools and colleges established in the principal mining districts of the Continent, apparently with the most beneficial results.[1]

Hence the Museum of Economic Geology became the 'School of Mines and of Science Applied to the Arts'. The small attendance of students during the first and ensuing sessions was a disappointment to everyone. It was expected that the mining districts at least would have sent students, for:

> The education contemplated in this School differs essentially from that given in colleges, where general education is the primary object. Although it is intended to give general instruction in science to those who require elementary knowledge, still, the chief object of the Institution is to give a practical direction to the course of study, so as to enable the student to enter with advantage upon the actual process of mining, or of the Arts which he may be called upon to conduct.[2]

Edward Forbes, Professor of Natural History, addressing the School in October 1853 remarked:

> It was supposed that opportunities for scientific instruction such as are here

[1] Chambers, op. cit., p. 11.

[2] *First Prospectus of the Government School of Mines* (1852).

afforded would have been appreciated by intelligent persons among the middle and higher ranks . . . With the exception of a chosen few, the anticipation has proved fallacious . . . There is, indeed, no stronger argument in favour of the State taking the initiative in scientific instruction of the kind given here, than the fact that the classes of the people who cannot afford to pay high fees, or come to learn during the hours of the day, are anxious and thankful for it; whilst those who ought to support deserving institutions of private foundation have yet to be imbued with a taste for natural knowledge before they will do that which should be at once a duty and a pleasure.

In spite of attracting fewer students than anticipated, the School nevertheless soon outgrew its premises. Edward Frankland constantly drew attention to the urgent necessity for larger premises.

A Member of Parliament alluded to its crowded state in the House of Commons in 1869:

> Dr. Percy's laboratory being in the backyard of a tailor's shop and Professor Huxley's anatomical preparations having to be made in a closet about eight feet square.[1]

Pronounced a failure by a Select Committee of the House of Commons the chief government technical institution, the Royal College of Science and Royal School of Mines, nevertheless possessed the most illustrious scientific staff in the kingdom. This included Hofmann, Playfair, Frankland (chemistry), Huxley (natural history) and George Gabriel Stokes (physics).

Huxley expressed the opinion that the College was not a failure.

> On the contrary, I think that, even if it had done nothing more than show the value of scientific training, the College has been a considerable success.[2]

Factors Accounting for their Limited Success

It was hoped that the result of the existence of the above institutions — University College, Owens College, the Royal College of Chemistry and Royal School of Mines — would be the production of future managerial leaders in industry, research scientists and teachers of science and technology.

The continued production of such a corps required three prerequisite conditions. First, establishments offering first-rate professional training and research facilities. Second, an adequate supply of educated, talented student entrants. Third, a sufficiency of posts offering attractive remuneration and good conditions in which their professional training could be utilised.

The *sine qua non* of such a programme was adequate finance. Each of the institutions considered above was handicapped by lack of financial support.

Owens College, Manchester, had come into existence due to the generosity of John Owens. Later, two further subscriptions of £100,000 came respectively from Frederick Beyer, a Bavarian who settled in Manchester, and became a successful industrialist, and

[1] Chambers, op. cit., p. 34.
[2] Ibid., p. 33.

Joseph Whitworth, the Manchester engineer. Thus, three individuals between them contributed £300,000. Later, when no suitable applicants came forward for the Chair of Engineering, Beyer offered to double the proffered salary of £250 per annum, by which means they succeeded in obtaining the services of Osborne Reynolds.

Not surprisingly the State contributed nothing to these establishments. The prevailing philosophy was that of *laissez-faire* individualism.

From time to time the Trustees of Owens College urged on the Government the claims of their college for support. For example, in July 1853 a deputation saw the Prime Minister, the Earl of Aberdeen:

> Mr. Faulkner reported, on behalf of the deputation, the interview they had had with Lords Aberdeen, Granville and John Russell about a Government grant. It was the old story. Their lordships fully recognised the importance of the application and promised it should receive the most careful consideration of Her Majesty's Government. And there it ended.[1]

Again, in 1868, when £150,000 was needed for new buildings a subcommittee was formed to press for government aid.

An influential deputation, supported by the town councils of Manchester, Salford, Stockport, Bolton, Oldham, Stalybridge and Wigan obtained an audience with Disraeli, who was then Prime Minister. In his reply,

> Disraeli assured them of the great importance he attached to the subject which they had laid before him . . . It had his fullest sympathy and would command the greatest consideration from his colleagues when he brought its claims before them. 'But if Her Majesty's Government in the exigencies of the State, should be unable to comply with your request, I am quite certain that the public spirit and the generosity of Lancashire will not allow the interests of the college to suffer.'[2]

Nothing came of the application. However, in November 1868 the Disraeli Government was replaced by that of Mr. Gladstone, Robert Lowe becoming Chancellor of the Exchequer. A deputation first saw Mr. W. E. Foster and Earl Grey. Both were favourably disposed. The deputation then waited on the Prime Minister.

> Mr. Gladstone asked whether they had seen the Chancellor and Lord Grey. In reply it was stated that these gentlemen and Mr. Foster had been seen, and the two latter were much more favourable than the former, but it was well known that Mr. Lowe possessed peculiar views on education. Mr. Gladstone explained that Mr. Lowe had to find the money and there were great difficulties in the way of meeting the application.[3]

Mr. Robert Lowe certainly did have peculiar views. A deputation from the Scottish Meteorological Society went to Mr. Lowe in 1869 for a grant of £300 and was greeted with the words:

> I hold it as our duty not to spend public money to do that which people can do for themselves.[4]

[1] Thompson, op. cit., p. 145.
[2] Ibid., p. 331. [3] Ibid., p. 332.
[4] Cardwell, op. cit., p. 98.

However, Mr. Lowe was far from being alone in holding such views. Herbert Spencer in *State Education — Self Defeating* wrote that:

> On the whole the experience of the past is proof of the danger of government interference, and of the instability of extreme centralisation, while it affords conclusive evidence of the superior and enduring value of voluntary efforts.

There was a real fear, too, on the part of the recipients of becoming dependent on the State. As one member of the deputation to Gladstone was to say later:

> He was glad the Government had refused them a grant. There was plenty of money to be had in Manchester, let them look for that and be independent of government help and interference.

The executive committee of the Manchester deputation drew up a statement of government aid existing at the time. Out of a total of £127,138, Scotland received £43,354, Ireland £24,918, and England £58,866. In England the money was distributed as follows:

(*a*) for buildings

£25,000 .	University of London

(*b*) for education, science and art

£11,800 . .	learned societies
£9,063 . .	University of London
£12,253 .	School of Mines
£750 .	College of Chemistry

The attitude adopted by these respective governments, though in keeping with the prevailing philosophy, is somewhat paradoxical; for in 1855 a Select Parliamentary Committee had been set up to consider

> whether any means could be adopted by the Government or Parliament that would improve the position of science or its activities;

and it reported that

> there was a widespread feeling of the importance of science but there were only a few grants available for the support of science.

It considered that a Government Board of Science should be established and that the State should endow Chairs of Science, in order to encourage the flow of university-trained men. Neither of these recommendations was acted upon.

Had the various governments done all in their power to support these institutions success would not have been ensured, for higher educational establishments were further hampered for most of the century by the poor qualifications of entrants. This was due to the absence of a system of good general education. In Manchester, for example,

> the Statistical Society took a census in 1834, and their report is deplorable in the extreme . . . A comparison was made between the efficient system adopted in Prussia, and the deplorably bad condition of things in Manchester, a comparison that applied with as much force to the teachers as to the scholars; for whereas in the former country the teacher was specially trained for his office, and was not allowed to assume it till he had passed a satisfactory examination, in England the education of the lower classes is left with the few exceptions of charity schools in the

> hands of ignorant and uneducated men, who are often destitute of every qualification for their office.[1]

The Principal of Owens College was forced to complain in 1852 that school education in Manchester was so bad that the students were insufficiently prepared to receive the benefits of true collegiate training. Many thought that a Junior School was necessary to correct the notoriously bad preparation of students entering the College. On 9 July 1858 the Manchester Guardian observed:

> Explain it as we may, the fact is certain that this college, which eight years ago it was hoped would form the nucleus of an University, is a mortifying failure.

Seeking the causes of its failure, the *Manchester Examiner* remarked:

> We are compelled to look for the causes of non-success elsewhere than in the collegiate machinery . . . the institution is either in advance of our felt wants or altogether unsuited to the economical conditions of Manchester life . . . it is too good for us.[2]

The *Examiner* divided the Manchester youth into two classes. Those who, through their parents' good fortune, could afford a scholastic training until they were eighteen years old, and those whose parents thought it necessary in the severe competition of life to put their sons into business at the age of fifteen. The latter could not afford the three years of collegiate life; the former would not consider the idea of completing their education at a small provincial college when the old universities of Oxford and Cambridge were available to them.

Thus, the supply of suitable students was bedevilled by class attitudes with regard to education. Each type of institution was felt to be suited to a particular class in society — the Mechanics Institutes for artisans, Owens College for the lower middle class: Oxford, Cambridge and the Public Schools remaining the preserve of the upper classes.

The Royal School of Mines also suffered from the unpreparedness of its student entrants. Playfair, addressing the School in 1852, on *Industrial Instruction on the Continent*, gave details of the various systems of instruction pursued in foreign technological establishments and demonstrated the necessity for similar teaching in England. He pointed out the absurdity of pupils entering the School untrained in science, with the consequent loss of time involved in having to learn the elements of science rather than its applications.

Even had there been a continuous flow of well-trained and educated students coming from the institutions, the state of industry was such that there would have been no posts for them to fill.

Despite rapid growth and expansion the dominant characteristics of British industry remained the absence of science and of the scientific attitude of enquiry.

> The multiple machines of the nineteenth century were the fruits of much ingenuity but relied little on science and gave little back to it. The typical inventor was usually a workman or amateur who contrived to find the most convenient arrangement of wheels, rollers, cogs or levers designed to imitate the movement of the craftsman at higher speed and using steam power . . .

[1] Thompson, op. cit., pp. 23–24. [2] Ibid., p. 198.

> The archaic development of industry made it impossible for the links between science and industry to have any rational or planned basis . . . Little or no provision was made until the end of the century for science itself, let alone its application to practical purposes.[1]

Mechanics' Institutes and Other Innovations

Institutions which could have produced a scientifically educated managerial *élite* and a supply of industrial research scientists were discussed in the last section. An institution designed to produce the artisan and craftsman trained in scientific technique first appeared in England in 1823. This was the Birkbeck Mechanics' Institute, London, founded by George Birkbeck and others. The syllabus included mathematics, chemistry, applied chemistry, hydrostatics and electricity. Soon every major town possessed its Mechanics' Institute. By 1850 there were over 600 of these, enrolling half a million members; the greatest concentrations of the institutes were found in the North Midlands, Lancashire and Yorkshire, and Cornwall.

However, they failed to achieve their principal objectives. Their prime object was to teach the sciences underlying the industrial arts. They failed in the first place because the class of people for whom they were intended was too unprepared and uneducated. They failed also because they became diverted from their intended purpose. The artisan class was increasingly replaced by the middle class; technical education became instead 'liberal' adult education. Science gave way to philosophy, literature and drama. Mechanics' Institutes were, however, progenitors of the Royal College of Science and Technology, Glasgow (now the University of Strathclyde); the Heriot–Watt College, Edinburgh; and the Manchester College of Science and Technology. They contained some illustrious alumni, notably John Neilson and Sydney Gilchrist Thomas.

Another development at this time was the emergence of various other institutions such as the Sheffield People's College started by the Rev. R. S. Bayley; F. D. Maurice's Working Men's College; Muspratt's College of Chemistry at Liverpool; and the Leeds Arts and Science Institution established by the Nussey brothers. Like the Mechanics' Institutes, each of these was the inspiration of groups of like-minded individuals, and the continued existence of such establishments depended on the acceptance of the burden of financial support by these groups. Neither directly nor indirectly did the State provide any support for them.

Reform at Oxford and Cambridge

During mid-century Oxford and Cambridge began the reforms which were to transform them from the ineffective establishments that they had been in the late eighteenth century to institutions more in line with the German universities and the English University Colleges which emerged towards the end of the nineteenth century.

In the second decade of the century Whewell, Airy and others formed a strong mathematics school at Cambridge. Unfortunately, the substantial numbers of brilliant mathematicians produced by Cambridge during mid-century did not make the

[1] J. D. Bernal, *Science and Industry in the Nineteenth Century* (Routledge, 1953), p. 28.

contribution to the advance of science that they might have done, for after qualifying in mathematics many of them entered the Church or took up law. Later in the nineteenth century success in the Cambridge Mathematical Tripos was considered an admirable foundation for physicists — Clerk Maxwell and J. J. Thomson were two who pursued such a course.

Agitation, both from within and without, led to the establishment of the Natural Science Tripos at Cambridge in 1851, and the Oxford Honour School in Natural Science in 1850. Notwithstanding these reforms it was not until 1875 that a Chair of Engineering was created at Cambridge. It was 1871, too, before experimental physics found favour at Cambridge, despite the views held by George Gabriel Stokes, Professor of Mathematics at Cambridge, who in 1858 had remarked:

> I entertain a very strong opinion as to the great value of a course of lectures, mainly experimental, on natural philosophy. I think it is a great defect in our system here, that our students have so little opportunity for attending or encouragement to attend lectures of this kind.[1]

During mid-century out of 165 Fellowships at Oxford and 105 at Cambridge only nine and three respectively were in natural science. Huxley in giving evidence to a Select Committee was outspokenly critical of scientific education at Oxford and Cambridge.

> I think if the manufacturer who sent his son to Oxford or to Cambridge to take an ordinary degree expected that he would thereby secure the smallest atom or scintilla of scientific knowledge, he would be mistaken . . . it is fair to say that any one might have taken the highest honours at the university and yet might never have heard that the earth went round the sun . . . I think that the spirit of the teaching at our older universities is entirely opposed to the spirit of scientific thought. At present they are hardly to be trusted with scientific education.[2]

The Public Schools and Grammar Schools

The curricula of Oxford and Cambridge tended to be reflected in the curricula of the Public Schools and endowed Grammar Schools. Designed partly as 'feeders' for Oxford and Cambridge and at the same time as training schools for gentlemen they were consequently dominated by the educational ideals of Oxford and Cambridge.

> If we find in the country and town schools little preparation for occupations, still less for the future agriculturalist or mechanic, we find in the Grammar Schools much greater defects. The middle class . . . are fed with the dry husks of ancient learning. The applications of chemical and mechanical science to every-day wants . . . and such a knowledge of public economy in the largest sense of the term . . . are all subjects worth as much labour and enquiry . . . as a little Latin learnt in a very imperfect manner, with some scraps of

[1] Thompson, op. cit., p. 214.

[2] Thomas Huxley's evidence to Select Committee on Scientific Instruction (London, *Parliamentary Papers*, session 1867–8).

Greek to boot — the usual stunted course of most of our Grammar Schools.[1]

Augustus de Morgan speaking of Grammar Schools in 1832 complained:

among a people who depend for their political greatness on trade and manufactures there was not, generally speaking, in the education of their youth one atom of information on the products of the earth . . . nor any account of the principles whether of mechanics or chemistry which, when applied to these products constituted the greatness of their country.[2]

Headmasters and teachers no less than parents were antagonistic to science. The headmaster of one famous Public School considered that 'scientific instruction was worthless as education'.[3] Thomas Arnold went even further and did not think physical science to be a fit study for boys. The Public Schools were imbued with the values of their own education, which was inimical to science. This was to be an obstacle to the introduction of science in these schools.

Liberal as the Minister may be under whose control the general education of the nation may be placed, there is little doubt that in this country the greater number of its instructors will be drawn from among such of the graduates of the ancient universities as both by their training and position must be, to a great extent, disqualified from assigning their due importance to the practical branches of science. Such persons may be eminent in scholarship and abstract science, and yet ignorant of the fact that the continued prosperity of their country absolutely depends upon the diffusion of scientific knowledge among its masses. They may, with the most sincere and earnest intention, not only fail to advance, but even exercise a retarding influence on such diffusion, and may object to a course of study which, as now pursued, is irrespective of religious teaching. Experience has shown in how sickly a manner practical science is allowed to raise its head under the direction of those persons whose pursuits are alien to it; whilst in every land where it has had due support the greatest benefits have resulted.[4]

Things had not changed by 1870 for in 1868 Matthew Arnold, following a tour of the Continent, remarked:

In nothing do England and the Continent at the present moment more strikingly differ than in the prominence which is now given to the idea of science there, and the neglect in which this idea still lies here . . . Our dislike of authority and our disbelief in science have combined to make us leave our school system . . . to take care of itself as it best could. Under such auspices our school system has naturally fallen all into confusion; and though properly an intellectual agency, it has done and does nothing to counteract the indisposition to science which is our great intellectual fault. The

[1] Sir Thomas Wyse, *Education Reform* (1837). Quoted in M. Argles, *South Kensington to Robbins* (Longmans, 1964), pp. 12–13.

[2] C. F. Singer *et al.*, *A History of Technology*, vol. v (Oxford, Clarendon Press, 1958), pp. 781–2.

[3] Argles, op. cit., p. 13.

[4] Private communication from Sir Roderick Murchison, Principal, Royal College of Science, to Lord Stanley, President of Board of Trade, 25 Jan. 1856.

result is, that we have to meet the calls of a modern epoch, in which the action of the working and middle class assumes a preponderating importance, and science tells in human affairs more and more, with a working class not educated at all, a middle class educated on the second plane, and the idea of science absent from the whole course and design of our education.[1]

Secondary Technical Education

There was one field in which the Government, when it did act, did so with surprising alacrity, according to the standards of the day. This was in the field of technical education at the Secondary School level. In 1853 it set up the Department of Science and Art. This was to promote the creation of 'science schools' and subsidise teachers of science. This was the main agency of technical education and was based on the 'payment-by-results' system. By 1870 there were over 200 schools, a school being any institution or part of an institution which qualified for a grant. Some of these schools, for example, were parts of Mechanics' Institutes allocated for this purpose. Even in this field the traditional attitude towards state aid prevailed. Sir Henry Cole, Secretary of the Department of Arts, commented in his memoirs:

> To obtain grant assistance an institution had already to be endowed by a patron or a charitable trust. The work thus done is mainly done by the public itself on a self-supporting basis as far as possible, whilst the State avoids the error of continental systems, of taking the principal and dominant part in secondary education.[2]

[1] Matthew Arnold, *Higher Schools and Universities in Germany*, 2nd ed. (Macmillan, 1892), p. 198.

Scientific Societies

Among the general public, scientific societies continued to thrive and increase in number. The focus of interest in science was by now the British Association. In 1822 a Dr. Oken of Munich had suggested a plan for an annual meeting of German scientists. This first took place at Leipzig. David Brewster, inspired by this idea when on a visit to the Continent, proposed a similar scheme in this country. Disillusioned by the Royal Society, Charles Babbage greeted the idea with enthusiasm and he and Brewster became the prime movers in the formation of the British Association for the Advancement of Science which first met at York in 1831.

Its object was to

> give a stronger impulse and more systematic direction to scientific inquiry, to obtain a greater degree of national attention to the objects of science and a removal of those disadvantages which impede its progress, and to promote the intercourse of the cultivators of science with one another and with foreign philosophers.

The Times was openly hostile to the British Association and was scornful of the Association's aims and activities. Notwithstanding the assessment of *The Times* the British Association became a valuable instrument in the movement for scientific advance. As a financing body, however, the British Association was no substitute for state aid. Between 1831 and 1931 its total grants for the support of physical, natural and social sciences amounted to only £92,000.

Scientific societies still tended to reflect the

[2] Sir Henry Cole, *Fifty Years of Public Life*, vol. i (Bell, 1884), p. 313.

interests of amateurs and laymen in scientific matters. Membership figures of the leading societies were given as:

Royal Zoological Society	2,923
Royal Botanical Society .	2,422
Anthropological Society .	1,031
Royal Society . .	528
Meteorological Society .	306
Entomological Society .	208
Ethnological Society .	219
Chemical Society .	192[1]

This list does not differ markedly from that given by Babbage in 1831. The only significant addition is that of the Chemical Society and it is noteworthy that there was still no physics society.

The 'Scientific Lobby'

The period 1865–75 can perhaps be viewed as a watershed in the history of British science and technology.

From this time on there was increasing awareness of the necessity for state intervention and of the need to integrate science into education. The fact that science had become educationally acceptable is nowhere more evident than in the transformation of Oxford and Cambridge during the latter part of the century. This transformation was limited to acceptance of science. Not so at the new 'civic' universities, which were ready to introduce a variety of technological disciplines. It was after 1870, too, that 'original research' became recognised as a function of a university.

That such changes became possible was partly the result of the proselytism of a small group of influential figures. Foremost in this 'scientific lobby' were Charles Babbage, Lyon Playfair and Thomas Huxley. But many others, too, were enthusiastic in the cause of scientific reform and they helped to change the climate of opinion in England.

Despite Britain's success at the Great Exhibition of 1851 Playfair was compelled to point out that in future technological and industrial success would depend on the recognition of the importance of science and the extent to which this was followed up by action to promote scientific and technical advance.

> As surely as darkness follows the setting of the sun, so will England recede as a manufacturing nation, unless her industrial population become much more conversant with science than they are now.[2]

In his view there was

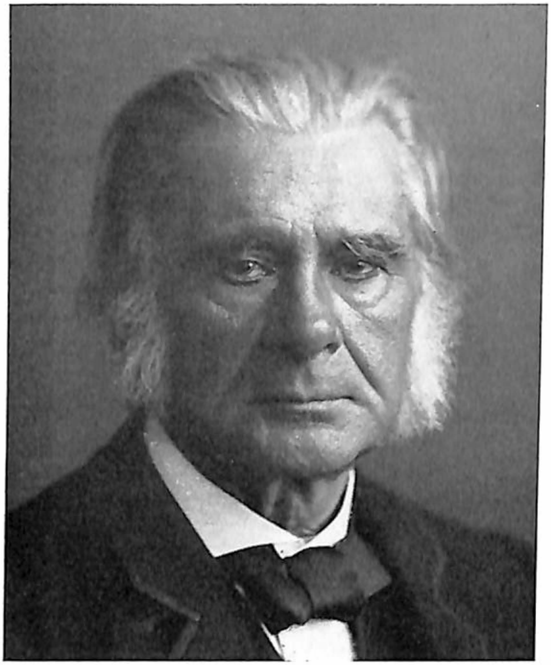
> an overweening respect for practice and a contempt for science . . . In this country we have eminent 'practical' men and eminent 'scientific' men but they are not wholly united and generally walk in paths wholly distinct . . . From this absence of connection there is often a want of mutual esteem and a misapprehension of their relative importance to each other.[3]

Playfair drew attention to the fact that Britain's advantage in natural resources

[1] Leone Levi, *On the Progress of Learned Societies*: Address to the Economic Section of the British Association, Norwich, 1868.

[2] Lyon Playfair, *The Study of Abstract Science Essential to the Progress of Industry*.

[3] Lyon Playfair, *Industrial Instruction on the Continent*. Introductory Lectures to the Government School of Mines 1851–2 (quoted in Cardwell, op. cit., p. 68).



Thomas Henry Huxley (1825–95)

A prolific writer and lecturer, he played a leading role in promoting the cause of science in England. He was an ardent champion of the theories of Charles Darwin, and became known as 'Darwin's bulldog'.

Sir Lyon Playfair (1818–98)

Professor of Chemistry at the Royal Institution, London, and at Edinburgh University. He later became a politician and played an active part in promoting science, particularly industrial chemistry.

would gradually be offset by increasing efficiency in transport and a situation would arise in which success would go to the scientifically organised nation.

That Playfair's prognostications were to become true was borne out by his own experiences at the Paris Exhibition of 1867:

> I am sorry to say that the opinion prevailed that our country had shown little inventiveness and made little progress in the arts of industry since 1862 . . . when I found some of our chief mechanical and civil engineers lamenting the want of progress in their industries, and pointing to the wonderful advances which nations are making; when I found our chemical and even textile manufacturers uttering similar complaints; I naturally devoted attention to elicit their views as to the causes . . . the one cause upon which there was most unanimity of conviction is that France, Prussia, Austria, Belgium and Switzerland possess good systems of industrial education for the masters and managers of factories and workshops, and that England possesses none . . . My inquiry of 1853 into industrial education on the Continent was

> a private one, and has neither official aid nor sanction.[1]

Huxley and Herbert Spencer, among others, were highly critical of traditional education and argued for an extension of the concepts of liberal education and culture to include science. Huxley, in evidence to a Royal Commission, said:

> My conception is that our present system of education should be turned upside down. At present the universities make literature and grammar the basis of education; and they actually plume themselves upon their liberality when they stick a few bits of science on the outside of the fabric. Now that in my apprehension is not real culture: nor is it what I understand by a liberal education. The thing you really have to do is, in my opinion, to invert the whole edifice, and to make the foundation science, and literature the superstructure — the final covering.[2]

Spencer, likewise, drew attention to the narrowness of an outmoded education.

> Had there been no teaching but such as goes on in our public schools, England would now be what it was in feudal times . . . The vital knowledge has got itself taught in nooks and corners, while the ordained agencies for teaching have been mumbling little else but dead formulae.[3]

Spencer emphasised that science was not only important to the welfare of a nation but was also an indispensable element in a cultural education.

In his Inaugural Address as Rector of Aberdeen University Huxley quoted J. S. Mill's panegyric on classical studies:

> In cultivating, therefore, the ancient languages as our best literary education, we are all the while laying an admirable foundation for ethical and philosophical culture.

Huxley argued that the following statement would be just as valid as that of J. S. Mill:

> In cultivating, therefore, science as an essential ingredient in education we are all the while laying an admirable foundation for ethical and philosophical culture.[4]

The newly emerging universities, however, were to be strongly influenced by the German ideal of *wissenschaft* as well as by the English ideal of liberal education.

> There remains but one possible pattern on which a University can be constructed . . . This is sometimes called the German type . . . the Professor of a modern university ought to regard himself primarily as a learner, and a teacher only secondary . . . he must consider that he is there on his own account, and not for the sake of his pupils.[5]

[1] Letter from Dr. Lyon Playfair to the Rt. Hon. Lord Taunton (*Journal of the Society of Arts* (7 June 1867), vol. xv, pp. 477–8).

[2] T. Huxley, *Evidence to Select Committee on Scientific Instruction* (1858).

[3] H. Spencer, *Education: Intellectual, Moral and Physical* (1st ed. 1861; Watts & Co., 1934), p. 23.

[4] T. H. Huxley, quoted in *Science and Culture*, p. 44.

[5] Mark Pattison, *Suggestions on Academical Organisation* (Edinburgh, Edmonson & Douglas, 1868), p. 157.

The Emergence of a Scientific Society

Hence the universities became centres of research and the degree requirements of the University of London reflected the new attitude to specialised knowledge:

> a thorough knowledge limited to a comparatively small range is preferable to a slighter acquaintance spread over a more extended area.

During the 1860s there was widespread agitation by individuals and scientific bodies for government action to improve the scientific and industrial state of the country. It was during these years that a Colonel Strange made a notable contribution to the cause of reform. Colonel Alexander Strange of the Royal Engineers returned to this country from service in the Indian Army in 1861. On his return he was elected to the Councils of the Royal Society and the Society of Arts. The titles of some of the papers he read to the Society of Arts and to the British Association indicate his advanced views — *On the Necessity for State Intervention to Secure the Progress of Physical Science; On the Relation of the State to Science; On Government Action in Science*. In these he advocated the setting up of an Advisory Science Council under a Minister of Science which would be empowered to administer research grants. He also proposed a chain of government-sponsored research institutions.

A Royal Commission was set up in 1870 to examine the whole question of scientific education and the advancement of science. The Devonshire Commission reported in 1872 that there should be generous state endowment of science. It was a responsibility of the State to set up research laboratories under the supervision of a Council of Science and a Minister of Science. It further acknowledged that there should be a general reform of scientific education both at secondary and university level.

Hence by the 1870s several of the main idealogical conflicts had been resolved. There was now general recognition that the State had a duty to foster science. No longer could it be wholly dependent on the efforts and goodwill of individuals. The necessity for a general reform of scientific education was also accepted. Finally, the status of original research was to be increasingly ensured in the universities if not in industry.

In spite of the general climate of opinion favourable to reform there was to remain considerable inertia in the efforts to redress the consequences of a century of misguided thinking.

Chapter Three

1870–1914 CONSOLIDATION

> We have entered upon the most serious struggle for existence to which the country was ever committed. The latter years of the century promise to see us in an industrial war of far more serious import than the military wars of its opening years . . . We must be careful to organise for victory.

IN spite of this prophetic warning given by Huxley in 1887 there was a conspicuous failure to organise for victory. It was during this period that Germany and America gained the industrial rewards of an earlier investment in science and technology.

That is not to say that Britain stagnated industrially

> British industry . . . more than doubled its output between 1870 and 1913. But in the world as a whole there was a fourfold increase and whereas Britain in 1870 produced one-third of the world output of manufactures, in 1913 it produced only one-seventh.[1]

This period was one of increasing world prosperity and expansion in which Britain shared and which induced a euphoric feeling of material well-being. Industrial expansion was not of itself the result of industrial planning and foresight. It was more the result of the production of a new range of goods and the opening up of new markets which brought an increasing demand for the new and old products. The expansion was securely founded in increased coal and steel production, improved communications and an abundance of cheap labour.

Industry in the Last Quarter of the Century

The coal industry achieved its greatest output, of 287 million tons, in 1913. But while Britain mined 50% more coal than America, Germany and France combined in 1870, by 1900 she produced 70% less than they; while British output doubled, Germany's quadrupled and America's increased eightfold.

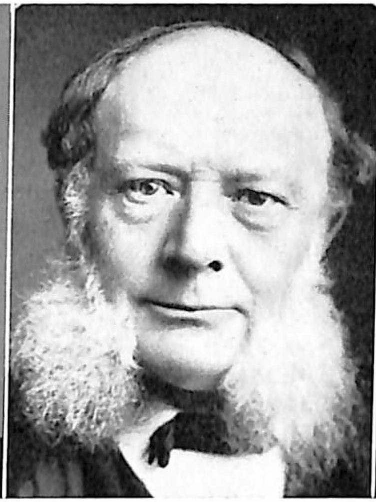
The transition from iron to steel occurred during the second half of the century. While British production of pig-iron trebled between 1850 and 1900, steel production increased from 60,000 tons to 5 million tons. Britain possessed an initial advantage in steel, as in many other products, for the basic technological discoveries were of British origin. Notwithstanding this advantage British steel production was overtaken by that of Germany before the end of the century. British steel production exceeded that of Germany by 2 million tons in 1890; by 1900 German steel production exceeded Britain's by over a million tons.

Bessemer and William Siemens showed how to make steel cheaply and in bulk from phosphorus-free iron ores. The second major breakthrough in the steel industry was made by Sidney Gilchrist Thomas, who, in 1878,

[1] W. Ashworth, *Economic History of England 1870–1939* (London, 1960), p. 34.

Sidney Gilchrist Thomas (1805–85)

His process unfortunately enabled Belgium and Germany to make steel as cheaply as Britain.



Sir William Siemens (1823–83)

Inventor of the regenerative furnace for steel-making.

Sir Henry Bessemer (1813–98)

His discovery caused world steel output to soar from half a million to twenty-eight million tons between 1870 and 1890.

demonstrated the making of steel from phosphorus-bearing iron ores and this doubled the potential ores available for steel production.

Not one of these three figures received assistance from academic, scientific or government sources.

> Bessemer was an inventor with no formal education; Siemens a trained engineer; Thomas a police court clerk with a classical education and a passionate interest in chemistry.[1]

Of the three Thomas came nearest to the modern concept of a scientist.

> He alone appears to have been conscious of what he was trying to do. He alone analysed the whole problem and found a theoretical solution which was successful in practice.[2]

Circumstances prevented Thomas from pursuing a university career, but due to the existence of the Birkbeck Institute he was enabled to pursue his chemical studies during the evening and a cellar became the laboratory for his experiments.

Steel for iron was one of the three major innovations of this period, the other two being the emergence of electrical industries and the creation of new chemical industries. By 1900 Germany led in all three.

The major example of German efficiency was seen in the dyestuffs industry. W. H. Perkin of the Royal College of Science had discovered mauve, the first of the coal-tar dyes, in 1856. Chemists turned their attention to the production of synthetic dyestuffs but the initiative quickly passed to Germany—not surprisingly, for she possessed greater

[1] Bernal, *Science and Industry*, p. 94. [2] Ibid., p. 95.

facilities for the study of organic chemistry, larger numbers of chemical engineers and an adequate supply of highly-trained scientists and technicians from university research departments and technical institutes. In 1860 the number of patents relating to dyes filed in Britain over a five-year period was 20, whereas in Germany there were 52. By 1900 these numbers had become 8 and 427 respectively. The irony of Britain's position is revealed in the following quotation:

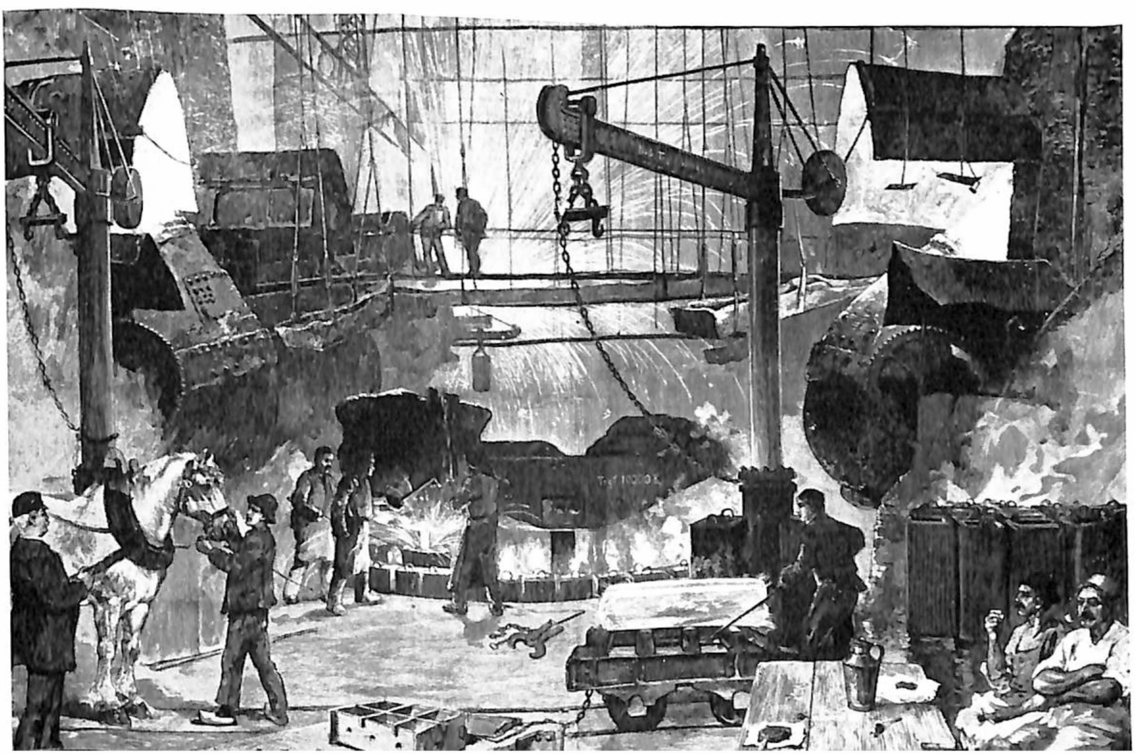
> England produces immense quantities of benzene, the greatest part of which goes to Germany, there to be converted into aniline dyes, a considerable quantity of which goes back to England. No other country is so far advanced in the manufacture of the coal-tar colours as Germany. The quantity of alizarine manufactured by the German makers far surpasses the English production.[1]

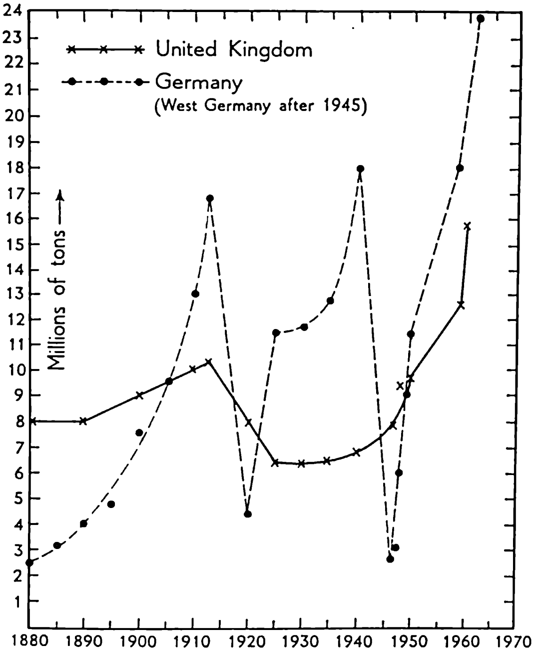
Britain was in fact importing four-fifths of her dyestuffs from Germany and it was not until 1914 when the supply ceased that the Government actively encouraged the industry.

[1] F. Versmann, *Alizarine, Natural and Artificial* (New York, 1873). Quoted in G. Gore, *The Scientific Bases of National Progress* (Williams & Norgate, 1882), p. 66.

The Bessemer Works

In 1860 Bessemer patented his tilting converter. This could make steel cheaply and in bulk, and by 1900 nearly two million tons of steel were being produced annually in Britain by the Bessemer method.

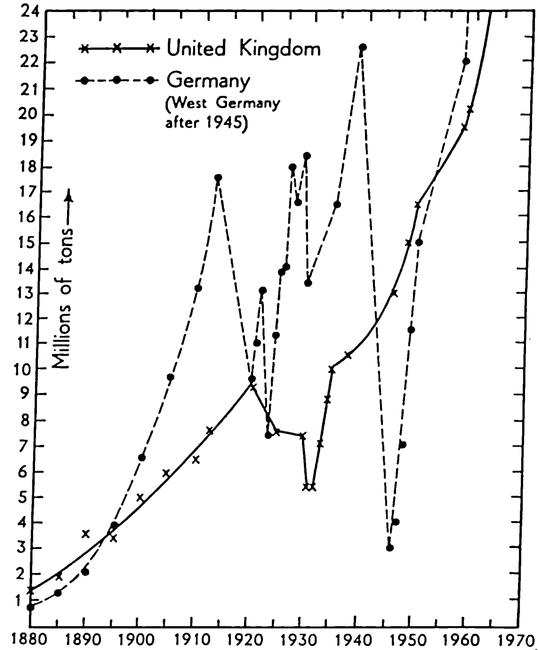




Graph 1. Production of pig-iron and ferrous alloys in Great Britain and Germany, 1880–1965.

Sources:

I. Svennilson, *Growth and Stagnation in the European Economy*, pp. 257–9. U.N. Economic Commission for Europe, 1954.
Statistical Summary of the Mineral Industry, 1958–63. World Production, Exports and Imports (88-2201-0-63). Ministry of Overseas Development. H.M.S.O., 1965.



Graph 2. Production of steel ingots and castings in Great Britain and Germany, 1880–1965.

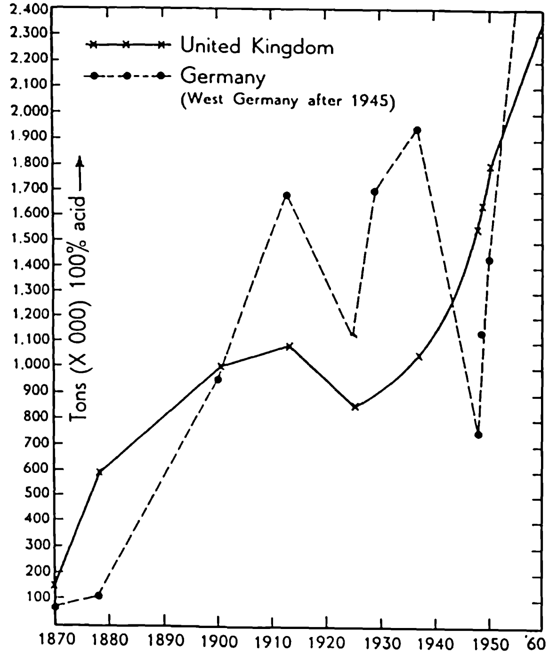
Sources:

I. Svennilson, op. cit., pp. 262–3.
Statistical Summary of the Mineral Industry, 1958-63. World Production, Exports and Imports (88-2201-0-63). Ministry of Overseas Development. H.M.S.O., 1965.

Britain, once the 'workshop of the world', was, during this period, increasingly saddled with obsolescent equipment and techniques. Because of Britain's early lead in the Industrial Revolution other countries were forced, in attempting to emulate this success, to maximise efficiency, organisation, education and training. Hence in Germany technical and scientific education received strong financial support from the State. In industry close relations were maintained with the universities and there was a greater willingness to use scientists and technical men at all levels.

In England suspicion of technical training and innovation was deep-rooted among men and management. Further, the leaders of industry lacked the education and training best suited for their positions.

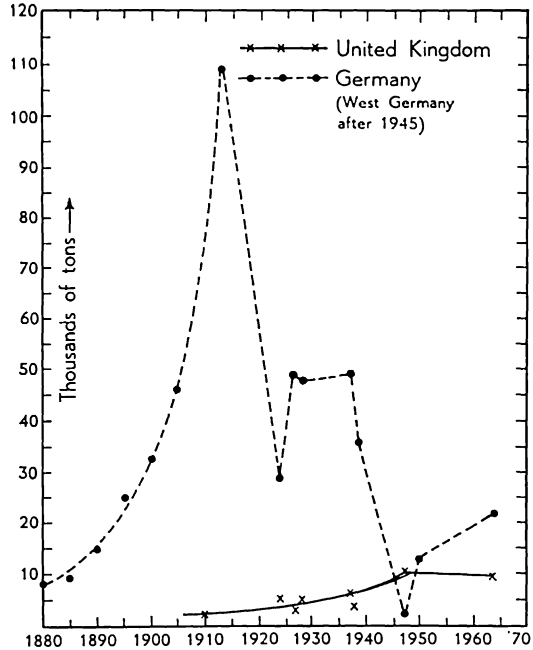
> The fact remains that the wealthy manufacturer . . . reverses the example of the conquering Romans and sends his son to



Graph 3. Production of sulphuric acid in Great Britain and Germany, 1870–1965.

Sources:

I. Svennilson, op. cit., pp. 286–7.
The Chemical Industry, 1964–5. A Study prepared by the Chemical Products Special Committee. O.E.C.D., Paris, 1966.



Graph 4. British and German exports of synthetic dyestuffs, 1880–1965.

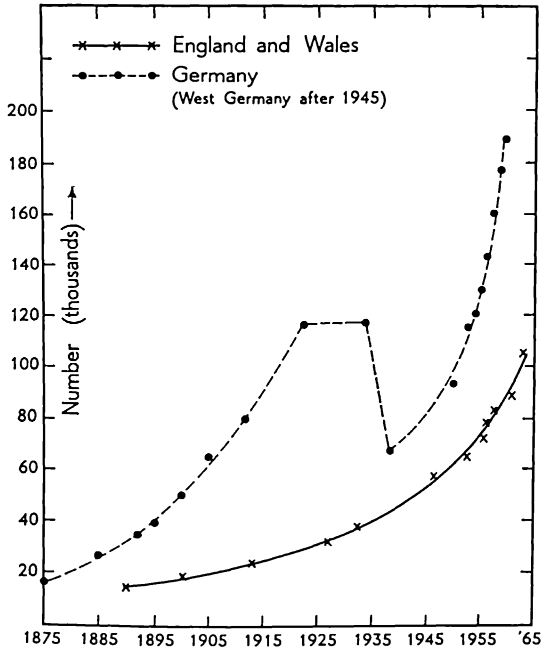
Sources:

I. Svennilson, op. cit., p. 292.
L. F. Haber, *The Chemical Industry during the Nineteenth Century*, p. 219. Oxford, Clarendon Press, 1958.

a classical school to learn Latin and Greek as a preparation for cloth manufacturing, calico printing, engineering or coal mining . . . After his scholastic career, he enters his father's factory at 20 to 24, absolutely untrained in the chief requirements of the business he is called upon to direct, the complex details of which he has never had an opportunity of mastering . . . Is it fair to the young chemical or jute manufacturer that he should have been taught nothing of chemistry or of practical mechanics, steam, electricity, methods of commerce or even of modern languages?[1]

The danger of overstressing invention and practical skills at the expense of scientific research was pointed out by George Gore, Principal of the Birmingham Institute of Scientific Research.

[1] T. H. Huxley, *Technical Education*: Inaugural Address at Dundee Technical Institute (1888).



Graph 5. Growth of the University population in: (a) *England and Wales, and* (b) *Germany, 1875–1965.*

This graph includes students at University Colleges in England and Wales and at Technical High Schools in Germany (West Germany after 1945).

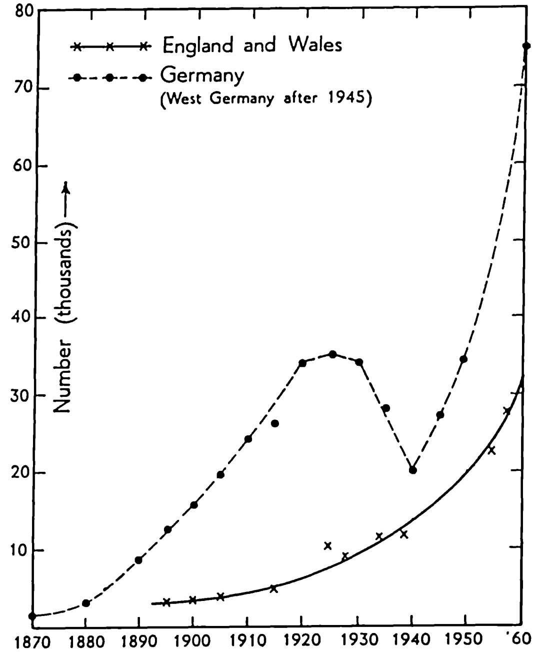
Sources:

1. *Germany*

Minerva, *Jahrbuch der Gelehrten Welt*, by R. Kukula and K. Trübner. Verlag Karl J. Trübner, 1891– .
W. Lexis, *Die Deutschen Universitäten.* A. Asher & Co., Chicago, 1893
World Survey of Higher Education, UNESCO, 1966.

2. *England and Wales*

Minerva, *Jahrbuch der Gelehrten Welt*, by R. Kukula and K. Trübner. Verlag Karl J. Trübner, 1891– .
Board of Education: Reports from Universities and University Colleges participating in the Parliamentary Grant.
M. Argles, *South Kensington to Robbins.* Longmans, 1964.
University Grants Commission, Annual Returns.



Graph 6. Students of science and technology at University: (a) *England and Wales, and* (b) *Germany, 1870–1965.*

This graph includes students at University Colleges in England and Wales and at Technical High Schools in Germany (West Germany after 1945).

Sources:

1. *Germany*

Minerva, *Jahrbuch der Gelehrten Welt*, by R. Kukula and K. Trübner. Verlag Karl J. Trübner, 1891– .
W. Lexis, *Die Deutschen Universitäten.* A. Asher & Co., Chicago, 1893
World Survey of Higher Education. UNESCO, 1966.

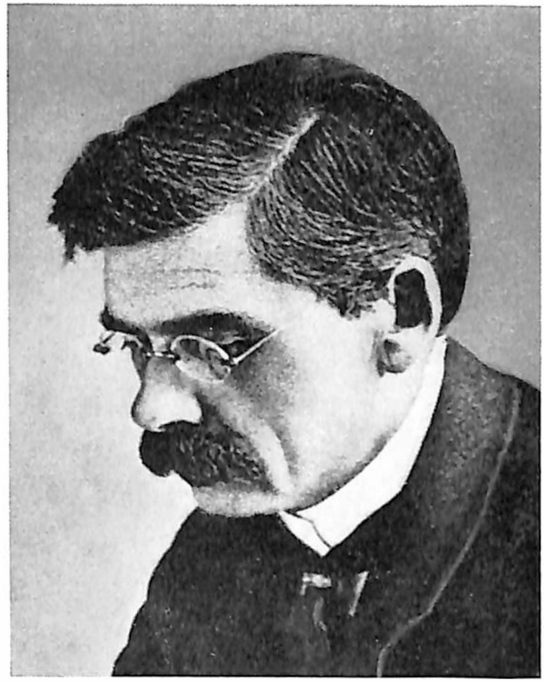
2. *England and Wales*

Board of Education: Reports from Universities and University Colleges participating in the Parliamentary Grant.
University Grants Commission, Annual Returns.
G. L. Payne, *Britain's Scientific and Technical Manpower.* O.U.P., 1960.
M. Argles, op. cit.
University Colleges, Great Britain — Treasury Grant-in-Aid, 1897, 1901, 1907.
Report of the Robbins Committee on Higher Education, 1963.

In this country [he said] such great practical results have been obtained by means of invention, that many persons suppose a sufficiency of inventive skill will enable us to effect every possible scientific object . . . the progress of invention, however, depends upon that of discovery, and these various inventions wanted by manufacturers and others probably cannot be perfected until suitable new knowledge is found . . . In consequence of our so-called 'practical spirit' we overestimate the power of invention and undervalue the discovery of new absolute truths; because invention has done so much, we think it will continue to do so, but the latter depends on a continued supply of discoveries.[1]

Whilst research is being neglected, manufacturers and others are asking for improvements in their machines and processes . . . and inventors are continually trying to supply their demands, by exercising their skill with the aid of scientific information contained in books; but after putting manufacturers and themselves to great expense, they very frequently fail, not always through want of inventive skills but often through want of new knowledge attainable only by means of new research.[2]

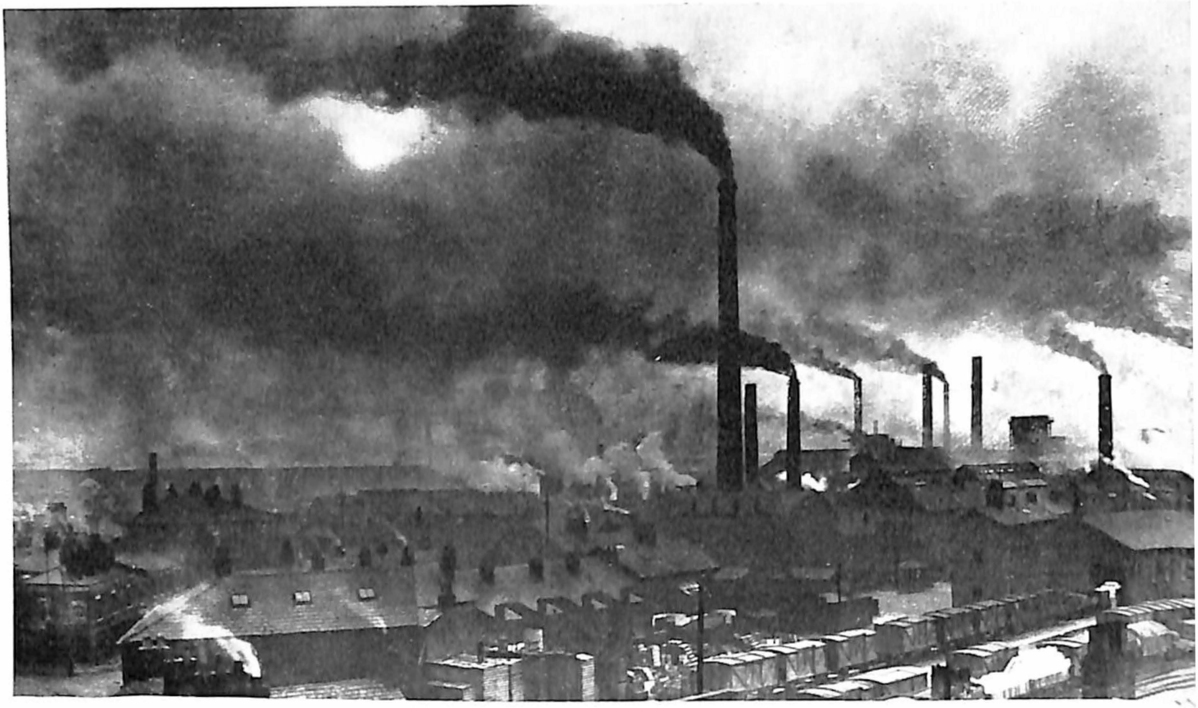
It has been objected that Continental nations, the Germans in particular, have pirated our patents, infringed our designs, mutilated our labels and taken our improvements wholesale . . . But we have had the great advantage of being first in the markets of the world; and that advantage can only be retained by our being the first in the pursuit of original research and not by purchasing foreign inventions . . . The industry of the Germans in scientific research is quite remarkable, they are availing themselves of the great fountain of knowledge to a much greater extent than ourselves and are already beginning to reap the reward.[3]



Ferdinand Hurter (1844–98)

Of Swiss nationality, he was educated at Zürich Polytechnic and Heidelberg University. In 1867 he joined the firm of Gaskell & Deacon, Widnes, as chief chemist and later, in 1891, became the chief chemist to the United Alkali Company on its formation. One of the foremost authorities in the Leblanc soda industry.

[1] Gore, op. cit., pp. 72–74.
[2] Ibid., pp. 68–69.
[3] Ibid.



Smoke over Leblanc Widnes

In 1850 Widnes was a rural village of 2,000 inhabitants. During the next few decades it became a leading centre for the manufacture of soda by the Leblanc process. At the peak of the development of the Leblanc industry more than a million tons of coal were consumed annually in the chemical works of the town.

The new instrument of scientific advance was to be the research laboratory — be it in a university or industry or a government establishment.

> As the century progressed science began to play a bigger part in universities and government teaching establishments. Talented amateurs gave way to professionals . . . Success of inventors like Edison led to the setting up of large research laboratories. The industrial laboratory and government research laboratory brought science back in to industry and the profession of scientific research worker was created, and it became impossible for the inventor to succeed against big firms. The 19th century was a century of transition for science. It changed from an elegant ornament of society, practised by virtuosi, to an essential factor in everyday production of goods and services.[1]

[1] Bernal, op. cit., p. 151.

Along with this change there also occurred a change in the character of industry. The old industries of coal, iron and steel, textiles and heavy chemicals were supplemented by a diversity of new industries the origins of which owed more to scientific research than to the empirical discoveries of practical men — such were the dyestuffs, fertilisers and explosives industries; the non-ferrous metals industries; electrical generation and distribution and electro-chemical industries.

Scientific Manpower

In 1902 a Committee set up by the British Association for the Advancement of Science counted 502 chemists, of whom 107 were graduates. The figure was recognised as being on the low side and the President of the Association, Sir James Dewar, estimated the upper limit to be 1,500. Even this figure compared unfavourably with Germany's total of 4,000 industrial chemists, 84% of whom were

Hurter's Laboratory

The United Alkali Company, on its formation in 1891, centralised its research under the control of its chief chemist, Dr. Ferdinand Hurter, at Widnes. It was the first industrial laboratory in England to carry out systematic research in all branches of the chemical industry. Hurter's original staff comprised six trained chemists, a clerk and a general handyman.

university trained as compared to 47% of the British number. Further, the Germans awarded degrees for original research and not for 'questions asked and answered on paper'.[1] The chemists turned out by the English system were:

> Chock full of formulae, they can recite theories and they know textbooks by heart, but put them to solve a new problem, freshly arisen in the laboratory, and you will find that their learning is all dead.[2]

Cardwell points out that at this time 70% to 75% of chemists were teachers, and continues:

> It is merely a corollary of this to say that the majority of those who were reading for degrees in chemistry at that time were doing so in the anticipation of becoming teachers, if this was true of chemistry, it must 'a fortiori' have been true of physics and the other 'pure sciences'.[3]

Between 1907 and 1914 out of 3,318 science graduates 1,077 (33%) were in fact Elementary School teachers.

> Casting about for students, the new universities perceived in the primary teaching profession, a vast field to be cultivated, and as the supply of training colleges was quite inadequate to meet this demand for teachers the universities succeeded in obtaining from the government a licence to train, in regular university courses, large numbers of students whose expenses were paid out of public funds on condition that they undertook to devote themselves to the profession of primary teaching.[4]

Cardwell concludes:

> It cannot be said that industry offered great opportunities to the increasing numbers of young science graduates.[5]

During the last half of the nineteenth century the leading technological centre in England, the institution most likely to produce the managerial technologist and scientific research worker was the Royal College of Science and Royal School of Mines. From a survey[6] of the careers of 850 former pupils it is possible to draw certain conclusions.

Out of 850 former pupils spread over forty years only 170 (20%) had entered industry at some stage in their careers. It is not unreasonable to assume that no other institution contributed nearly as many. Furthermore, the majority entered mining and brewing, with the chemical industry coming a poor third. Many of the positions they held were not in managerial or research spheres but in those of the inspectorate.

Some 32% of the total number (i.e. 275) went abroad, either immediately on qualifying, or at a later stage in their careers. They went principally to India, Australia and South America. It can be argued that Britain was herself benefiting from the development of the Dominions, but a loss of one in three

[1] J. N. Lockyear, *Education and National Progress*, p. 118.
[2] Cardwell, op. cit., p. 158.
[3] Ibid., p. 160.
[4] Ibid., p. 162.
[5] Ibid.
[6] T. G. Chambers, *Register of Associates and Old Students of the Royal College of Chemistry, the Royal School of Mines and the Royal College of Science*. (Hazell, Watson & Viney Ltd., 1896).

technologists was a serious drain on resources at a time when Britain herself needed every scientist and technologist.

At some time in their careers 243 (28%) took up teaching, 15% entered university or its equivalent and 13% went into other forms of teaching. It is interesting to note that forty-five had been to German universities either before entry or after leaving, whereas the comparable figure for Oxford and Cambridge was seventeen. This was a not altogether unfair reflection of their relative status, for Oxford and Cambridge had little to offer technologists at the time. Some indications of research publications are given and from these it is possible to suggest tentatively an upper figure of 75 (9%) as having participated in research. Thus, of a representative sample of the leading technologists of the era, only one in ten actually undertook some research and much of this was of a trivial nature. At the beginning of this period Edward Frankland produced figures to show that, so far as chemists were concerned, not only was England training fewer than her competitors but they were also less productive in research. He attributed this difference to the low status of research in England and to the absence of state support and state laboratories.

Emergence of the Civic Universities

The most significant feature of the education world during the last quarter of the century was the emergence of the new 'civic' universities. These followed the pattern created by University College, London, and Owens College, Manchester, a pattern which included research and technological studies.

The Civic University Colleges were founded in response to local and national needs. First, to provide a liberal education which would be more broadly based than that at Oxford and Cambridge and which would better serve the interests of the commercial middle classes. Second, to supply the facilities for the training of the cadres of scientists and technologists required to meet the needs of a competitive industrial nation.

> There was a national feeling in favour of British institutions which would do for British industry what the polytechnics were doing on the continent. It became accepted policy that higher technology should be incorporated into the new university colleges for the manager-technologist. Therefore the most powerful argument for the new University Colleges was one based on their utilitarian value. Technology entered British Universities partly through a chance encounter of history and partly through the deep conviction among leaders of educational thought that scientific and technical education should not be separated from liberal studies.[1]

It must be conceded, despite the reforms carried out at Oxford and Cambridge, that the civic universities were much more open-minded and ready to accept what to some appeared technological subjects of dubious academic value. Thus University College, London, was the first to pioneer engineering and after 1870 became the main teaching centre for this subject. Owens College under Roscoe developed a chemical research school along German lines. Leeds set up a Faculty of

[1] Ashby, op. cit., pp. 63–64.

Technology in which dyeing, chemistry and leather manufacturing were studied. Metallurgy and mining were first studied at Sheffield. Further details of the introduction of technologies are given in Appendix II.

These institutions were founded as the result of the foresight and initiative of local merchants and manufacturers, and learned societies such as the Literary and Philosophical Societies. The Council for the Higher Education of Women also played a notable part. These local groups succeeded in their aims in spite of the lack of state support. Owens College, as pointed out earlier, owed its existence to three donations of £100,000. At Leeds the Yorkshire College was opened after £60,000 had been raised by public subscription, and £20,000 was collected to found the Newcastle College of Physical Science. Government subsidies can almost be ignored in comparison. Some £15,000 of Treasury grants was distributed among the University Colleges in 1889. A Committee of Grants was formed for this purpose in 1903 by which time the grant was £27,000. In response to pressures the Treasury doubled its grant in 1904. In Germany the Physikalische-Technische Reichsanstalt of Charlottenburg alone received a subsidy of half a million pounds. On average the German universities received 70% of their income from the State.

CIVIC UNIVERSITIES

College	*Opened*	*Became an independent university*
University College, London	1828	1836
King's College, London	1831	1836
Durham	1833	1833
Owens College, Manchester	1851	1903
Hartley Institute, Southampton	1862	1952
Newcastle College of Physical Science	1871	1963
York College of Science, Leeds	1874	1904
College of Science for the West of England, Bristol	1876	1909
Firth College, Sheffield	1880	1905
University College, Nottingham	1881	1948
University College, Liverpool	1882	1903
University Extension College, Reading	1892	1926
Exeter Technical and University Extension College	1895	1955

Owing to the munificence of Sir Josiah Mason, who contributed £200,000, Mason's College was opened in Birmingham in 1880. It was founded specifically for the purposes of advancing science and technology and

> to provide enlarged means of scientific instruction . . . and to promote the prosperity of the manufactures and the industry of the country.

Huxley spoke at the opening of the College. He asserted that England was reaching the crisis of the battle over education in which physical science was entering the arena as a third force in competition with ancient literature and modern literature. He commented on the opposition to scientific education and reiterated his plea for a wider definition of culture embracing both the Sciences and the Arts. Some of his remarks would not be inappropriate at the present time.

> How often have we been told that the study of physical science is incompetent to confer culture; that it touches none of the higher problems of life; that the continual devotion to scientific studies tends to generate a narrow and bigoted belief in the applicability of scientific methods to the search after truths of all kinds . . .

Technology in which dyeing, chemistry and leather manufacturing were studied. Metallurgy and mining were first studied at Sheffield. Further details of the introduction of technologies are given in Appendix II.

These institutions were founded as the result of the foresight and initiative of local merchants and manufacturers, and learned societies such as the Literary and Philosophical Societies. The Council for the Higher Education of Women also played a notable part. These local groups succeeded in their aims in spite of the lack of state support. Owens College, as pointed out earlier, owed its existence to three donations of £100,000. At Leeds the Yorkshire College was opened after £60,000 had been raised by public subscription, and £20,000 was collected to found the Newcastle College of Physical Science. Government subsidies can almost be ignored in comparison. Some £15,000 of Treasury grants was distributed among the University Colleges in 1889. A Committee of Grants was formed for this purpose in 1903 by which time the grant was £27,000. In response to pressures the Treasury doubled its grant in 1904. In Germany the Physikalische-Technische Reichsanstalt of Charlottenburg alone received a subsidy of half a million pounds. On average the German universities received 70% of their income from the State.

Owing to the munificence of Sir Josiah Mason, who contributed £200,000, Mason's College was opened in Birmingham in 1880. It was founded specifically for the purposes of advancing science and technology and

> to provide enlarged means of scientific instruction . . . and to promote the prosperity of the manufactures and the industry of the country.

Huxley spoke at the opening of the College. He asserted that England was reaching the crisis of the battle over education in which physical science was entering the arena as a third force in competition with ancient literature and modern literature. He commented on the opposition to scientific education and reiterated his plea for a wider definition of culture embracing both the Sciences and the Arts. Some of his remarks would not be inappropriate at the present time.

> How often have we been told that the study of physical science is incompetent to confer culture; that it touches none of the higher problems of life; that the continual devotion to scientific studies tends to generate a narrow and bigoted belief in the applicability of scientific methods to the search after truths of all kinds . . .

CIVIC UNIVERSITIES

College	*Opened*	*Became an independent university*
University College, London	1828	1836
King's College, London	1831	1836
Durham	1833	1833
Owens College, Manchester	1851	1903
Hartley Institute, Southampton	1862	1952
Newcastle College of Physical Science	1871	1963
York College of Science, Leeds	1874	1904
College of Science for the West of England, Bristol	1876	1909
Firth College, Sheffield	1880	1905
University College, Nottingham	1881	1948
University College, Liverpool	1882	1903
University Extension College, Reading	1892	1926
Exeter Technical and University Extension College	1895	1955

. . . For the purpose of attaining real culture, an exclusively scientific education is at least as effectual as an exclusively literary education. But, in the belief of the majority of Englishmen culture is obtainable only by a liberal education; and a liberal education is synonymous with one form of literature — that of Greek and Roman antiquity. The man who has learned Latin and Greek, however little, is educated; while he who is versed in other branches of knowledge is no more than a respectable specialist. The stamp of the educated man, the University degree, is not for him, . . .

Arnold tells us that the meaning of culture is 'to know the best that has been thought and said in the world' . . . We may dissent from his assumption that literature alone is competent to supply this knowledge. Having learnt all that Greek, Roman and modern literature have to tell us, it is not self-evident that we have laid a sufficiently broad and deep foundation for that criticism of life which constitutes culture. Indeed neither nations nor individuals will really advance if their common outfit draws nothing from the stores of physical science.

Nevertheless, I am the last person to question the importance of genuine literary education, or to suppose that intellectual culture can be complete without it. An exclusively scientific training will bring about a mental twist as surely as an exclusively literary training.[1]

[1] Huxley, *Science and Culture*, pp. 1–23.

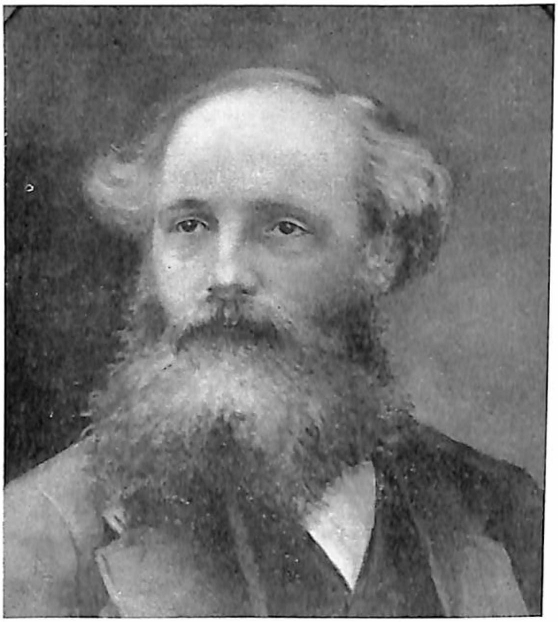
Science at Oxford and Cambridge

Reforms at Oxford and Cambridge followed the abandonment of traditional attitudes and were part of a trend towards a more specialised scientific education. Some of the reforms also reflected the attitude of the body known as the Association for the Organisation of Academical Study which had adopted the following resolution with regard to research:

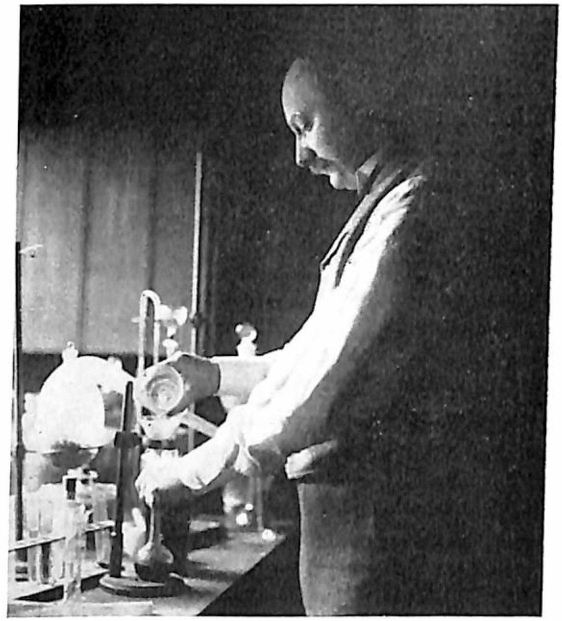
> In any redistribution of the revenues of Oxford and Cambridge the chief end to be kept in view is the adequate maintenance of Mature Study and Scientific Research as with the view of bringing the higher education within the reach of all who are desirous of profiting by it. To have a class of men whose lives are devoted to research is a national object. That it is desirable, in the interests of national progress and education, that Professors and special institutions shall be founded in the Universities for the promotion of scientific research. That the present mode of awarding Fellowships as prizes has been unsuccessful as a means of promoting scientific research.

The natural sciences were now fully incorporated in the curricula. This put into effect the recommendations of the Devonshire Commission of 1872, namely, that scientific research was a prime function of the universities and that it was the duty of the universities to produce teachers and professional scientists.

As mentioned earlier, Cambridge was not the first to recognise the value of experimental physics as a teaching and research subject. University College, London, and Owens College, Manchester, had been the first to



James Clerk Maxwell (1831–79)
First Professor of Experimental Physics at the Cavendish Laboratory, Cambridge.



Lord Rayleigh (1842–1919)
Professor of Experimental Physics at the Cavendish Laboratory, Cambridge.

incorporate this subject in the 1860s. The Cavendish laboratories at Cambridge and the Clarendon laboratories at Oxford were not opened until the early 1870s. During the first quarter of the twentieth century, however, the Cavendish became the leading research centre in physics.

The origins of the Cavendish were characteristic of the way things were done at the time. At Cambridge, the Natural Science Tripos comprising the subjects of botany, chemistry, applied mechanics and physics had been in existence since 1851 — yet there had been no experimental work in physics. A Syndicate was appointed in 1868 to review the position and recommended the appointment of a professor, the provision of a laboratory and a stock of physical apparatus. The cost of the new building, £6,300, was entirely borne by the Duke of Devonshire, Chancellor of the University, who also provided the apparatus.

Clerk Maxwell, previously Professor of Natural Philosophy at King's College, London, when appointed to the new Chair of Experimental Physics at the Cavendish, confessed to not having any previous experience of teaching experimental work. He was later to report:

> The Chancellor has now completed his munificent gift to the University by furnishing the Cavendish laboratory with apparatus suited to the 'present state of science'.[1]

[1] Alexander Wood, *The Cavendish Laboratory* (C.U.P., 1946), p. 11.

Suspicions — arising from the list of apparatus drawn up by Maxwell — that the laboratory was not really adequate for research, are confirmed by the fact that his successor, Lord Rayleigh, was immediately struck by the inadequacy of the available apparatus. To remedy this situation Rayleigh inaugurated an Apparatus Fund to which he himself donated £500. Later Rayleigh was to give a further £5,000 for an extension to the laboratory. Maxwell's interests at the time were mainly theoretical and very little experimental research was carried out under him. The success of the Cavendish was established by his successors, Rayleigh and J. J. Thomson, and its reputation reached its peak in the era 1919–37 under Ernest Rutherford. Lord Rayleigh introduced undergraduate teaching in practical physics. Prior to this the laboratory catered only for those who had taken the Mathematical Tripos and who wished to change over to physics.

When Rayleigh left the Cavendish in 1884 for a Chair at the Royal Institution — a move which reflects the relative status of Cambridge and the Royal Institution — he had produced sixty research papers and the foundations of success had been laid. He was followed by J. J. Thomson, the discoverer of the electron. It was under his aegis that the University began the practice of allowing students from other universities to come to Cambridge and engage in advanced study and research. One of the first to do so was the young New Zealander, Ernest Rutherford, who came as an 1851 Research Exhibitioner. The Commissioners of the 1851 Exhibition had set aside a sum of money from the proceeds of the Exhibition to furnish research students from the Colonies with grants of £150 a year. Only two out of a total of twenty-nine came to the Cavendish in 1895, but during the years 1896–1921 60 out of 103 were to come. By 1914 the reputation of the Cavendish was sufficient to attract students from the Continent, America and the Dominions.

Advances in Technical Education

In the field of technical education an Act of Parliament had empowered local authorities to set up technical instruction centres. During the succeeding half-century technical education was to make considerable progress. In 1881 the first English technical college was opened at Finsbury by the City and Guilds Institution. This was followed in 1885 by the opening of the Central Institute of the City and Guilds Institution at South Kensington. This was intended to be equivalent to a German or Swiss Polytechnic, the students being prospective technical teachers or industrialists. By now the Education Act of 1870 had been in operation long enough for sufficient numbers of students with a reasonable standard of general education to be available. The report of a Royal Commission on Technical Instruction recommended in 1881 that metalwork, drawing and woodwork be taught at Elementary level and that more science be taught at Secondary School level. The National Association for the Promotion of Technical Education was formed in 1887 and two years later it published a survey of technical education in England. It found that the majority of teachers received little, if any, scientific instruction.

Towards the end of the century two further Acts brought about an increase in the finances available for technical education. In 1889 the Technical Instruction Act empowered local

Finsbury Technical College

Founded in 1881 by the City and Guilds Institute, this was the first and most celebrated technical college in London. Compare its foundation with the Charlottenberg Institute.

authorities to raise a penny rate, and in the following year the Local Taxation (Customs and Excise) Act enabled certain sums from customs and excise duties to be allocated to local education authorities.

However, in 1904, Michael Sadler was compelled to draw attention to the elementary nature of a great deal of the work in technical education. Much of the emphasis was on evening work and unfortunately the standards and effectiveness, he said, of the evening Technical Schools were very low. The root cause of the trouble was that unlike the German polytechnics, the technical education movement in England was aimed, not at the production of the managerial technologist, but at the production of a technically competent 'rank and file'.

By 1908 there were 23 polytechnics in London and 110 in the provinces. The staffs of these involved 300 chemists, of whom only a dozen or so were engaged in research. Professor Meldola called for a 'general recognition of research as an educational principle'[1] so that these polytechnics could become centres of scientific and technological research. The teachers were overburdened with teaching duties and the atmosphere was not conducive to research.

Professor Meldola concluded:

> That is one of the reasons why the polytechnic movement has produced such a small effect upon the chemical industry . . . A school of science which is not also a centre of research is bound to degenerate and become a mere cramming establishment scarcely worth the cost of maintenance.

The Board of Education in its Report of 1908 laid the blame for the slow growth of technical education on the attitudes of industry, namely, the small demand for trained men,

[1] Raphael Meldola, *5th Annual Report of the British Science Guild* (1911) (quoted by Cardwell, op. cit., p. 169).

preference for the works-trained technologist, and prejudice against the 'college-trained' man.

The number of full-time technical students per 10,000 population in 1900 was 12·8 in the United States of America, 7·9 in Germany and 5 in England. By 1914 there were some 2,500 full-time students of engineering and technology in English universities and technical institutions. Nevertheless this was only a small fraction of the comparable figure for Germany. At the outbreak of the First World War technical education in England remained inferior in quantity and quality to its counterparts in Germany and the United States of America.

Science in the Education of Adults

Propagandists for science found two potential sources of mass audience who were eager to receive instruction in science; these were working men and the middle- and upper-class women who were denied opportunities

Charlottenburg Technical Institute

Originally founded as a technical school in 1821, this became the *Königliche Technische Hochschule* in 1879, when the building was constructed at a cost of half a million pounds. Heavily subsidised by the State — 70% of its annual running costs were provided from central funds — it possessed remarkable technical equipment, and had professors in a wide spectrum of scientific and technical subjects. It soon became the leading technological institute in Europe.

for higher education. In addition to teaching the theories and discoveries of science, lecturers impressed on their audiences the cultural significance of science and its importance to the state of the nation. Popular science lectures to large audiences became the vogue, audiences differing markedly from the genteel and influential character of those that Davy and Faraday had attracted at the Royal Institution.

In 1867 the North of England Council for Promoting the Higher Education for Women had been organised. It invited James Stewart, a young Fellow of Trinity College, Cambridge, to deliver a series of lectures on education at Leeds, Liverpool, Sheffield and Manchester. He chose instead to lecture on the History of Science. His lectures actually comprised aspects of astronomy, light, electricity and magnetism. Despite the formidable appearance of such a course of lectures, Stuart actually lectured to enthusiastic audiences of up to 100 women![1]

He followed this up with lectures to railwaymen at Crewe under the auspices of the Mechanics' Institute, and at Rochdale at the invitation of the Equitable Pioneers Co-operative Society. Meanwhile, Henry Roscoe had organised a series of Penny Science Lectures for large audiences of working men. Huxley, too, was lecturing at the Working Men's College and the Working Men's Club and Institute in London. Others to pursue similar activities were Sir John Herschel, John Tyndall and Charles Kingsley. Thus, in the latter half of the century, science played an important role in the general education of adults. Science became so popular that by 1890, 42% of the courses organised for adults by the universities of Oxford, Cambridge and London were in science and the audiences included large numbers of artisans and women.

Continued Dissatisfaction

The society of late Victorian England was becoming increasingly professional and technological. The newly-created Scientific Societies reflected the tendencies of the age and contrasted with those formed in the days of Babbage. The emphasis was now on engineering and technology rather than on those sciences which could be pursued by amateurs and dilettantes. The following selection gives an indication of the newer type of society.

Chemical Society	1841
Institution of Mechanical Engineers	1847
Institution of Gas Engineers	1863
Iron and Steel Institute	1869
Physical Society	1874
Institute of Chemistry	1877
Institute of Mining Engineers	1889
Institute of Mining and Metallurgy	1892

Considerable industrial progress had been made; scientific achievements were many; society was becoming increasingly 'professionalised'. Yet there remained those who were dissatisfied with the slow rate of progress. They did not look at the state of science and industry with any great satisfaction but looked outwards at the Continent and at America, and came to the conclusion that 'what might have been' was more significant than 'what was'.

The controversy over state intervention continued and the view still prevailed that

[1] T. Kelly, *A History of Adult Education in Great Britain* (Liverpool U.P., 1962), pp. 219–20.

science was best done by amateurs. The Astronomer Royal, for example, commented:

> I think that successful researches have in nearly every instance originated with private persons, or with persons whose positions were so nearly private that the investigators acted under private influence, without incurring the danger attending connection with the State. Certainly I do not consider a Government is justified in endeavouring to force, at public expense, investigations of undefined character, and, at best, of doubtful validity: and I think it probable that any such attempt will lead to consequences disreputable to science. The very utmost, in my opinion, to which the State should be expected to contribute, is exhibited in the large grant entrusted to the Royal Society.[1]

The 'large grant' referred to was the annual distribution of £4,000 of government money by the Royal Society. Until 1914 this was to remain the only external source open to the universities for financing research. The Earl of Craufurd, likewise, was of the opinion that:

> It is not at all desirable that the British tax-payer should be required to put his hand in his pocket to provide salaries for gentlemen who might be working rightly or wrongly. He could not control them, and while there are such a body of amateurs in the country, I think the researches may be very well left to them.[2]

One objection to state endowment of scientific research was that posts would be created and filled by persons of little ability desiring an easy occupation. To obviate this George Gore, Principal of the Birmingham Institute of Scientific Research, proposed that:

> Provision should be made, that in case a professor persistently failed to make, complete or publish his researches, or devoted less than the stipulated amount of time to such labour in the institution without reasonable cause, he should be removed.[3]

In assessing the causes for the absence of scientific research Gore gave among his reasons one which is commonly cited today:

> For each single man who can discover, there exist many who can teach. But with teaching in addition to research, and all the usual educational machinery — lectures, apparatus, pupils, registration of students, receipt of fees, examinations and marking of papers — it is the testimony of nearly every teacher in science, that he 'has no time for research'.[4]

Gore drew attention to what he considered were grave anomalies in society. The Royal Institution, for instance, spent only some £250 a year on scientific research whereas the annual expenditure of the British and Foreign Bible Society amounted to over £200,000. A bishop, he said, was paid £10,000 a year, a general £3,000, but Faraday's official salary at the Royal Institution had been a mere £200 a year. The distribution of £4,000 a year by the Royal Society was not good enough. Further, it was not used in the most efficient manner:

[1] *The English Mechanic*, no. 831 (1881), pp. 586–7.
[2] Ibid., no. 830 (1881), p. 560.
[3] Gore, *The Scientific Basis of National Progress*, p. 194.
[4] Gore, op. cit., p. 203.

> It is not the pure sciences, but the concrete and applied ones, such as meteorology, geology, and natural history . . . which have received the greatest degree of support from our Governments. . . . The men we reward the highest are not those who discover knowledge, but those who use it or apply it; . . . all of them gentlemen who render great service to the nation by using, diffusing, and applying knowledge already possessed.[1]

Another critic held the view that money

> might be best applied in establishing in the great centres, physical and chemical laboratories such as that which the Duke of Devonshire has established at Cambridge.[2]

Gore, like Playfair, pointed out that in the long run the national economy depended on the successful pursuance of scientific research. The emphasis on the applications of science, while rewarding in the short-term, would eventually lead to the decay of the foundations of science and technology, i.e. of research in 'pure' science.

> There is uneasiness at present respecting our ability to maintain our position in the race of progress and as our future success as a nation depends largely upon science, it is desirable to call attention to the great public importance of new, scientific knowledge . . . By the neglect of scientific investigation we are sacrificing our welfare as a nation. The greatest obstacle to the discovery of new knowledge lies in a widespread ignorance of the dependence of human welfare on scientific research . . . Science is fast penetrating into all our manufactures and occupations and those who are unscientific will have much less employment and will be left behind in the race of life. England will also be compelled, by the necessities of human progress and the advance of foreign intellect, to determine and recognise the proper value of scientific research as a basis of progress. National superiority can only be maintained by being first in the race, and not by buying inventions of other nations . . . Scientific research is not pursued because scarcely a member of the legislature is fully acquainted with the national importance of scientific discovery. . . . It is not pursued because of the 'practical' mind of the English . . . The intense desire which exists in this country for 'quick returns' has shown itself in the much greater readiness to aid technical education than to promote permanent progress by scientific research.[3]

Not only did economic progress depend on science but moral progress also, argued Gore, ultimately depended on the diffusion of science. Science, he claimed, invited the sympathies of different nations; *increased friendly feelings between them; diminished the probability of war!*

> The extension of new scientific knowledge is influencing morality and gradually reducing the selfishness of mankind.[4]

Sir Humphry Davy had earlier stressed the importance of the moral aspect of science.

> The origin, as well as the progress and improvement, of civil society is founded in

[1] Gore, op. cit., 54–57.
[2] Dr. Robinson, in the *English Mechanic*, 17 Aug. 1881, p. 83.
[3] Gore, op. cit., pp. 34–55.
[4] Ibid., p. 135.

> mechanical and chemical inventions. The comparison of savage and civilised man demonstrates the triumph of chemistry and mechanical philosophy as the causes not only of physical, but ultimately even of moral improvement.[1]

Spencer and Huxley were among others who took the same line. Such an argument, no doubt, had a strong emotional appeal to late Victorian society. Thus in his *Essays on Controversial Questions* Huxley included one on 'Science and Morals'. Spencer claimed that science was as good as languages not only in the training of memory and cultivating of judgment but also in inculcating moral discipline.

> Not only is science best for intellectual discipline, it is also best for moral discipline. The discipline of science is superior to ordinary education because of the religious culture that it gives. Thus to the question we set out with . . . What knowledge is of most worth? The uniform reply is science . . . Yet this study immensely transcending all other in importance is that which in an age of boasted education, receives the least attention.[2]

That Gore was merely destructive in his criticism could not be claimed even by his worst critic for he outlined a programme of reforms, nearly all of which have been adopted in the present century. To administer and foster science, he claimed, a Minister of Science with sound scientific knowledge and a Scientific Council were needed. The State should maintain laboratories of scientific research. National and provincial colleges should be set up — the former supported by the State and the latter by local authorities — in which the pursuance of scientific research would be the principal object. Finally, he called for the incorporation of original research in the requirements for science degrees along the lines of the German Ph.D. system.

Needless to say none of Gore's reforms was immediately implemented. Twenty years later, Sir Norman Lockyear, in his Presidential Address to the British Association, could still point to the neglect of science in the schools and universities and to the general absence of scientific research.

[1] Davy, *Consolations of Travel*, p. 242.
[2] H. Spencer, *Education: Intellectual, Moral and Physical* (1861; Watts & Co., 1934), p. 49.

Chapter Four

1914–39 STAGNATION

> In the conditions of modern life the rule is absolute: the race which does not value trained intelligence is doomed. Not all your heroism, not all your social charm, not all your wit, not all your victories on land or at sea, can move back the finger of fate. Today we maintain ourselves. Tomorrow science will have moved forward one more step, and there will be no appeal from the judgement which will then be pronounced on the uneducated.[1]

IT was to become increasingly clear as time went on that society was to be dependent on science and technology not only for its military capability but also for its material prosperity. Nations would be forced to compete with one another in the spheres of scientific research and technical expertise.

The First World War soon showed how inadequately prepared and inefficiently organised British industry was for supplying the arms necessary to defeat an adversary such as Germany. Jolted out of lethargy by the war the British Government energetically, if not very effectively, tackled the problems of organising industry and of harnessing technological manpower.[2] This spirit of urgency just as quickly evaporated with the winning of the war.

In the twentieth century Russia and China have revealed how rapidly societies can change under the impact of a technological revolution. England, having accepted in principle the need for science and technology, was very slow in adapting to make effective use of them. Paradoxically, therefore, while progress was rapid compared with past achievements this period could with justification be claimed to be one of relative stagnation.

To be sure, England at this time was psychologically too complacent and too hidebound by tradition to move forward purposefully towards a scientifically based society. What occurred was, as a result, a series of tentative and isolated reforms rather than the gradual unfolding of some overall strategy.

The greatest gains were made in the educational field. The teaching of science became as important as more traditional subjects in the Grammar Schools, and the elements of science were even taught in Elementary Schools. At the universities science, technology and scientific research became increasingly important. Indeed, four-fifths of the research carried out in this country at the outbreak of the Second World War was conducted within the universities.

With the exception of those of outstanding ability, mainly the 'scholarship boys', the universities remained the domain of those

[1] A. N. Whitehead, 1916 (quoted in M. R. Argles, op. cit., p. 137).

[2] 'The employment of scientists for war purposes in the First World War was a very haphazard business. Most of the young scientists who joined ordinary combatant units, were sorted our afterwards, if at all.' Sir George Thomson, *J. J. Thomson and the Cavendish Laboratory* (Nelson, 1964), p. 146.

who could afford it. However, the 'ladder' to the university that Huxley spoke of was being created. Even so, since the 'scholarship boys' formed a small minority of the school population the ladder was designed to allow only a few to rise via the Grammar Schools and the new County Secondary Schools.

Unfortunately the opportunities available to scientists and technologists after qualifying remained limited and even the first-class honours graduate frequently had to become a Primary School teacher. The high standard of science teaching at all levels of British education was, as in the nineteenth century, a consequence of the lack of research facilities.

The Doctrine of University Autonomy

During this period the Government was increasingly compelled to assist in the financing of university education and research. Even so, of a total income of nearly £5 million in the session 1934–5 the Treasury contribution amounted to only 32%, a further 10% coming from local authorities. The universities were still dependent on endowments to the extent of some 14% of their total income.[1] Like the people of Manchester (see Chapter Two) who, on being refused a grant by Gladstone, decided to raise the money themselves so as 'to be free from government interference' and then failed to obtain sufficient funds by subscription, the universities, having adopted the principle of autonomy, were likewise handicapped by the lack of funds. It is interesting to note that the income from endowments at Cambridge equalled that of the State contribution, while for Oxford endowments even exceeded state aid. The average endowment for all other universities amounted to only a quarter of those of Oxford and Cambridge.

> The bogy of State-interference has been much overworked. There are other forms of interference more sinister, and in Great Britain and America at least, more common: and these are often tolerated by academic tories. Indeed, the State may approach the universities as a rescuer rather than a dragon. Indeed the dogma of freedom from external interference may be, and in the past often has been, used to deny internal freedom . . . State action is truly a 'hindrance of hindrances'. It does not stifle, but augments or even creates freedom. To raise the standard of 'autonomy' against such intervention would be hypocrisy.[2]

Treasury grants had been formerly administered by a body called 'An Advisory Committee'. In 1919 this was changed to the University Grants Committee which was charged

> to enquire into the financial needs of university education in the United Kingdom and to advise the government as to the application of any grants that may be made by Parliament towards meeting them.

When, in 1922, Oxford and Cambridge first applied for government grants a Royal Commission found that Oxford

[1] J. D. Bernal, *The Social Function of Science* (Routledge, 1942), p. 420.

[2] Sir Walter Moberley, *The Crisis in the University* (S.C.H. Press, 1949), p. 243.

had not played a full part in science education, and that the proportion of science teachers and research students was not large enough for a university of its size. The report, pointing out that the system of college laboratories was uneconomic and wasteful, called for a greater degree of centralization.

The Cavendish at Cambridge meanwhile went from strength to strength under Ernest Rutherford's leadership. During the session 1927–8 fifty-three papers were published and in 1931–2 sixty-four. In the year 1958 twenty-one Chairs of Physics at British universities were held by former Cavendish men and in the Dominions twenty-two. An important development had occurred since the war — the adoption of the German Ph.D. degree. In this country it was awarded to the holder of a first degree who successfully pursued original research for a period of several years. By 1929 there were thirty-seven of these research students at the Cavendish. These had come from many countries, having, like Rutherford, been attracted by the reputation of the Cavendish.

One of the difficulties of relying on private endowment was that the head of a department used up valuable time in seeking financial support. On two occasions at the Cavendish, Rutherford required large sums. These he needed for building a special laboratory for the Russian physicist Kapitza and for an urgently needed extension to the Cavendish. He was fortunate in obtaining £15,000 and £250,000 respectively from the industrialists Ludwig Mond and Lord Austin. Professors of lesser repute would possibly not have been so successful in raising the money. Rutherford himself appealed for greater support for universities.

> We may confidently predict an accelerated rate of progress of scientific discovery beneficial to mankind . . . It is necessary that our universities and other specific institutions should be liberally supported so as not only to be in a position to train adequately young investigators of promise, but also to serve themselves as active centres of research.

Science, Technology, and University Expansion

The emergence of new universities and the expansion of the student population triggered off controversies which were to be revived in the fifties and sixties.

There was opposition to university expansion on the grounds that it would lead to a lowering of standards.

> As education advances, the general level of trained intelligence rises, but not, unfortunately, with the result of producing more and more of the really first class . . . A highly competent mediocrity is a real danger to a nation, and above all, to a university. For the more competent and widely distributed that mediocrity becomes, the more it fears and resents those who rise above it; a latent but ineradicable antagonism between mediocrity and quality is inevitable.[1]

[1] Abraham Flexner, *Universities, American, English and German* (O.U.P., 1930), pp. 255–6.

1914–39 Stagnation

> Those who know our universities best are haunted by the fear that a democratic enthusiasm, as genuine as it is ill-formed, may result in an attempt to increase the quantity of university education at the expense of its quality.[1]

> This should be a period of retrenchment and reform: it should not be a period of further expansion . . . one cannot but deprecate the attempts that are being made to found universities up and down the country . . . if matters continue as they are at present we are promised a spate of new universities. These will lower the standard of education in the universities that are already in being.[2]

Other critics saw the universities becoming merely vocational factories producing large numbers of graduates who had benefited only to the extent of obtaining degrees enabling them to earn a livelihood.

Admiration for German universities which had ceased after the outbreak of war in 1914 had been replaced by a respect for the American universities. Ramsay Muir[3] pointed out that Iowa, with a population of only 2 million, had as many universities as England, and that Iowa State University was larger than Oxford and Cambridge combined. He also drew attention to their 'immense facilities for research in every subject bearing upon industry'. British universities were also turning, albeit rather more slowly, to new technologies. Thus Industrial Administration and Photographic Technology were taught at Manchester, Brewing at Birmingham, Aeronautics at Cambridge, Gas Engineering at Leeds, Glass Technology at Sheffield, Oil Technology at Birmingham and London. Naval Architecture, Leather Manufacture, Town Planning and Dairy Bacteriology were also taught. Hence in Britain, too, by 1939 there were facilities for research in every subject bearing on industry. By 1935–6, Professor Bernal[4] calculated that there were 600 academic posts in technology at English universities, and that there were 339 full-time students and 80 part-time students doing work at the post-graduate level. This did not come about without opposition. Flexner[5] considered that 'this technical development was deplorable' and Sir Ernest Barker[6] commented on 'the danger of technical zeal' and remarked that it was a 'great mistake to blur the distinction between university and technical college'.

The industrial depression aggravated what was already a serious shortcoming — the dearth of opportunities for scientific research. In such circumstances the Arts were a big attraction and this was reflected in the distribution of new Chairs created between

[1] E. Barker, *Universities in a Changing World*, ed. W. M. Kotschig and E. Prys (O.U.P., 1932), p. 119.

[2] Sir Charles Grant Robertson, *The British Universities* (Benn, 1930), p. 75.

[3] R. Muir, *America the Golden: An Englishman's Notes and Comparisons* (London, 1927), pp. 27–31.

[4] Bernal, *The Social Function of Science*, p. 417. Distribution of posts was now:

Arts . .	1,570	(i.e. Sciences and Technology exceeded the Arts)
Sciences .	994	
Technology	623	
Medicine .	533	

[5] Flexner, op. cit., pp. 255–6.

[6] Barker, op. cit., p. 119.

Thomson and Rutherford

Sir J. J. Thomson, discoverer of the electron, seen with Ernest Rutherford, his most famous pupil. Rutherford, Thomson's successor as Professor of Experimental Physics at the Cavendish, created an international reputation for himself as a leader of research physicists.

1925 and 1930. Of seventy-one new Chairs four only were in technology, fifteen were in mathematics and science and thirty-nine in the Arts.[1]

TABLE 4.I [2]

University Population

Stagnation in science is clearly brought out in the following table.

	1922–3	*1938–9*
No. of science students	5,970 (19·3%)	6,061 (16·2%)
No. of technology students	3,882 (12·5%)	4,217 (11·3%)
TOTAL no. in all faculties	31,079	37,433 —

Thus, while the total number of students at English universities increased at the rate of 1% per annum (said by some to be a copious invasion), the numbers of students studying science and technology remained virtually stationary.

The status of science at all levels in the educational system was unsatisfactory. J. J. Thomson in 1918 had been appointed Chairman of a Royal Commission to examine the position of science and he concluded that science did not

> occupy in our system of education a place commensurate with the influence on human thought and on the progress of civilization.[3]

The Growth of Technical Education

The other ascending ladder of education involved the technical colleges and polytechnics. By 1918 the pattern of technical education in this country had been well established — part-time evening instruction plus practical experience in industry — and by 1921 there were 22,000 students attending technical colleges. To satisfy the need for a national qualification in technology (other than a degree) the National Certificates and National Diplomas were instituted. These provided a qualification for the technician which would be acceptable to industry. They were immediately successful and during the twenties the number of awards trebled. But

[1] Argles, op. cit., p. 75.
[2] Ibid., p. 74.
[3] Sir George Thomson, *J. J. Thomson and the Cavendish*, p. 163.

technical education had by this time degenerated to the status of a poor relation of other forms of education. In 1926 a Board of Education Report[1] drew attention to the lack of facilities and amenities. The familiar complaint that technical education was being hampered by industry's attitude was continually reiterated. Firms were not interested in the education of their employees and the few firms that took an interest were only interested in part-time evening instruction and not in the newer day-release schemes. The following impressive figures, which taken by themselves implied an enormous expansion, really hid the unsatisfactory rate of progress. Industry was complacently satisfied with the existing supply of technical manpower.

	Full-time students	*Part-time students*
1909 .	4,000	750,000
1938 .	42,000	1,280,000

Government and Scientific Research

The main feature of government intervention into the scientific field during this period was the creation of government research laboratories. They came under the control of a new government agency, the Department of Scientific and Industrial Research, which in its first year of existence (1916) distributed £330,000. It came into being as a result of a White Paper published in 1915. This announced a 'Scheme for the Organisation and Development of Scientific and Industrial Research'. A Committee of the Privy Council was formed to

1. Institute specific researches.
2. Establish institutes for applied science.
3. Establish research fellowships.

The Committee found that industry was frequently unable to finance research and that it needed large organisations to tackle many problems. The White Paper commented:

> It is obvious that the organisation and development of research is a matter which greatly affects the public educational system of the Kingdom. A great part of all research will necessarily be done in universities and colleges aided by the State and the supply and training of a sufficient number of young persons competent to undertake research can only be secured through the public system of education.

The D.S.I.R. advised the setting up of numerous research bodies. These are listed below along with the year in which they came into existence.

TABLE 4.II

Government Research Bodies

Fuel Research Board . .	1917
Fuel Research Station . .	1918
Food Investigation Board .	1918
Low Temperature Research Station .	1919
Building Research Board . .	1920
Forest Products Research Board	1921
Chemistry Research Board .	1922
Water Pollution Research Board	1927

By 1939 the D.S.I.R. was spending nearly £1 million on grants for research purposes and for maintaining establishments such as

[1] *Survey of Technical and Further Education in England and Wales* (H.M.S.O., 1926).

the National Physical Laboratory, the Chemical Research Laboratory, and the Geological Survey and Museum. It also supported twenty-two industrial Research Associations, in addition to the Medical Research and Agricultural Research Councils which had been created in 1913.

However, the financing of research, other than that carried out in government establishments, was not entirely satisfactory. A Parliamentary Committee on Science had put forward a proposal for an Endowment Fund for scientific research. This

> was rejected on the grounds that it would be unwise to subsidize research to a greater extent than industrialists were themselves willing to contribute and secondly that the principle of endowment was inherently unsound.[1]

It was pointed out earlier that Rutherford was enabled to finance two major projects at the Cavendish as a result of the generous support of two leading industrial figures. Professor Bernal was highly critical of this method of financing research and gave an illuminating insight into what this principle of private endowment meant in practice.

> Under modern conditions private benevolence is the worst method of financing research. It is highly irregular in its incidence and largely unpredictable in its amount . . . from whatever motive the sums are given, the existence of large donors or potential donors is a standing temptation to individual scientists or groups of scientists to intrigue for a share of these gifts. The money does not go in general where it is most needed, but to those who are most skilled in the art of extracting money from the wealthy. The present method of financing research is not one that has been deliberately conceived, it has grown up as an accumulation of expedients for different developments as they arose. Its complexity and inefficiency is due largely to the fact that it has never been reviewed as a whole.[2]

A characteristic example of the way in which research was all too often conducted in this period was the discovery of penicillin. Originally discovered by Alexander Fleming in 1929, it was reinvestigated later by Sir Howard Florey and Dr. E. Chain at the Sir William Dunn School of Pathology.

> The original laboratory plant for making penicillin was a remarkable Heath Robinson contraption, involving a household bath, a milk cooler and numerous milk churns. With this, however, the Oxford workers established how to 'brew' penicillin and how to concentrate it. Industrial chemists took those established principles, and proceeded to transform the process out of all recognition.[3]

Research in Industry

There had been great expectations in the industrial world following the creation of the industrial research associations during the First World War. Although by 1939 these had increased in number to twenty-two their

[1] Bernal, *The Social Function of Science*, p. 318.
[2] Bernal, op. cit. pp. 416–19.
[3] W. E. Dick, *Biochemical Industries* taken from *A Century of Technology*, ed. P. Dunsheath (Hutchinson's Scientific and Technical Publications), p. 193.

expenditure on research remained disappointingly small and they did not live up to their early promise. The expenditures of some of these during 1936 are cited in Table 4.III.

TABLE 4.III

Industrial Research Associations

British Cast Iron Research Association	£13,000
Research Association of British Flour Millers	£7,000
British Non-Ferrous Metals Research Association	£25,000
Linen Industry Research Association	£15,000
Research Association of British Rubber Manufacturers	£7,000

Source: *Industrial Research Laboratories* (Allen & Unwin, 1936).

Industrial Research Laboratories provides a further list of 23 firms employing some 159 research staff and a total annual research expenditure amounting to some £120,000. An indication of the small sums involved is given by the fact that three major firms — Edison Swan Electric Company, Glaxo, and British Drug Houses — spent respectively £3,000, £10,000 and £1,500 on research in 1936. At this time the number of factories in England was in the region of 160,000; these employed some 5 million workers. Their contribution to research amounted to 23 research laboratories and 160 research staff. It must be admitted that these figures are very much on the low side, for not all the research laboratories were listed. Nevertheless they give some indication of the orders of magnitude involved.

Bernal estimated that government grants to Research Associations for specific tasks amounted to £400,000 and the estimated economies amounted to £3,200,000 annually which meant an 800% return on money invested.[1]

It has been said that industry's part in scientific research between the wars was small compared to that of the universities and the government agencies. Tables 4.IV and 4.V give some indication of the relative scientific activity in this period. In the industrial contribution allowance must be made for the fact that much of the industrial research was state financed and therefore industrial research directly sponsored by private industry must have been correspondingly smaller.

Research Expenditure

One item of research expenditure has been of increasing importance in the era following the Second World War, namely, expenditure on defence research.

Already in the 1930s this item accounted for a considerable proportion of the total expenditure on research — in 1934, for example, it amounted to one-third of the whole.

Bernal pointed out that the figure of £2 million for independent research is a very approximate one and could be in error by as much as 50%. Nevertheless, it is true that with the imminence of war in the late thirties there was a marked increase in independent research.

Sir Julian Huxley in *Scientific Research and Social Needs* estimated that the total spent

[1] Bernal, op. cit., p. 430.

TABLE 4.IV[1]

Scientific and Technological Research

Number of research papers appearing in four leading scientific journals and four leading technological journals selected for 1924, 1929, 1932, 1936

	Academic	*Government*	*Industry*
Scientific journals .	1,144	63	28
Technological journals	[illegible]	185	157

[1] Bernal, op. cit., p. 425.

TABLE 4.V[2]

Research Expenditure 1934

Universities, learned societies, independent foundations .	£1,500,000
Government financed	
Defence services .	£2,000,000
Industrial research	600,000
Medical research .	150,000
Agricultural research	200,000
Industrially financed	
Contributions to Research Associations . .	200,000
Independent Research .	2,000,000
TOTAL	£6,650,000

[2] Bernal, ibid., p. 63.

on research in this country was £4 million to £6 million. This, he pointed out, was only 2% of the amount spent on drink, 3% of that spent on tobacco and 12% of that spent on gambling. This was during the non-affluent days of 1934. Further, it represented only 0·1% of the National Income whereas expenditure in the United States of America and U.S.S.R. was respectively £50 million (0·6% of the National Income). and £36 million (0·8% of the National Income).

In the heyday of Victorian prosperity George Gore had declared,

> In this country we have devoted ourselves relatively too much to the pursuit of money and too little to the pursuit of knowledge. The desire for wealth in this country is so great, that probably nothing but a loss of that wealth will ever make us properly encourage the pursuit of new knowledge.

Our industrial pre-eminence had really been lost in the closing years of the nineteenth century. It was not, however, until the fifties and sixties of the twentieth century, when countries such as Japan and Italy in addition to Britain's traditional competitors became economically more prosperous, that the truth of Gore's prophecy became sufficiently appreciated.

Chapter Five

THE WAR AND AFTER: A NEW AGE FOR SCIENCE

Science, Technology and National Prosperity

NO school speech day, village fête or political meeting in these days is complete without some speaker referring to Britain's future dependence on science and technology. This is not entirely new. What is, however, characteristic of the present time is the total acceptance of this thesis at all levels in society. Sir Leon Bagrit in his 1965 Reith Lectures commented:

> It is essential for our future national prosperity in Britain that we should modernize this country by spreading an understanding of the most advanced forms of technology as rapidly as we can and throughout the whole of our society. We must somehow induce industrial concerns to adopt these new techniques quickly and intelligently, and we must make sure that our universities, our technical colleges, and our schools are mobilized to produce the people with the background, the training, and the inclination which is necessary to bring this about. We must also see to it that the correct political decisions are taken to make it easier, not more difficult, to realise these aims.

—words that few would dissent from but which yet raise a host of problems.

The recognition of the association between science, technology and national prosperity, now universal, has been the result, as Gore predicted (see Chapter Four), of Britain's declining economic power relative to other nations. The effect of this was aided by the intensive propaganda in favour of science and technology during the fifties. In this campaigning Lord Snow and Lord Bowden filled the roles formerly occupied by Playfair and Huxley.

In his advocacy of the idea that the economic strength of a country depended on the efficiency of its technology, Lord Todd, in the thirteenth Dalton Lecture of the Manchester Royal Institute of Chemistry, warned that expenditure on scientific research was increasing at the rate of 15% per annum and that this could not continue indefinitely without a corresponding growth in the national product. The political parties in the British General Election of 1964 vied with one another in their claims to be the party best suited to create the new 'scientific Britain'. A great deal of this political interest in science and technology stemmed from Mr. Harold Wilson's speech to the Labour Party Conference at Scarborough in 1963. In a speech during the election he said:

> Our failure to develop science and technology is leading to a mass sell-out to foreign concerns . . . Britain, once the workshop of the world, is becoming the dumping ground for the products of overseas industries that are just that bit quicker in getting off the mark than we are.'

Failure, if such there had been, had not been one of intent, it seems, for in 1956 a Government White Paper had declared:

> The aims are to strengthen the foundations of our economy, to improve the standards of living of our people and to discharge effectively our manifold responsibilities overseas. Success in each case will turn largely on our ability to secure a steady increase in industrial output, in productive investment, and in export of goods and services of the highest quality at competitive prices.[1]

And, it went on:

> If Britain fails to meet the demand for scientists to which an increase of productivity will give rise, and on which it depends . . . there is little hope of our remaining a great power or even of our paying for the imports needed to sustain our economic life.[2]

During the nineteenth century unfavourable comparisons were usually drawn between Britain on the one hand and France, Germany and America on the other. To these economic rivals have now been added Russia, Japan and Italy. According to Lord Snow:

> There is something wrong with us. For 1938 let us take the national product as 100. In the United States it has gone up to 225, West Germany 228, in the O.E.E.C. countries to 165 but in Britain only to 150. For 1950 take the base 100. West Germany has jumped to 225, France 170, Italy 202, O.E.E.C. countries to 164 but Britain only to 129.[3]

One of Britain's failures to act decisively has been in the field of computers and many see this example as symptomatic of Britain's ability to invent being offset by failure to develop. Professor Stanley Gill, of Imperial College, London, called this failure to develop computers

> the biggest national tragedy of the century . . . whereas in 1950 we were leading the world in this subject we have completely and bitterly failed to rise to the occasion. We are now even falling behind the rest of the Western world in the rate we are developing and exploiting computers.

The following table illustrates this state of affairs.

TABLE 5.I

Computers per million population, 1964

U.S.A.	240	West Germany	46
Switzerland	80	Denmark	44
Sweden	59	Belgium	43
France	56	U.K.	28
Norway	49		

The 'computer scandal' had its parallel in the development of synthetic dyes in the nineteenth century and is merely one example of what many interpret as indecision and lack of purpose in the technological world.

It is becoming increasingly hard to believe in the possibility of Britain extricating herself

[1] *Technical Education* (Cmnd. 9703), 1956.
[2] *Higher Technical Education* (Cmnd. 8357), 1956.
[3] C. P. Snow, 'Education and Sacrifice', *New Statesman*, 17 May 1963.

from the present difficulties without abandoning the traditional posture of 'muddling through'. Despite this, one American, at least, is quite optimistic as regards Britain's ability to succeed in the present crisis.

> Always in the past British traditionalism, conservatism, a penchant for 'muddling through' has been leavened by hard common sense, a stoical determination under stress, and — at crucial moments — a saving perspicacity. There is no reason to suppose that these qualities have disappeared or that they will not again enable Britain to meet the latest crisis in its long eventful history.[1]

Expansion and Scientific Manpower

Scientific advance and social change have not been so rapid in Britain as they have been in some other countries. To state this is not to deny that Britain has changed out of all recognition during the last two decades. The most notable changes have been in scientific expenditure and scientific manpower.

Total expenditure on scientific research in 1934 (see Chapter Four) was £6½ million; in 1956 it was £300 million; in 1964 it was £600 million. In three decades it has multiplied by a factor of one hundred. Nevertheless, in 1956 the United States spent $9,000 million on research and according to the 1956 figures British investment would have had to be doubled to match the American investment on a population basis. Almost half the research in America is financed by private industry and the total expenditure is carried equally between government and industry. The respective contributions in Britain are 75% and 25%. Hence there is a great need for expansion of research in private industry in Britain.

> The scientific effort in many industries is far too small and in some industries . . . such as shipbuilding, building and contracting, and textiles the research effort falls considerably short of the best standards in other countries.[2]

Industry's research expenditure in Britain in 1956 was 0·8% of industrial output compared to 1·9% in the United States.

The number of qualified scientists and engineers in Britain in 1956 was 141,700 (0·6% of the working population as compared to 0·9% in the U.S.A.).[3] By 1961 there were nearly 210,000 scientists and technologists at work in Britain.[4] The real weakness of British manpower, however, is in technology, for the proportion of scientists in the 1956 figure amounted to 44%, whereas the corresponding proportion in America was 30%. This bias in favour of 'pure science' is partly due to the high prestige value of mathematics and physics in higher educational circles. This is reflected in a high proportion (42%) of the scientists being physicists and mathematicians compared to 24% in the United States.

In Britain there is an over-concentration of scientific manpower in three industries,

[1] G. L. Payne, *Britain's Scientific and Technological Manpower* (Stanford U.P., California, and O.U.P. (1960)), p. 398.

[2] *Advisory Committee on Scientific Policy. Annual Report, 1956–7* (Cmnd. 278).

[3] Payne, op. cit., p. 31.

[4] *Report of the Manpower Committee of the Advisory Council on Scientific Policy* (Cmnd 2146), 1963.

namely aircraft, chemicals and electrical engineering. These between them absorb 50% of the total supply of scientists and engineers as compared to 37% in the U.S.A.[1] In 1936 Professor Bernal wrote

> there is a tradition in British industry that is definitely inimical to science and consequently to the scope and freedom given to industrial research.[2]

The social evaluation of industry in Britain differs markedly from many other nations — particularly Russia and America.

> To be a high industrial executive in America is not only eminently 'respectable' but is 'socially desirable'. It is the prevailing opinion that business attracts the best talent from educational institutions, whereas in Britain there is a strong tendency for the best students to find their way into the Civil Service and the professions generally.[3]

While firms say that they are unable to find suitable graduates Payne found they really prefer apprentices, owing to their 'greater practical experience'.

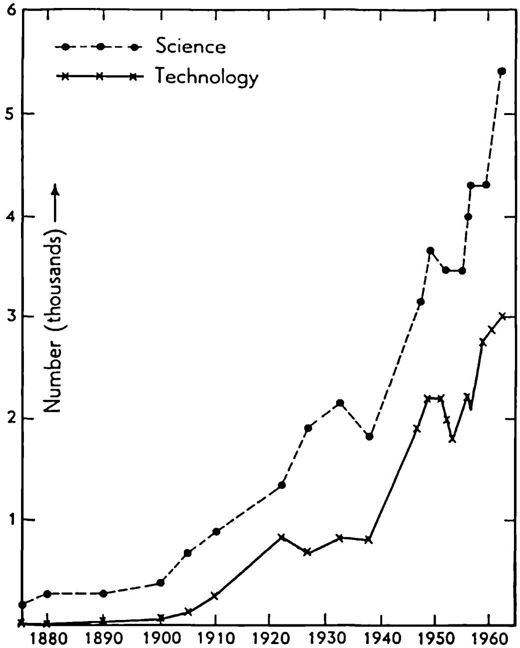
> Management frequently seems to feel that a university education does not quite compensate for the lack of industrial experience of the entering graduate.[4]
>
> . . . Among conservative managements, especially in long-established family-owned firms that dominate many segments of British industry, the middle way is not yet recognised as a necessary or even desirable adjunct to the competent craftsman they have nurtured. [Such firms] offer little scope for research and development, and their operating procedures are too settled to warrant additional expensive technologies for purely supervisory duties. . . . Where the new product, method or technique on which a business was built was the empirical result of a journeyman's ingenuity, it is apt to be assumed that the firm can continue to thrive without the direct participation of theoretical science or engineering.[5]

But as well as opposition from within industry there is the additional problem of attracting the able into industry. In this respect the 'dark image of technology' acts as an effective obstacle. In a recent debate in the House of Lords, it was pointed out that the Arts are flourishing in the universities, pure science was also quite sound but technology was falling behind because of the stigma of social 'unacceptability'. Lord Todd stated that he found this very puzzling, for technological subjects in their relation to industry provided as good an intellectual discipline as did pure science. But the younger generation still spurned industry:

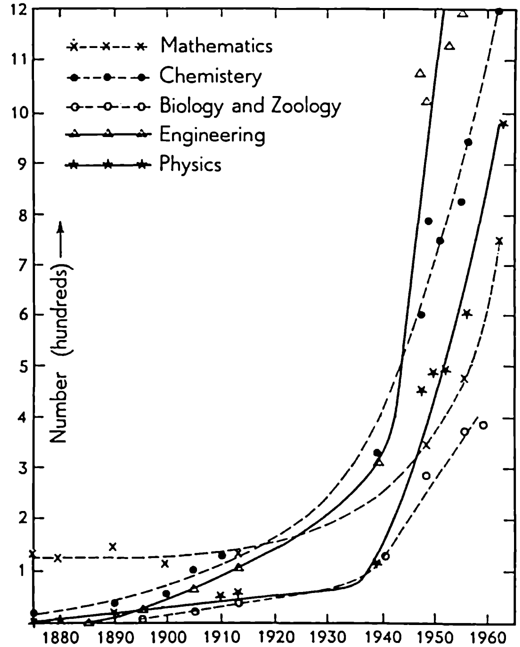
> As a nation we decline to believe in the technological revolution . . . we have got to change the climate of society at least enough to respect those who make the wealth.

In 1964 the technological departments of universities, the Colleges of Advanced Technology, and the higher Technical Colleges

[1] Payne, op. cit., p. 364.
[2] Bernal, *The Social Function of Science*, p. 56.
[3] British Productivity Council, *Education in Management*, p. 8 (quoted by Payne, op. cit.).
[4] Payne, op. cit., p. 67.
[5] Ibid., p. 66.



Graph 7. Students of science and technology in England and Wales, 1875–1965.



Graph 8. Honours graduates in science and technology in England and Wales, 1875–1965.

Sources:
University Grants Commission, Annual Returns.
M. Argles, op. cit.
G. L. Payne, op. cit.
World Survey of Higher Education, UNESCO, 1966.
Calendars of the Universities and University Colleges (1870–1914).

Sources:
University Grants Commission, Annual Returns.
Robbins Report on Higher Education, 1963.
G. L. Payne, op. cit.
University Calendars (1870–1941).

discovered that the numbers of prospective recruits were considerably less than the vacancies that existed. One explanation of this was that a swing to the Arts had occurred in the sixth forms of the Grammar Schools. A swing to the Arts began possibly as the result of a bottleneck in the Science Faculties of the universities during the late 1950s. That is, it was becoming clear that it was increasingly more difficult to gain entry into a university Science Faculty than to an Arts Faculty. Awareness of this fact among sixth formers may have started this trend. Another contributory factor was that — as pointed out in a report of the Universities' Central Councils for Admissions — the failure rate among Science Faculties was higher than among Arts Faculties. The effects of these were further added to by the effects of the increasing difficulties of recruitment of suitable science teachers to the Secondary Schools.

There are some signs that this swing may now be at an end but it has, during the last few years, given rise to considerable disquiet, for it is felt that owing to early specialisation youngsters of fourteen are being asked to make uninformed choices. These are frequently made under undue influences from masters who are themselves the products of an educational system which rates pure science highly and undervalues technology. Hostile to industry and technology, they share the prejudices of the young and are not the best propagandists for technology. In its *Annual Report* for 1963 the Oxford University Department of Education found that

> The public image of science and technology current among sixth formers is largely based on a quite unusual degree of ignorance about the nature of technology.

If this trend continues it is likely to have serious consequences for British scientific manpower, already weighted unduly in favour of 'pure science'. According to Mr. Colin Leicester of the Department of Applied Economics at Cambridge, Britain will be seriously short of mechanical engineers by 1970. Mr. B. J. Holloway, Secretary of the Manchester University Appointments Board, pointing out that only 71% of the vacancies in technology were taken up, speaks of 'manpower starvation' and predicts that the worst deficiencies will be in rubber, plastics, textiles and paper industries. In 1963 the Manpower Committee of the Advisory Council on Scientific Policy predicted that Britain would be short of 28,000 scientists and technologists, the main deficiency being in electrical engineering.

The Changing Face of Education

The scientific revolution has been responsible for an acceleration in the rate of social change and perhaps no section of British life has undergone such a psychological metamorphosis as the universities. It is now firmly believed that the key to national progress lies in the quality of a nation's scientific and technical manpower, this in turn being dependent on the quality and extent of higher education. This has subjected the universities and other institutions of higher education to pressures for expansion. They have come under further pressures as a result of the variations in birth-rate (i.e. the 'bulge') and the increased awareness of educational opportunities throughout all levels in society.

Higher educational establishments in 1963 contained some 200,000 students. To meet the urgent need for an expansion in higher education the Robbins Report proposed a doubling of the student population to 390,000 by 1973 and a further increase to 500,000 by 1980. A major characteristic of university expansion since the war has been the increased proportion of scientists and technologists in the student body — 26% in 1938 rising to 35% in 1955.

Since the late nineteenth century an essential feature of British universities has been the status attached to research. University research in science in 1955–6 was almost wholly supported out of government funds. The universities themselves provided only half a million pounds out of a total of 14·4 million.[1] Great care has to be taken not to infringe the principle of university autonomy:

> If university autonomy is to be a reality, we should continue to minimise our intervention in the allocation of funds within universities.[2]

Another danger to university freedom arises from contract work. In 1956 this amounted to 13% of the total university income. American universities rely far more heavily on this source of income, which amounts to 50% of their total income. Small as the contribution in Britain is at present, the Advisory Council for Scientific Policy has stated that contract work

> should not be allowed to grow and government support of free research in universities should always be at a level sufficient to enable university research to flourish without increasing resort to contract work.

It is true that

> the essential characteristic of a university is the advancement of knowledge and without active research a university withers away.[3]

But the British universities, as pointed out earlier, have adopted not only the spirit of *wissenschaft* from the German universities but also the concept of liberal education from Oxford and Cambridge. To be sure:

> to admit that education is the concern of the universities is to insert a wedge that can easily open the door to the demand for the exploration of many forms of thought and awareness. Clearly there must be priorities. Universities have differed in the extent to which they think that education in a fuller sense is their explicit concern.[4]

The British universities have attempted, not without misgivings, to integrate research and vocational study into the older philosophy of education. In this transition in function 'the dead hand of tradition' has held back 'the adjustment of the educational system to the changing needs of society' [5] and it has caused

> a conflict . . . between the needs of an industrial society for a scientific and technical élite, and the ideals of a liberal education derived from a society in which such an education was appropriate for a predominantly governing and administrative élite.[6]

Though many concessions have been made, over the years, to vocational demands on education, the universities still feel with Herbert Spencer, that 'education has for its object, the formation of character'. Great stress is laid on the growth of spirit, broadening understanding and sharpening of intellect that can be achieved

[1] Payne, op. cit., p. 361.
[2] University Grants Committee, *University Development 1952–57* (Cmnd. 534 par. 93).
[3] W. F. K. Wynne-Jones and S. K. Runcorn, 'Expanding Universities', *The Guardian*, 1 May 1962.
[4] R. S. Peters, 'Britain's Changing Universities', *The Guardian*, 23 Nov. 1964.
[5] S. F. Cotgrove, *Technical Education and Social Change* (Allen & Unwin, 1958), p. 190.
[6] Ibid., p. 205.

Manchester University

The Manchester Institute of Science and Technology was formerly known as the Manchester College of Science and Technology. This started as the Municipal School of Technology, which arose in turn out of the Mechanics' Institute.

through communal life in a university. A university's real job, it has been said, 'is to turn out men whose academic qualifications are an addendum to their true manhood'.[1]

However, with the replacement of communal life by a '9 to 5 procedure', diminution of staff–student contact (particularly in sciences and technologies with their large classes and absence of tutorials) the influence of 'university life' on the student is increasingly diminished. These factors tend to make the university less an educative influence than an institution for vocational training.

> There is a lack of communication—many students do not really experience the university at all . . . education is an influence, not a commodity.[2]

Emphasis on scientific research and expanding technologies has brought about a rapid increase in scientific knowledge and introduced the necessity for early specialisation in education. According to Sir George Pickering, Regius Professor of Medicine at Oxford:

> The greatest evil today is specialisation at an early age.[3]

Lord Bowden has pointed out that Britain is the only country where specialisation occurs so early.

> It is the universities who demand the entrance qualifications which have forced schools to specialise more and more.[4]

In an age when scientific knowledge doubles every decade this may well get worse rather than better. At the universities:

[1] Payne, op. cit., p. 154.
[2] Susan Cooper, 'Crisis 1970: Scramble for Degrees', *Sunday Times*, 7 Oct. 1962.
[3] *The Guardian*, 13 Nov. 1964.
[4] *The Listener*, 22 Oct. 1964.

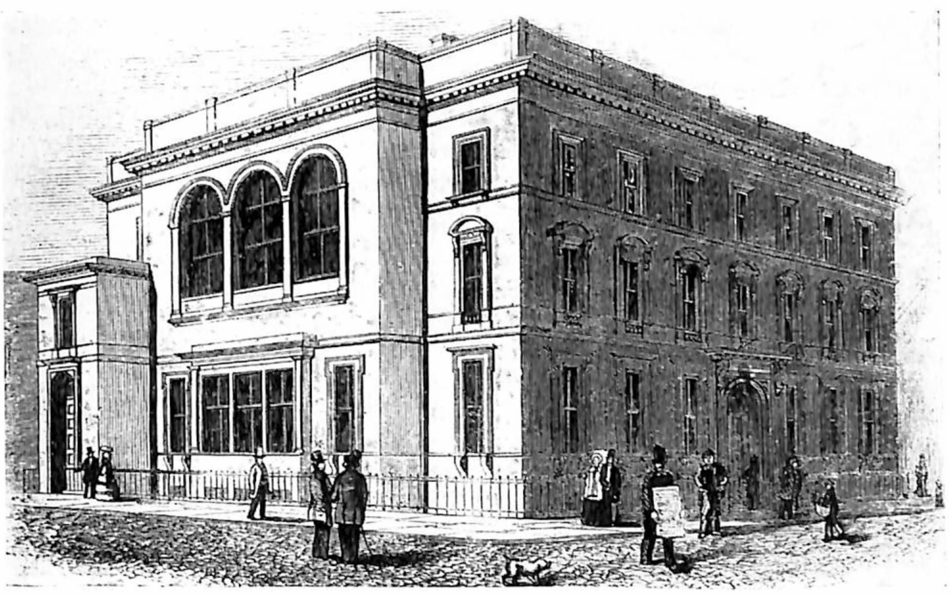
The War and After: A New Age for Science

Growth of knowledge brings increased specialisation even at the undergraduate level. Universities which on educational grounds resist the trend to specialisation will risk losing their places in the academic hierarchy and will become mere 'liberal arts colleges'. The social demand for technical specialists will mean that universities will produce more technically informed but fewer culturally educated people. At a time when society faces the prospect of increased leisure, it is paradoxical that the specialist technical education which makes that leisure possible increasingly unfits its recipients for the use of leisure.[1]

[1] Bryan Wilson, 'Pressures and Growing Pains', *The Guardian*, 24 Nov. 1964.

To meet the needs of a scientific society a modern equivalent of the traditional concept of liberal education is called for. Thus in the 1965 Reith Lectures Sir Leon Bagrit called for a 'balanced education' in the following terms:

We shall have to produce men and women who are able to understand the



The Mechanics Institute, Manchester

Founded in 1824, its development can be traced to the present-day Manchester Institute of Science and Technology, the technology faculty of the University of Manchester.

significance of the past, who are in the stream of current ideas and who can make use of them, and who have the quality of imagination that is capable of foreseeing and welcoming the future.

University expansion has once more triggered off a controversy over academic standards.

> Many within the universities have feared that continuous expansion can only lead to a disastrous fall in academic standards and an emphasis on routine teaching which could destroy the universities as centres of learning and research.[1]

In spite of all talk of cataclysmic expansion and the 'more means worse' argument, British university education remains highly selective. In 1962, 113,000 students qualified for higher education (14·5% of the age group). Of these 30,000 entered university (4% of the age group). There is only one chance in twelve in Britain of getting full-time higher education. In the United States of America it is one in three. Higher education in America differs in other respects, too. Both in the United States and in Russia there is a greater emphasis on the duty of the university to the State. American universities have a duty to research into problems facing society and to offer adult education to any American who desires it.

In Russia, Lord Bowden found a close association between the world of learning and the world of industry. Technological universities are incorporated into factories just as in Britain medical schools are incorporated into teaching hospitals. In Russia, too, it is easier for people of all ages to qualify for a profession or to retrain themselves late in life. Lord Bowden considers that 'we have much to learn from the Russians' and that

> British universities must increasingly tend to imitate the pattern of the United States but even so we would be 20–30 years behind.

Social pressures on universities are, to a large extent, transmitted to the Grammar Schools. Thus an expansion of the Grammar School population (5% per annum) occurred alongside university expansion. University expansion did not keep pace with the increasing numbers entering the sixth forms of Grammar Schools. A survey of sixth forms in 1962 revealed nearly 20,000 pupils with the necessary minimum qualifications waiting for entry to university. Of these more than 5,000 failed to get a place.[2] Despite unprecedented expansion the Grammar School population, as in the case of the universities, is highly selective and selection has been criticised for producing a wastage of potential talent.

The teaching of science has in the past received greater emphasis in the maintained Grammar Schools than in the Public Schools. Much of the leeway was made up as the result of financial aid (£3 million) to the Public Schools from industry. This enabled them to increase their accommodation by 50%. At present the percentages of students studying science in the sixth forms are 60% and 40%

[1] W. F. K. Wynne-Jones and S. K. Runcorn, 'Expanding Universities', *The Guardian*, 1 May 1962.
[2] Association of University Teachers pamphlet, *Why we need more places at University* (1963).

in Grammar Schools and Public Schools respectively.

A tradition of British scientific education has been the very high standard of its educators. This, in the past, was a reflection of the inadequacy of industry and the absence generally of scientific research. This resulted in the severe limitation of opportunities open to science graduates. With the removal of these deficiencies education has suffered from the competition from industry and from greater opportunities to pursue scientific research. This has been accentuated by the overall shortage of scientific manpower. Payne, in an analysis of scientific manpower, discovered that the position had worsened between 1956 and 1959. During this period the number of science teachers was expected to rise by 18%, but the actual increase was only 10%. This 'was due to the persistent shortage of science teachers available for the schools. The actual addition of 2000 such teachers was more than 1500 less than expected requirements. . . . Clearly, it is in the schools that the shortage of scientists is most acute'.[1]

A feature of twentieth-century education has been the emergence of a new category of students, namely women students. The Robbins Report in its estimates of future demand for university places drew attention to the further hidden reserves of untapped potential among the female population.

> Another illusion suggests that all children of the working class together with female children are beyond hope, predestined to ignorance, not capable of any serious education.[2]

The Robbins Report points out that only one in four university students is a woman. There seems to be a deeply-rooted belief in British society that they are innately inferior, despite the abundance of evidence from Russia and China — where there are nearly as many women engineers and mathematicians as men — to indicate that this is untrue. While women will be coming forward in ever-increasing numbers for all branches of higher education, the numbers taking up careers in science and technology are also bound to rise significantly. Payne points out that the current supply estimates of scientific manpower

> ignore half the population and neither public opinion nor the social and economic organisation of the country has adapted itself to the idea of a provision for the large scale employment of women in advanced engineering work.[3]

Women represent only 0·1% of all qualified engineers and among 10,000 members of the Institution of Production Engineers in 1959 there were only six women. In 1957 the *Journal of Technology* commented that:

> For the past month one of our correspondents has been trying to find a single British firm to come out and declare the opportunities it offers to women educated in science. Not one of the firms approached showed willing . . . That prejudice can be so strong is odd and even a little terrifying.[4]

[1] Payne, op. cit., p. 89.
[2] Tyrell Burgess, 'Son of Robbins', *New Society*, 29 Oct. 1964.
[3] Payne, op. cit., p. 372.
[4] *Technology*, Apr. 1957, p. 43.

A woman engineer writing in a leading newspaper stated:

> Society has not yet come to terms with the intellectual woman engineer . . . at present engineering education and industrial training tends to have a de-humanising influence.[1]

In 1964 a British woman chemist was awarded the Nobel Prize for Chemistry, being only the third woman to achieve this honour. No woman has yet won the Nobel Prize for Physics. There is no reason why this should not occur in the future.

One firmly-held tenet of English education is its belief in education as a process continuing throughout life. The rapid increase in scientific and technical knowledge now means that professional training in science and technology must be conceived of in similar terms.

> Education, as Charles Carter said recently, 'is not an act of salvation, after which one is safe for eternity'. Yet we assume it is, in particular, that a three year undergraduate course is sufficient to set a man up for a lifetime. Doubtless in the nineteenth century a three year course in classics did set a man up for a lifetime, but that was in the days when a graduate could assume he would grow old in a world familiar to him as a youth. We are living in the first era for which this assumption is false and we have not faced the consequence of this fact. The present generation of students will still be employed in the year 2000; but long before then their degrees and diplomas will have become obsolete. Measures to combat obsolescence, therefore, become of prime importance.[2]

Lord Bowden has pointed out that not nearly as much attention is devoted to the professional retraining of graduates and to the further education of adults in Britain as there is in Russia or America. He found that one-third of the total bill for education in America was allocated for these purposes — in Britain the amount is negligible.

The New Status of Technical Education

During the 1860s and 1870s the technical education movement received a great impetus as a result of the growing awareness of Britain's loss of prestige in the industrial world. A similar awareness has given rise to a resurgence in technical education during the late 1950s and early 1960s. Apart from these two periods of activity the growth of technical education was highly unsatisfactory due to a number of causes.

> The major factor in the slow growth of technical education was the apathetic and hostile attitude towards the application of science to the production process. . . . there is no evidence of any pressure by industry before the 1930's for any extension of technical education.[3]

Industry has been traditionally suspicious of the 'other worldliness' and lack of indus-

[1] *The Guardian*, 9 Sept. 1963.

[2] Sir Eric Ashby, *Investment in Man*, Address to the British Association for the Advancement of Science, 1963.

[3] Cotgrove, op. cit., p. 81.

trial contact of the university technologist. This 'other worldliness' is inherent in university policy as defined by the University Grants Committee:

> The work of a university in technology should be more closely related to fundamental science or other relevant studies than that of a technical college. In general the courses should be more widely based on higher standards of fundamental science and contain a smaller element of training related to immediate or special work in industry . . . a university graduate in engineering has still far to go before he has completed his training as an engineer . . . and he might well be less useful than the technical college man in the day to day business of industry.

The growth of technical education has been, to a large extent, an *ad hoc*, empirical process and the very names of the institutions reflect the nature of this growth. The term 'technical college' covers technical institutes, polytechnics, colleges of commerce and colleges of art and crafts. A Government White Paper of 1956 attempted to rationalise technical education by organising it on the basis of an integrated system of colleges of advanced technology, regional colleges of technology, area technical colleges and local technical colleges.

Technical education establishments now amount to some 10,000 different units ranging from very small evening institutes to large city colleges of technology. Of these only about 600 can lay claim to being major institutions. In the decade between 1947 and 1957 the numbers of students in technical education almost doubled — from approximately 600,000 to nearly 1,200,000. Expansion in numbers necessitated numerous major building projects and between 1954 and 1959 money for these increased threefold, from £5 million to £15 million.[1]

The status of technical education was raised by the creation of the colleges of advanced technology (now separate universities). For their students a new award was designed — the Diploma in Technology — 8,000 of which were granted in 1963. This Diploma is studied for on a sandwich basis, time being divided between college study and industrial practice. Thus a new generation of technologists is being trained in an attempt to offset the academic bias of previous technologists. Prior to the introduction of the Diploma in Technology many of the major technical colleges had a long tradition of university-level work through their London external degree courses. In 1958 there were in fact sixty-two colleges in which degree courses could be undertaken. In addition there were thirteen technical colleges affiliated to universities and this enabled them to offer the degrees of those universities. Eight were in London, and one each in Glasgow, Manchester, Edinburgh, Sunderland and Cardiff. Some of these were actually technological 'faculties' of the universities. In Chapter Four it was seen that the National Certificate and National Diploma had been designed to provide industry with a corps of well-trained technical and professional men. Between their introduction in 1921 and 1951 fifteen National Certificates came into being; these covered engineering, mining, commerce, textiles, chemistry, physics and metallurgy. In 1958,

[1] Payne, op. cit., p. 223.

18,000 National Certificates and 10,000 Higher National Certificates were awarded to students studying on a day-release or part-time evening basis.

In addition to the colleges already mentioned there are the national colleges such as the College of Aeronautics. Although only a few in number, they serve an important function because of their highly specialised character. Lower down the scale of ability there are the City and Guilds courses and similar courses run by regional boards. These courses are craft courses and they have mushroomed to the extent that a quarter of a million students are examined annually and entries are growing at the rate of nearly 10% per annum.

Figures, however, tend to hide the weaknesses in English technical education. Thus, while there were nearly a million science and engineering students in establishments of further education — an increase of 200,000 in seven years — less than 2% were full-time students; 20% were part-time day students and 78% were evening students. Technical education is still bedevilled by its evening tradition and the reluctance of industry to release students for day-release and sandwich courses.

Scientific Societies in an age of Professionalism

The professionalisation of science was seen to begin in the last quarter of the nineteenth century, when the amateur was displaced from the centre to the periphery of science and technology and was replaced by the professionally trained man. The rapid growth of professional institutions with their rigid standards of entry is symptomatic of the increasing trend towards professionalism and meritocracy and to the increase of the scientific element in society.

There are now some fifteen major institutions, with a total membership of 166,000 (20,000 scientists and 146,000 technologists). The largest of these are the institutions of civil, mechanical and electrical engineering which between them comprise 65% of the total technological manpower. In contrast to America there is a scarcity of production and chemical engineers, who constitute only 8% of the total. In addition to the major professional bodies there are some 200 scientific societies ranging from societies like the Amateur Entomological Society to highly specialised bodies such as the Hospital Physicists Association. The majority of these publish a journal. There are additionally about 120 other scientific periodicals in circulation.[1]

The scientific community has moved a long way from the time of Babbage when there were only a dozen or so organisations of semi-amateurs. It is sufficiently broad to enclose amateur and professional alike. The doyen of societies — the Royal Society — has changed significantly since the days of Babbage. It has almost totally eliminated the amateur and election can no longer be bought for a fee of £50. Election now signifies the recognition by the Society of an important contribution to scientific knowledge on the part of the selected member. A change in policy and attitude was indicated by the President in his address to the Society in 1964 when he committed the Society to the

[1] *Directory of British Scientists* (Benn, 1963), pp. 1263–88.

support of technology. The annual election of Fellows is to be increased from twenty-five to thirty-two, the increase to be allocated to technologists. He also sees the Society developing in the future as an intermediary between the scientific world and the Government.

The Brain Drain

Notwithstanding the expansion — beyond all previous precedent — in scientific facilities, and despite the steps that have been taken to transform the conditions of society so that science and technology can flourish, a significant section of the scientific community has found British society unsuitable for the fulfilment of their creative scientific talents. There are obviously a variety of reasons to account for this migration of scientists — now commonly referred to as the Brain Drain — to other countries. It is none the less true that there is a hard core to which the above applies. These have been dissatisfied with the way in which science is organised in Britain and have opted to work in a society which they claim gives greater scope and recognition to scientific ability.

Concern over the state of British research reached a climax in 1963 following this disquieting exodus of scientists. In defence of this migration the A.C.S.P. had pointed out that

> large numbers of scientists and engineers have always taken up employment overseas, particularly in the Commonwealth and . . . emigration of this kind has generally been beneficial to our own interests.[1]

It is true that in the past this two-way migration has been of some benefit — the name of Rutherford immediately comes to mind — but this statement by the A.C.S.P. does not alter the fact that the numbers emigrating are considerable and are unfortunately increasing.

Between 1952 and 1956, 292 scientists and 1,467 engineers emigrated to America, and migration to Canada amounted to 542 scientists and 4,066 engineers.[2] Thus migration to America and Canada accounted for nearly 12% of Britain's output of scientists and technologists. A survey by the A.C.S.P. revealed that 189 postgraduate chemists and 144 postgraduate physicists left Britain between 1952 and 1956.

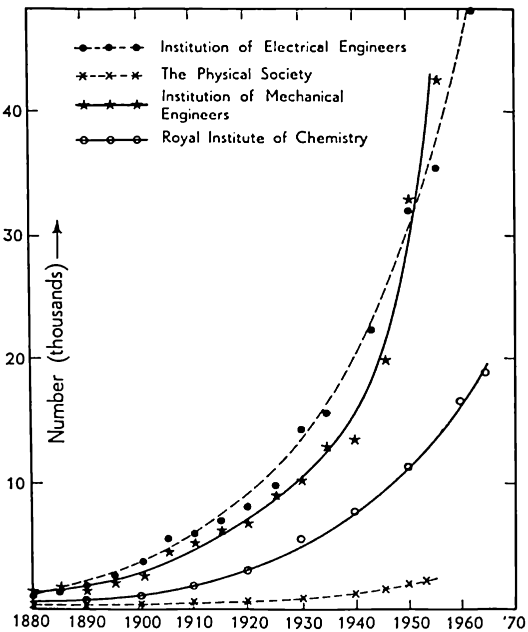
These represented 6% and 10% respectively of the numbers of postgraduate chemists and postgraduate physicists produced every year. Of the 115 Ph.D.s in science at Oxford since the war

> at least 25 are in America and give every sign of staying there.[3]

The reasons are not hard to find beneath the apparent glamour attached to science. The University Grants Committee reported in 1956 that:

> In some universities, laboratories are still housed in huts erected for emergency purposes in the 1914–18 war and scientific research is still carried out in ill-lit basements and cupboards.

[1] *Annual Report of the Advisory Committee on S.P. 1957–58* (Cmnd. 59), pars. 27–29.
[2] Payne, op. cit., p. 378.
[3] Dr. J. Wilks, *Technology* (Nov. 1959), p. 318.



Graph 9. The rise of the professional in science and technology: membership of leading professional institutions, 1880–1965.

Sources:
Compiled from data obtained from:
Proceedings of the Royal Institute of Chemistry
Proceedings of the Physical Society
Proceedings of the Institution of Civil Engineers
Journal of the Institution of Electrical Engineers
The assistance of the Secretaries of the above-named societies is gratefully acknowledged.

One eminent scientist, Dr. Leslie Orgel, theoretical chemist of Oxford, gave as his reason for joining the Brain Drain:

Facilities I want just aren't available in Britain. I want to switch from theoretical chemistry to molecular biology and chemistry of genetics, for which I need a laboratory and scientists and technicians to work with me. I spent a year trying to find something in Britain before I decided to go. In California I shall have a staff of six to seven scientists and two to three technicians — I could have had twenty if I had wanted them.' [1]

Dr. John Wilkes, Oxford physics don, in his evidence to the Franks Commission, emphasised those defects in financing research already pointed out by Bernal (see Chapter Four):

> Systems of seeking funds for research from outside sources have grown up haphazardly over a period of years. At times it works tolerably well, at times less so. What happens depends largely on goodwill rather than on any formal arrangements.

At Oxford, he said, the lack of money was hindering research. Time was wasted waiting for technical and workshop services. Also,

> outdated and inaccurate equipment is used because it is less expensive.

These were the sort of reasons, he argued, which accounted for the mounting frustrations of British scientists and which prompted them to leave for conditions which enabled them to pursue research more efficiently.

Inadequate facilities and poor financial

[1] *Sunday Times*, 6 Sept. 1964.

support are not the only factors involved in the problem of the Brain Drain.

> British universities are down at heel. For years they have gone hungry for funds, and have expanded while clinging to fossilised methods of administration . . . but our scientists also find the United States intellectually more stimulating. Berkeley and the Massachusetts Institute of Technology are fizzing with excitement. We shall probably have to follow her example and develop a few large centres . . . We shall have to divorce research from teaching . . . British academic life badly needs some of the enthusiasm, the openness to new ideas and experiments, and the vitality which so attracts British scientists to the best American centres. Governments cannot organize this, although they can promote conditions favourable to its growth.[1]

Disturbing as this loss of manpower is, it does not compare in magnitude with what seems to have been the migration in the last quarter of the nineteenth century — 32% (see Chapter Three).

Government, Science and Defence

Professor Herbert Butterfield in an article entitled 'Springs of Discovery' (*The Observer*, 9 July 1961) said:

> Possibly no peaceful or constructive cause in the universe could have given such drive and such direction to research as war and national rivalry have done in recent decades.

[1] John Davy, *Observer*, 10 Feb. 1964.

The demands of war created needs and wrought changes which were favourable to the rapid advance of science; at the same time they determined many of the features of the present scientific society. The momentum of scientific advance precipitated by the war was later maintained in the post-war era.

At the outbreak of war four-fifths of fundamental research was carried out at the universities. The war ended the dominant role of the universities. Both the Government and industry were then forced to invest heavily in research and development. Table 5.II gives a comparison between 1934 expenditure and 1963 expenditure.

TABLE 5.II

	1934 (approx.)	*1963* (approx.)
Government	£1 million	£151 million
Industry	£2 million	£213 million
Defence	£2 million	£246 million
	£5 million	£610 million

Industrial expenditure on research has increased from £68 million to £213 million in the last seven years. Government spending on civil research jumped from £6 million in 1945 to £151 million in 1963. This latter figure, however, is exceeded by government spending on defence research — £246 million. Total defence expenditure now amounts to over £2,000 million annually — some 30% of the national budget. This works out at £100 per family — a higher rate than any other country except the United States and Russia. Today, in Britain, nearly 2 million people are involved in defence contract work, 20,000 of them scientists. Defence expenditure, then, accounts for nearly half — £246 out of £634 million of the total expenditure on research and development. Defence contracts are not distributed evenly throughout industry but are highly concentrated in a few industries. The aircraft industry accounts for 40% of them; others are electronics and shipbuilding. In shipbuilding, for example, defence needs make up 23% of the total output.

Military projects with a scientific basis have been as much a vital part of the cold war as they were during the Second World War and the enforcement of strict war-time security regulations has continued to involve a certain limitation of scientific freedom.

> In the process of making use of the discoveries of science who will deny that in this process both the State and science have become corrupted?
>
> Three-quarters of British government money spent on science comes directly from the Defence Budget. In the U.S.S.R. and U.S.A. this figure is probably greater. . . . I remain obstinately of the opinion that in the long run, the marriage between science and defence is corrupting, and will at best turn science from a liberating to a destructive force, and ultimately dry up the wells of inventiveness in the scientist himself. . . . I therefore earnestly hope that at least a proportion of scientists in all countries will retain their freedom and integrity.[1]

Professor Butterfield, in the article quoted on page 85, went on to say:

> A system under which research has come to depend so much on the favour of government, on high organisation, on vast capital outlays, may sooner or later present us with problems of its own.

All governments of modern, industrialised societies are now faced with 'the problems' referred to by Butterfield, for the direction and pace of scientific and technological advance are now to a considerable extent the outcome of government policy.

> The general development both of science and industry leads inevitably to ever more intricate forms of organisation; our task is not to resist this tendency but to understand it and to see to it that when organisation is necessary it is used effectively and for good ends.[2]

As long ago as 1944 the Association of Scientific Workers had pointed out that:

> Those who are to run the government, industry, commerce, communications, indeed every branch of the national economy require, more than ever before, a grasp of scientific method as well as of its fruits in any particular field.[3]

In evidence to the Franks Commission the Civil Service Commission pointed out that 90% of those entering the Administrative class of the Service did no science while at university. The Commissioners wished that

> scientific disciplines provided, after a three-year university course, a larger regular supply of well-educated non-specialists.

[1] Lord Hailsham, *Science and Politics* (Faber & Faber, 1963).

[2] Bernal, *The Social Function of Science*, p. 167.

[3] Association of Scientific Workers, *Science in the Universities* (1944).

The idea is given support by the conclusions of an advisory group on science policy set up by the Organisation for Economic Development and Co-operation.

> One of the most important problems of educational policy in the immediate future will be to train scientists who are also knowledgeable about the essential and varied implications of their work and above all to develop an essentially new breed of public servants. This new public servant would be sufficiently trained in the methods and ways of science to be equal to the increasing number and importance of policy decisions having a high technical content.

The complex relationship between Government (representing society) on the one hand and scientists and technical experts on the other is a new phenomenon which has emerged as a consequence of the scientific and technological revolution. To make this alliance effective and fruitful is a problem which confronts society. Never before have the circumstances warranted so much concern over the organisation and control of scientific activity

In 1959 a Ministry of Science was created — now part of the Department of Education and Science. The need for such a Ministry was first advocated by Huxley, Gore, Colonel Strange and others nearly a century ago. The Government recently undertook a complete overhaul of the administration of science. The D.S.I.R. has been dissolved and a Science Research Council and Natural Environment Research Council has been set up, the responsibility for the application of scientific knowledge being transferred to a newly-created Ministry of Technology. These changes were incorporated in a Science and Technology Bill and in moving the second reading of this Bill the Secretary of the Department of Science and Education commented:

> I hope in the mechanism the Government is creating we shall be doing something more than merely setting up a structure of councils and arranging proper conditions of work for the people concerned. We shall be providing an atmosphere in which two temperaments — politics and science, so different in their approach — can accept cheerfully the necessity which is imposed on them by the world in which we live, of working together.

In spite of any changes that can be made in administrative machinery and advisory bodies, in the last analysis the final decisions regarding scientific policy rest with governments. In the post-war period Britain has attempted to cover too many avenues of development with too few resources. Commenting on this the Advisory Council for Scientific Policy said:

> If the resources which the Government can set aside for science cannot be increased sufficiently to allow us to embark on all the good scientific projects of which we know, it will be up to the Government itself to decide . . . what our national priorities should be . . . The problem of priorities in science and technology lies at the heart

of national science policy and therefore of our national destiny.[1]

The Impact of Science on Social Values

> We can look back half a century and see the wonderful advances in science which have been made in that period . . . They have extended the comforts of life to a much enlarged circle. Thus the knowledge and well-being of mankind must increase indefinitely to a limit which no one can foresee.[2]

> To increase the well-being and the enjoyment of material life is today the dominant idea of civilized nations. All their efforts are turned to industry because it is from that alone that one can expect progress. It is industry that gives birth to and develops in mankind new needs and gives them the means to satisfy them. Industry has become the life of the peoples.[3]

It would be true to say that these statements express the central philosophy of present-day society — a belief in the inevitability of material progress, a progress which has its foundations in scientific and technical innovations.

While it is salutary to affirm as a major aim of society 'the increase in the well-being and enjoyment of material life' of its peoples it is a little naïve to expect, as did these earlier enthusiasts of an industrial society, that this would be the direct and principal outcome of an expanding technology.

Social attitudes, to a large extent, have their origin in the educational system. This is no less true of attitudes to science than of other social attitudes.

> The advancement of science has its roots in the educational process. The advancement of science depends not only upon the training of professional scientists; it depends also upon the public image.[4]

Some critics of the educational system claim that it creates a society which is polarised into 'two cultures'.

Concerned at the narrowness of the training of scientists and technologists, the British Association undertook an enquiry into their education. It found

> that the graduate scientist and technologist too often displays a narrowness of views and interests and is unable to communicate effectively with others or to enter sufficiently well into their thoughts and feelings. . . . Criticism is . . . substantial enough to call for a reappraisal of the educational system that has moulded them.[5]

Lest it be thought that it is only the training and education of scientists and technologists which is at fault the committee took pains to point out that its survey did not imply that all was well with the education of the non-scientist.

Professor Butterfield sees the major defect

[1] *Annual Report* of the Advisory Council for Scientific Policy (1964).
[2] Thomas Jefferson, 1819.
[3] Marc Seguin (French scientist, philosopher), Introduction to *Traite sur l'Influence des Chemins de Fer* (1839).
[4] Sir Eric Ashby, *Investment in Man.* Address to the British Association, 1963.
[5] *The Complete Scientist — Report of the Leverhulme Study Group to the British Association* (O.U.P., 1961), p. 2.

in the educational system as a failure to do justice to the imagination.

> We ought to go on valuing science more than technology. And we ought to note that the sciences still have need of humanism . . . One of the defects of educational policy in a 'technological age' is the failure to do justice to imagination.[1]

Lord Brain, in his Presidential Address to the British Association, said that he was of the opinion that the schism in society was not between the scientific and classical outlook but

> between whose who see the world in terms of rapidly changing outlooks, and those who see it in terms of static environment, and frozen emotional attitudes of the past. The first group have to educate the second, which includes many of our rulers, as quickly as possible. This will mean spending more money and thought on education than we do at present. . . . The greatest need today is to acquire the power of looking ahead, forecasting, and preparing for the consequences of the accelerating developments of science and technology.

Among the general populace the prestige of science and technology has never been higher. This stems from the fact that science is seen to be successful. Science has two functions. It helps man to understand nature and it gives man power over nature. In a 'technological age' admiration for science springs largely from the second of these. Recently the Duke of Edinburgh said that science is so glamorous that many people firmly believe it can do no wrong. All too few people realise that this is a new-found glamour.

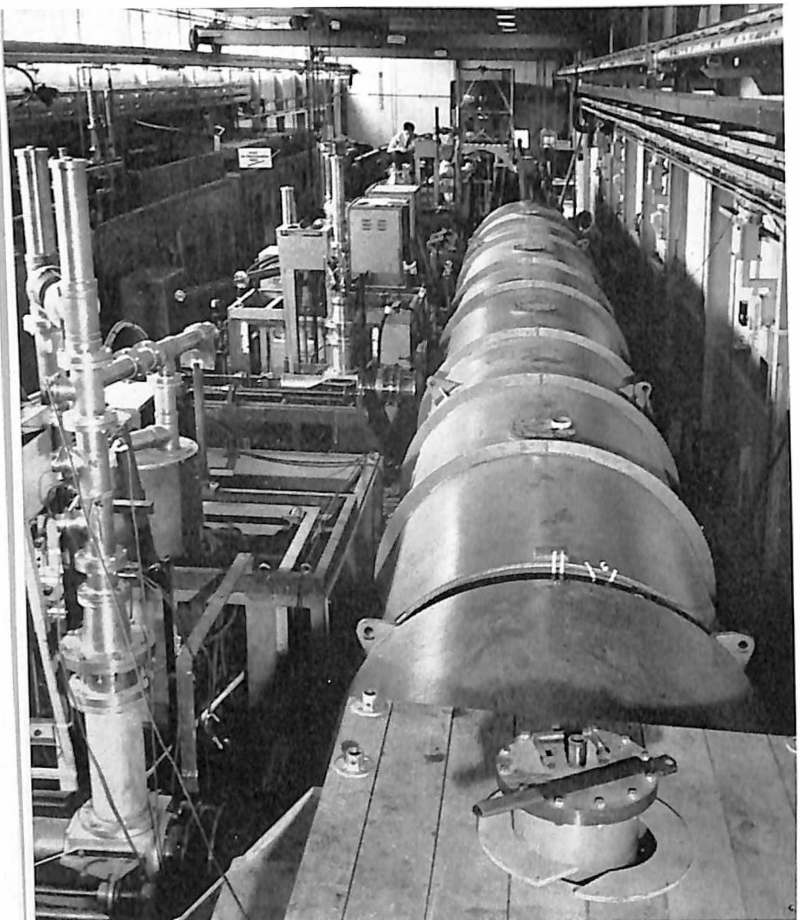
> We forget how very recent this faith in science is. . . . The contemporary tendency to put science in the centre of the picture is a mushroom growth of the past decade or two . . . No convincing case has been made in favour of this new worship of science. It seems very likely that it is a reaction to the spectacular successes of science in recent times, which war and the threat of war have largely made possible.[2]

Science has become identified with a spirit of adventure. It is also conceived as being rational and egalitarian. Many see its professionalism and strict standards of merit transforming an outmoded and inefficient society into a streamlined meritocracy. But science, too, is increasingly seen as an instrument of national prestige. Success in the scientific sphere is identified with national success. Conversely, failure, or lack of success, is equated with national failure. When the excited crowds surge out in Moscow or New York to herald yet another space success it might seem churlish to accuse them of xenophobic hysteria. It might be cynical to suggest that what they acclaim is not the success of international science but national technological capability. If true, however, it is a danger of which Ruskin warned a century ago.

> The struggle between man and machine is a grave danger to civilisation — it produces an unthinking exultation in mechanical achievement. His glory is not in his 'going', but in his 'being'.

[1] H. Butterfield, 'Springs of Discovery', *Observer*, 9 July 1961.

[2] J. Macmurray, *Religion, Art and Science*, p. 9.



A Linear Accelerator

A machine that can accelerate particles to high energies. Used in nuclear physics research.

To be sure, this society is not without its critics. To 'increase the well-being and the enjoyment of material life' requires the fullest exploitation of science and technology which become the 'means' to this 'end'. Macmurray points out that there is a danger that from being used as a means technology may quickly become an end in itself.

> To exploit power is to do something because it is possible, not because one has a good reason for doing it. The systematic exploitation of a continuously expanding technological capacity means that as new possibilities of action arise, we use them because we now have them, and not for any good to be attained by their use. The use of the new power has become a new value in itself. Means has become end. The fact that something has become possible is accepted as a reason for doing it . . . [1]

In 1963 the American car output exceeded the 1955 record of 7,130,000. Macmurray uses such a fact to illustrate his point.

> We take pride in the success of our motor industry in achieving ever greater

[1] Macmurray, op. cit., p. 23.

productive capacity, knowing but ignoring the fact that every increase in the number of cars on the roads involves inevitably a corresponding increase in the destruction of men, women and children. We have come to think that such technological advances must go on; and that any attempt to stop it in the interests of human life is reactionary and inconceivable.

Hence:

> Our characteristic social activity is the use of a progressive technology based upon scientific research. A scientific age is an age whose major social end is the development and application of scientific technology.[1]

These reflections and the concern for ends are echoed by G. H. Bantock.[2] He argues that the real nature of education is being neglected because it is increasingly valued as a commodity 'in the production of educated manpower' as the means of meeting the demands of an industrial society. 'Fundamental questions concerning ends are sadly neglected,' he says, and points out that 'our besetting danger is faith in machinery' and that we overrate 'doing' as opposed to 'knowing'.

Recently the journal *New Society* asked various intellectuals for their views on the sort of society they would like to see develop in England. The polarised attitudes of society are reflected in the following quotations from the replies they received.

Edmund Leach, social anthropologist at Cambridge, commented:

> My recipe for English society is that we go absolutely all out in pursuit of an advanced technology. Plan for the fully automated industry of the 1980's but don't worry too much about the appalling social upheavals which will result . . . Political leaders in the past have had to be experts in international diplomacy; future leaders will require a much better understanding of what is scientifically possible and sociologically essential. Our maximum effort should be concentrated on higher education in the natural and social sciences.

David Holbrook, English don at Cambridge, aligns himself with Macmurray and Bantock when he says:

> We are looking the wrong way. The future of English society depends upon something deeper and more crucial than scientific and technological development, the extension of education or other reforms in the management of things. It depends upon the quality of the national imagination. Even our scientists lack imagination, because their education has been so illiberal: many are illiterate and lacking in vision. Many of our 'educated' classes cannot really think because they have never been encouraged to explore experience at the rich deep imaginative level. We need to be able to feel before we can think, because ratiocinative capacities are grounded well and effectively only if they are grounded on a stable, balanced and mature sensibility — on an intuitive life, a psyche, which is capable of asking 'what for'.

As D. H. Lawrence once said,

> 'We need to ask, where does our go go to?'

[1] Macmurray, op. cit., p. 24.
[2] *Education in an Industrial Society* (Faber & Faber, 1963).

APPENDIX I

Biographical Sketches of English Scientists of the late Eighteenth and the Nineteenth Centuries

The following is a short list of scientists and technologists who lived and worked during the nineteenth century. It is during the nineteenth century, when the influence of science and technology was growing, that differences in the training and education of scientists in the various fields are apparent.

For a greater part of the nineteenth century the easiest access to a career in mathematics or physics was a Cambridge education. In the first group fourteen out of twenty-one were educated at Cambridge. Of the remainder, one only did not receive some form of education. The significance of a Cambridge education is largely confined to this group, for in other fields the education most likely to lead to the pursuit of scientific interests was a medical training, either at university or in the form of an apprenticeship to an apothecary or druggist.

In chemistry there were few effective facilities for training and the majority of the most distinguished chemists supplemented their education with a period of training abroad at the main centres of research. The layman's interest in science is brought out clearly in Group III. Here, as in the field of engineering and technology, there was a complete absence of formalised education and training.

Group I

Mathematicians and physicists

John Couch Adams (1819–92) Mathematician/Astronomer

Education	St. John's College, Cambridge
Positions held and contributions to science and technology	1858 Professor of Mathematics, St. Andrews University
	1859 Professor of Astronomy and Geometry, Cambridge
	Discoverer of planet Neptune

Sir George Bidell Airey (1801–92) Mathematician/Astronomer

Education	Trinity College, Cambridge
Positions held and contributions to science and technology	1826 Professor of Mathematics, Cambridge
	1828 Professor of Astronomy, Cambridge
	Seventh Astronomer Royal

Charles Babbage (1792–1871) Mathematician/Mechanician

Education	Trinity College, Cambridge
Positions held and contributions to science and technology	1828 Professor of Mathematics, Cambridge
	1834 Invented the principle of the analytical engine, forerunner of the modern automatic computer
	Was instrumental in founding the Astronomical Society (1830), British Association (1831) and the Statistical Society (1834)

Appendix I

Sir David Brewster (*1781–1868*) Physicist

Education	Edinburgh University
Positions held and contributions to science and technology	Principal of Edinburgh University
	Instrumental in founding the British Association. Noted for his experimental work on polarised light

Henry Cavendish (*1731–1810*) Physicist/Chemist

Education	Peterhouse College, Cambridge
Positions held and contributions to science and technology	Noted for researches on electricity
	Discovered the compound nature of water and nitric acid

Augustus de Morgan (*1806–71*) Mathematician

Education	Trinity College, Cambridge
Positions held and contributions to science and technology	1828 Professor of Mathematics, University College, London

Sir John Herschel (*1792–1871*) Astronomer

Education	Eton; St. John's College, Cambridge
Positions held and contributions to science and technology	Trained for the Law

William Mitchinson Hicks (*1850–1934*) Mathematician/Physicist

Education	St. John's College, Cambridge
Positions held and contributions to science and technology	Professor of Mathematics, Firth College, Sheffield
	Vice-Chancellor of the University of Sheffield

Robert Hunt (*1807–87*) Physicist

Education	No formal education. Apprenticed to doctor in London
Positions held and contributions to science and technology	1851 Lecturer in Mechanical Science, with its Applications to Mining, Government School of Mines
	1853 Lecturer in Experimental Physics, Government School of Mines

James Prescott Joule (*1818–89*) Physicist

Education	Private tutor
Positions held and contributions to science and technology	Established the principles of interconvertibility of various forms of energy

J. Norman Lockyer (*1836–1920*) Physicist

Education	Various schools
Positions held and contributions to science and technology	1881 Professor of Astronomical Physics, Royal College of Science

James Clerk Maxwell (*1831–79*) Physicist

Education	Edinburgh University and Trinity College, Cambridge
Positions held and contributions to science and technology	1856 Professor of Natural Philosophy, Marischal College, Aberdeen 1860 Professor of Physics and Astronomy, King's College, London 1871 Professor of Experimental Physics, Cambridge

J. H. Poynting (*1852–1914*) Physicist

Education	Cambridge University
Positions held and contributions to science and technology	Professor of Physics, Mason's College, Birmingham

Lord Rayleigh (*1842–1919*) Physicist

Education	Trinity College, Cambridge: Senior Wrangler, Mathematics Tripos 1865
Positions held and contributions to science and technology	1879 Professor of Physics and Head of Cavendish Laboratory 1887 Professor of Physics, Royal Institution, London

Sir Arthur William Rücker (*1848–1915*) Physicist

Education	Brasenose College, Oxford
Positions held and contributions to science and technology	1874 Professor of Mathematics and Physics, Yorkshire College, Leeds 1886 Professor of Physics, Royal College of Science, London

Appendix I

Sir George Gabriel Stokes (*1819–1903*) Physicist

Education	Pembroke College, Cambridge
Positions held and contributions to science and technology	1849 Professor of Mathematics, Cambridge 1854 Lecturer in Physics, Metropolitan School of Science 1885 President of the Royal Society

Sir Joseph John Thomson (*1856–1940*) Physicist

Education	Owens College, Manchester; Trinity College, Cambridge; Mathematical Tripos
Positions held and contributions to science and technology	1884 Professor of Physics and Head of Cavendish Laboratory, Cambridge

John Tyndall (*1820–93*) Physicist

Education	Private tuition; Marburg University; Berlin University
Positions held and contributions to science and technology	1854 Professor of Natural Philosophy, Royal Institution, London Lecturer in Physics, Royal School of Mines

William Whewell (*1794–1866*) Philosopher/Scientist

Education	Trinity College, Cambridge
Positions held and contributions to science and technology	1828 Professor of Mineralogy, Cambridge 1838 Professor of Moral Philosophy, Cambridge

Reverend Robert Willis (*1800–75*) Physicist

Education	Caius College, Cambridge. Trained in Theology
Positions held and contributions to science and technology	1837 Professor of Natural and Experimental Philosophy, Cambridge 1853 Lecturer in Applied Mechanics, Government School of Mines

Thomas Young (*1773–1829*) Physicist

Education	Trained privately in medicine Qualified in medicine at Cambridge Also educated at Göttingen
Positions held and contributions to science and technology	1801 Professor of Natural Philosophy, Royal Institution, London Noted for work on interference of light waves. Did much to establish the wave theory of light

GROUP II

Chemists

Henry Edward Armstrong (*1847–1937*) Chemist

Education	Royal College of Chemistry; Leipzig University
Positions held and contributions to science and technology	1871 Professor of Chemistry at Finsbury Technical College 1879 Professor of Chemistry at Central Institution, South Kensington Did much to improve the teaching of science

John Dalton (*1766–1844*) Chemist/Physicist

Education	No formal education
Positions held and contributions to science and technology	Tutor in Mathematics and Natural Philosophy, New College, Manchester Developer of the modern atomic theory

Sir Humphry Davy, Bart. (*1788–1829*) Chemist/Physicist

Education	Penzance Grammar School. Apprenticed to surgeon-apothecary
Positions held and contributions to science and technology	1798 Chemical Superintendent of Medical Pneumatic Institution, Clifton 1801 Director of the Chemical Laboratory, Royal Institution 1802 Professor of Chemistry at the Royal Institution 1820 President of the Royal Society Discoverer of potassium and sodium Established the science of electro-chemistry

Michael Faraday (*1791–1867*) Chemist/Physicist

Education	No formal education
Positions held and contributions to science and technology	1825 Director of the Chemical Laboratory, Royal Institution 1833 Fullerian Professor of Chemistry, Royal Institution Discovered laws of electrolysis Discoverer of electromagnetic induction

Sir Edward Frankland, Ph.D. (*1825–99*) Chemist

Education	Museum of Economic Geology; Jermyn Street; Marburg and Giessen
Positions held and contributions to science and technology	1851 Professor of Chemistry, Owens College, Manchester 1863 Professor of Chemistry, Royal Institution 1865 Professor of Chemistry, Royal College of Chemistry

Appendix I

Thomas Graham (*1805–69*) Chemist

Education	Glasgow and Edinburgh Universities
Positions held and contributions to science and technology	1830 Professor of Chemistry, Andersonian Institute 1837 Professor of Chemistry, University College, London

Frederick Guthrie Ph.D. (*1833–86*) Chemist/Physicist

Education	University College, London Heidelberg and Marburg
Positions held and contributions to science and technology	1856 Demonstrator in Chemistry, Owens College, Manchester 1859 Demonstrator in Chemistry, Edinburgh University 1868 Lecturer in Physics, Royal School of Mines Authority on science teaching

Sir William Henry Perkin (*1838–1907*) Chemist

Education	Royal College of Chemistry
Positions held and contributions to science and technology	Discoverer of aniline dyes

Sir Lyon Playfair, Ph.D. (*1818–98*) (*1st Baron Playfair*) Chemist

Education	St. Andrews; Andersonian Institute; Giessen
Positions held and contributions to science and technology	1843 Professor of Chemistry, Royal Institution 1851 Lecturer in 'Chemistry Applied to Arts and Agriculture', School of Mines 1858 Professor of Chemistry, Edinburgh University Politician, became Postmaster-General Active in the problem of health in industrial centres

Joseph Priestley (*1733–1804*) Chemist

Education	Theological training
Positions held and contributions to science and technology	Tutor in Literature and Belles-Lettres, Warrington Academy First person to separate oxygen from air

Sir William Ramsay, Ph.D. (*1852–1916*) Chemist

Education	Heidelberg, Tübingen
Positions held and contributions to science and technology	1880 Professor of Chemistry, College of West of England, Bristol 1887 Professor of Chemistry, University College, London Discoverer of argon, helium, krypton, xenon, radon

Sir Joseph Wilson Swan (*1828–1914*) Chemist/Physicist

Education	Apprenticed to druggist
Positions held and contributions to science and technology	Partner in firm of manufacturing chemists Invented prototype of electric light bulb

Sir Thomas Edward Thorpe, Ph.D. (*1845–1925*) Chemist

Education	Owens College; Heidelberg; Bonn
Positions held and contributions to science and technology	1874 Professor of Chemistry, Yorkshire College, Leeds 1885 Professor of Chemistry, Royal College of Science

William Hyde Wollaston (*1766–1828*) Chemist/Natural Philosopher

Education	Caius College, Cambridge; trained in medicine
Positions held and contributions to science and technology	First to detect palladium and rhodium Proved the identity of frictional and voltaic electricity

A. W. Williamson (*1824–1904*) Chemist

Education	Heidelberg; Giessen; Paris
Positions held and contributions to science and technology	1849 Professor of Chemistry, University College, London

GROUP III

Botanists, zoologists and geologists

Charles Darwin (*1809–82*) Naturalist

Education	Medical training at Edinburgh University Theological training at Christ's College, Cambridge
Positions held and contributions to science and technology	Author of *Origin of Species* Author of *Descent of Man* Put forward natural selection as basis of evolution

Appendix I

Erasmus Darwin (*1731–1802*) Physician/Scientist

Education	Medical training St. John's College, Cambridge, and Edinburgh University
Positions held and contributions to science and technology	Foremost physician of his day and an early advocate of evolutionary ideas

Sir Henry Thomas de la Beche (*1796–1855*) Geologist

Education	Royal Military College, Great Marlow (Now Sandhurst)
Positions held and contributions to science and technology	Director-General of the Geological Survey Director of the Royal School of Mines

Edward Forbes (*1815–54*) Naturalist

Education	Trained for medicine at Edinburgh University
Positions held and contributions to science and technology	Naturalist on H.M.S. *Beacon* Professor of Botany, King's College, London Lecturer in Geology, Government School of Mines Professor of Natural History at Edinburgh University

James Hutton (*1726–97*) Geologist

Education	Trained in medicine at Edinburgh and Paris
Positions held and contributions to science and technology	In practice as doctor Retired early to pursue his interests in geology Pioneer of the evolutionary explanation of geological phenomena

Thomas Henry Huxley (*1825–95*) Naturalist/Biologist

Education	Charing Cross Hospital Medical School
Positions held and contributions to science and technology	Surgeon on H.M.S. *Victory* Professor of Natural History at Royal School of Mines Fullerian Professor of Physiology, Royal Institution 1883 President of the Royal Society Privy Councillor

John W. Judd (*1840–1916*) Geologist

Education	Royal School of Mines
Positions held and contributions to science and technology	Professor of Geology, Royal School of Mines

Sir Charles Lyell (*1797–1875*) Geologist

Education	Trained for law at Exeter College, Cambridge
Positions held and contributions to science and technology	Author of *Principles of Geology*

Louis Miall (*1842–1921*) Biologist

Education	Self-taught
Positions held and contributions to science and technology	1876 Professor of Biology, Yorkshire College, Leeds

Sir Roderick Murchison (*1792–1871*) Geologist

Education	Royal Military College, Great Marlow
Positions held and contributions to science and technology	Director-General of the Geological Survey Director of the Royal School of Mines

Sir Andrew Ramsay (*1814–1891*) Geologist

Education	Grammar school, Glasgow; self-taught geologist
Positions held and contributions to science and technology	1847 Professor of Geology, University College, London 1851 Lecturer in Geology, Royal School of Mines Director-General, Geological Survey

Sir Warrington Smyth (*1817–91*) Geologist

Education	Trinity College, Cambridge
Positions held and contributions to science and technology	Lecturer, Mining and Mineralogy, School of Mines

Group IV

Engineers, metallurgists and inventors

Sir Richard Arkwright (*1732–92*) Inventor

Education	No formal education
Positions held and contributions to science and technology	Inventor of spinning machinery

Appendix I

Sir Henry Bessemer (*1813–98*) Engineer/Inventor

Education	Self-acquired education in engineering
Positions held and contributions to science and technology	Discoverer of the first process for making inexpensive and *plentiful* steel

Joseph Bramah (*1749–1814*) Engineer/Inventor

Education	None
Positions held and contributions to science and technology	Inventor of hydraulic press

Isambard Kingdom Brunel (*1806–59*) Civil and Mechanical Engineer

Education	Lycée Henri Quatre, Paris
Positions held and contributions to science and technology	Designer of Clifton suspension bridge, Bristol Docks, and the first transatlantic liner

Edmund Cartwright (*1743–1823*) Inventor

Education	Clerical training at Oxford University
Positions held and contributions to science and technology	Inventor of the power-loom

Samuel Crompton (*1753–1828*) Inventor

Education	None
Positions held and contributions to science and technology	Inventor of the spinning-mule

James Nasmyth (*1808–90*) Engineer

Education	None
Positions held and contributions to science and technology	Inventor of steam hammer Did much to improve machine tools

John Percy (1817–89) Metallurgist

Education	Medical training at Edinburgh University
Positions held and contributions to science and technology	1851 Lecturer in Metallurgy, School of Mines Pioneer of metallurgy as a scientific subject

Osborne Reynolds (1842–1912) Engineer/Physicist

Education	Queen's College, Cambridge
Positions held and contributions to science and technology	1868 Professor of Engineering, Owens College

William Ripper (1853–1937) Engineer

Education	Apprentice in dockyard
Positions held and contributions to science and technology	1884 Professor of Mechanical Engineering, Firth College, Sheffield 1917 Vice-Chancellor, Sheffield University

W. E. Roberts-Austen (1843–1902) Metallurgist

Education	Royal School of Mines
Positions held and contributions to science and technology	1880 Professor of Metallurgy, Royal School of Mines

Sir William Siemens (1823–83) Inventor/Industrialist

Education	Göttingen University
Positions held and contributions to science and technology	Invented regenerative furnace for steel making

John Smeaton (1724–92) Civil engineer

Education	None
Positions held and contributions to science and technology	Founder of civil engineering profession

Appendix I

George Stephenson (*1781–1848*) Inventor

Education	None
Positions held and contributions to science and technology	Began as colliery engine-wright, became a consultant railway engineer. Designed first public passenger-train locomotive.

Robert Stephenson (*1803–59*) Engineer

Education	Edinburgh University
Positions held and contributions to science and technology	Railway engineer Designer of Menai tubular bridge and Conway bridge

Sidney Gilchrist Thomas (*1850–85*) Inventor

Education	Self-taught. Supplemented by evening study at Birkbeck Institute
Positions held and contributions to science and technology	Discovered how to separate phosphorus from iron, in the Bessemer Converter

Richard Trevethick (*1771–1833*) Engineer

Education	None
Positions held and contributions to science and technology	Pioneer of high-pressure steam-engines

James Watt (*1736–1819*) Inventor and Civil Engineer

Education	No formal education. Apprentice to instrument-maker
Positions held and contributions to science and technology	Inventor of the modern condensing steam-engine Supplied the inventive genius in the firm of Boulton & Watt, of which he was a partner Carried out surveys for canals and prepared plans for harbours

Sir Joseph Whitworth, Bart. (*1803–81*) Mechanical engineer

Education	None
Positions held and contributions to science and technology	Introduced standard screw threads

APPENDIX II

Short Notes on the Development of Science and Technology in English Universities

In the growth of the science faculties of the colleges, which were the progenitors of university colleges and universities, there were, generally speaking, common lines of development. The basic core of the curriculum usually included — though not in all cases — mathematics, physics, mechanics and chemistry. Natural history, geology and mineralogy sometimes formed an addendum to this core either as one subject or individually.

Almost all the new colleges went through an initial phase during which they were concerned with work of a fairly elementary nature, i.e. of about G.C.E. 'O' level, for the minimum age of entry was frequently as low as sixteen and in some cases even fourteen.

Nevertheless, by the turn of the century the colleges had without exception aspired to degree-level teaching and many had developed distinctive schools of research in several scientific and technological subjects.

A synopsis of the salient features of the teaching in science and technology in English universities is given below.

The Cambridge teaching in mathematics was reformed early in the nineteenth century and thereafter *throughout the century* Cambridge was notable for its mathematics teaching. Its products were found everywhere and almost without exception the first Chairs of Mathematics created in the new provincial colleges were held by Cambridge men. In the absence of an equivalent training in experimental physics, physicists in the nineteenth century were frequently Cambridge mathematicians with a strong bias towards mathematical physics. Be that as it may, many of them made substantial contributions to experimental research in physics at the new colleges, and two of them, Lord Rayleigh and Sir J. J. Thomson, established the reputation of the Cavendish for its experimental research.

Under the influence of men like von Hofmann, Sir Lyon Playfair and Sir Henry Roscoe, teaching and research in chemistry made rapid progress in the second half of the century. University College, London, was the first to appoint a Professor of Practical Chemistry (1845), but the Royal College of Chemistry under von Hofmann and Owens College under Roscoe also became flourishing centres of chemical research.

Pioneers of engineering as a university subject included University College, London; King's College, London; and Owens College, Manchester. It is of interest to note that the first Chair in Engineering was established at University College as early as 1846 whereas Oxford did not appoint its first Professor of Engineering until 1908. Meanwhile by 1900 nearly all the other colleges had developed Faculties of Engineering with Chairs in Civil, Mechanical and Electrical Engineering.

The first Chair of Metallurgy was created by the School of Mines in 1851. This subject later received emphasis at King's College, London, and at Sheffield. Mining was an integral part of the curriculum at the Museum of Economic Geology when it was set up in 1839. It continued to be an important part of the teaching when this institution later became the School of Mines. Other centres to develop the teaching of mining were the Newcastle College of Science (i.e. a constituent college of Durham University); Sheffield; and Birmingham.

As well as more orthodox Chairs in engineering in the 1870s University College, London, created Chairs of Mechanical Technology, Chemical Technology and Electrical Technology. Other developments in technology in the nineteenth century were in brewing at Birmingham and dyeing and leather manufacture at Leeds.

1. *Oxford University*

By the opening of the nineteenth century there were already Chairs in Astronomy, Geometry, Natural Philosophy, Experimental Philosophy and Botany. However there were no laboratories and no practical work.

In 1803 a Chair of Chemistry was instituted. Chairs of Mineralogy and Geology were instituted in 1813 and 1818 respectively.

A Chair of Zoology appeared in 1861 and Pure Mathematics in 1892.

In 1900 the Wykeham Chair of Physics was instituted and electricity and magnetism were assigned to this while mechanics, sound, light and heat were assigned to the Professor of Experimental Philosophy.

A Chair in Engineering did not appear until 1908 when a Chair of Engineering Science was created.

2. *Cambridge University*

At Cambridge Chairs in Mathematics; Chemistry; Natural and Experimental Philosophy; Botany; Astronomy and Geometry; and Geology had been created during the seventeenth and eighteenth centuries.

The Natural Science Tripos was established in 1851. Honours could be awarded but not a degree and no one could sit for it unless he had passed all the examinations required for admission to a first degree in arts, law or medicine. The subjects for the examination included physics, chemistry, botany and geology. At this time there were professorships in natural philosophy.

The Natural Science Tripos did not become popular until several years after its introduction. Few students entered for it and the first Fellowship to be awarded to a successful student in the Tripos was not until 1867.

The colleges could not provide the laboratories on an adequate scale. Only the university could do this and it objected to doing so. In 1871 the Natural Science Tripos was reorganised. Previously, students had had little chance of showing their skill in practical work but greater emphasis was now given to it.

In the same year a Chair of Experimental Physics was instituted and the Cavendish Laboratory was opened. In 1875 a Chair of Engineering was created. The Jacksonian Chair of Natural Philosophy endowed at Trinity College in 1782 was, in 1878, transferred to the University.

In 1879 the Degree of Doctor of Science was instituted. Considerable dissatisfaction prevailed over the fact that the colleges and the University did not co-operate over the provision of facilities for science. Additional laboratories were needed and there was inadequate instruction in biology and geology.

3. *London University*

(i) *University College, London* (1826)

1827 Chairs in Natural Philosophy and Astronomy, Mathematics, Chemistry and Engineering and Application of Mechanical Philosophy to the Arts.

A second appointment in Chemistry was contemplated — 'The Application of Chemistry to the Arts' — but this post was unfilled. In the previous year von Liebig had opened his Chemistry Laboratory at Giessen.

1841 Chair of Geology instituted.
1845 Chair in Analytical and Practical Chemistry.
1846 Chairs in Mathematical Principles of Engineering and Descriptive Machinery.
1867 Chair in Pure and Applied Mathematics.
1868 Chairs in Experimental Physics; Applied Mathematics and Mechanics.
1878 Chairs in Chemical Technology and in Mechanical Technology.
1882 Chair in Civil Engineering and Surveying.
1884 Chair in Electrical Technology.
1897 Chair in Municipal Engineering.

(ii) *King's College, London* (1828)

At the outset Chairs in Mathematics, Chemistry, Natural History and Zoology, Natural and Experimental Philosophy and Geology were created.

The Chair in Natural and Experimental Philosophy was held by a Cambridge mathematician and there was no laboratory or practical work.

During the years 1838 to 1840 a start was made on the development of engineering in the College. A class in civil engineering was begun in 1838 and this included machine drawing and surveying land, in 1839 a Lectureship in Manufacturing Art and Machinery was instituted. In 1834 Sir Charles Wheatstone was appointed to the Chair of Experimental Philosophy but soon ceased to lecture to students and devoted the whole of his time to research.

An attempt to establish military engineering and strategy by the creation in 1849 of a Chair of Fortification and Military Tactics had to be reluctantly abandoned as a failure.

In 1851 the College followed the example of University College by creating a Chair of Practical Chemistry. A novel development was the instruction given in the arts and crafts of photography.

Despite the appointment of Sir Charles Lyell to the Chair of Geology in 1828 this subject made little headway, for Sir Charles soon resigned and the department subsided into insignificance. Metallurgy was first seriously developed in 1879 when a professor was appointed.

The scope of teaching in engineering was further extended by the creation in the 1860s of Chairs in Free-hand Drawing, Geometrical Drawing and The Arts of Manufacture. During the 1890s the Engineering Department was reorganised on the basis of three Professorships — Civil, Mechanical and Electrical Engineering. By this time the Department had more students than any other in the country.

(iii) *The Royal School of Mines and Royal College of Science* (1853)

The Royal School of Mines was begun as the Museum of Economic Geology in 1839.

Appendix II

The Royal College of Science was formerly the Royal College of Chemistry, set up in 1845.

When these two Colleges were combined as one unit it constituted the foremost centre of science and technology in the country. There were Lectureships in Mathematics and Mechanics (1851), Physics (1853), Applied Mechanics (1851), Chemistry (1845), Practical Chemistry (1851), Metallurgy (1851), Biology (1851), Mining (1839), Geology (1839) and Natural History Applied to Geology (1851).

These Lectureships, however, were equivalent to the Professorship of the universities and other colleges. Scientists holding Chairs at the latter frequently relinquished them to take up a Lectureship at the former (see examples in bibliography). Its teaching staff, at various times, included some of the most illustrious men of science of the late nineteenth century — such as Hofmann, Lyon Playfair, Edward Frankland (chemistry); John Tyndall, George Stokes (physics); Huxley (biology); John Percy (metallurgy); and Sir Andrew Ramsay (geology).

4. *Bristol University* (1909)

Formerly The College of the West of England, established in 1874.

The only Chair in science at the outset was a Chair in Chemistry, although mathematics, mechanics, physics, geology and textiles were also taught.

An Engineering Department was set up in 1878. The Professor of Engineering was also responsible for physics — separate Chairs for these subjects were not introduced until 1893.

In the following year a joint Chair in Geology and Zoology was instituted.

5. *Birmingham University* (1900)

Formerly Sir Joseph Mason's Science College, established in 1880.

At the inauguration of the College there were Chairs in Mathematics, Physics, Chemistry and Biology. To these were added Geology (1881), and Engineering (1881).

Two years later a Department of Coal Mining and Colliery Management was set up. In the same year a Lectureship in Metallurgy was created and this became a Chair in 1897, when Chairs were also created in Zoology and in Brewing.

The appointment of a Professor of Brewing was followed shortly after by the creation of the British School of Malting and Brewing — an unusual departure from accepted lines of development.

6. *The University of Durham* (1832)

The University began with a Chair in Mathematics, held by a Cambridge-trained cleric, a Readership in Natural Philosophy and a Lectureship in Chemistry.

A Lecturer in Engineering was appointed in 1843 but science and technology made little progress and in 1871 a College of Physical Science, intended to be the faculty of science, was opened at Newcastle. It had the special function of teaching the sciences underlying mining, agriculture and manufactures. Hence in 1880 a Chair in Mining was instituted, followed in 1891 by a Chair in Agriculture and Forestry.

7. *The University of Leeds* (1904)

Formerly The Yorkshire College of Science, established 1874. Initially there were Chairs in Mathematics and Experimental Philosophy; Chemistry; and in Mining, Geology and

Metallurgy. But, in addition, the Clothworkers Company of London provided a Department of Textile Industries. They followed this by financing the School of Dyeing set up in 1877.

By the time the college was granted independent university status teaching in science and technology had been expanded to include civil, mechanical and electrical engineering, mining, agricultural and leather manufacture.

8. *The University of Liverpool* (1903)

Formerly University College, Liverpool, established in 1881 and a constituent college of the Victoria University.

At the opening of the college there were Chairs in Experimental Physics, Inorganic Chemistry and Natural History. These were quickly followed by a Chair in Mathematics (1882) and a Chair of Engineering (1886). There were no developments in new subjects in the 1890s but in the next decade Chairs were instituted in Physical Chemistry (1903), Electric Power Engineering (1903) and Civil Engineering.

The university was one of the first to pioneer biochemistry, in which a Chair was created in 1902.

9. *The University of Manchester* (1903)

Formerly The Owens College, established in 1851, it was founded through the generosity of John Owens. In that year Professorships were created in Mathematics, Pure and Mixed; Chemistry and Physical Science; and Natural History. At the opening of the Owens College these were reorganised into Chairs of Mathematics; Natural Philosophy; Botany; and Geology.

Engineering first achieved professional status in 1868 and in 1874 a Chair in Geology, Paleontology and Mining was instituted.

A Chair of Applied Mathematics was created in 1881 and in the same year the Professor of Natural Philosophy was retitled Professor of Physics.

10. *The University of Nottingham* (1948)

Formerly the University College of Nottingham, opened in 1881.

At the opening of the college there were Chairs in Physics, Mathematics and Mechanics; Chemistry and Metallurgy; and Natural Sciences. In 1884 the first of these was reorganised into two separate Chairs, Mechanics and Engineering; and Mathematics and Physics, and a further Chair in Engineering created. In the same year a School of Engineering was opened. Experimental Physics did not achieve professorial status until 1906.

11. *The University of Sheffield* (1905)

Originally the Firth College, established in 1879. At its opening there were only two scientific Chairs — those in Mathematics and Chemistry. There was no Chair in Physics, this subject being taught by the Professor of Chemistry.

In 1884 a Lecturer was appointed in Biology and was promoted to Professor in 1888.

The session 1883–4 saw the first moves to establish a strong Technical School within the College. It was hoped to collect £15,000 and appoint professors in Mechanical Engineering and Metallurgy. However, the response of industry was disappointing and only £3,000 was collected. Nevertheless the new Chairs were instituted.

Engineering and metallurgy received further emphasis by a number of non-professorial appointments in the 1890s. In 1892 physics received recognition by the creation of a separate Chair for that subject. The same year saw a Chair of Mining instituted. The teaching of coal mining had taken place right from the start and as early as 1882 an evening course of an extension kind had been held in coal mining. The Chair in Mining already mentioned was supplemented in 1905 by a Chair in Mining Chemistry. Meanwhile, in 1903, a Diploma in Mining had been instituted.

Appendix II

12. *The University of Southampton* (1952)

Originally the Hartley Institution, founded in 1862.

For most of the nineteenth century the work done at the Institution was mainly of secondary school and technical college level. This included the teaching of mathematics, physics, chemistry and elementary engineering. It was not until the 1900s that Chairs were created in Physics; Civil and Mechanical Engineering; Chemistry; Biology and Geology; Zoology and Electrotechnics.

FURTHER READING

An excellent beginning to a more detailed study can be made through the section entitled 'The Scientific Spirit in England, and the similar ones on France and Germany in volume i of J. T. Merz's *History of European Thought* (1896). This should be followed up by a study of D. S. L. Cardwell's *The Organisation of Science in England* (1957) — an admirable analysis of the whole period — and M. Argles's *South Kensington to Robbins* (1964). The latter contains a useful bibliography of official reports on science and technology, education, and industry.

Comparisons between the English and German systems of secondary education and higher education in the nineteenth century are given in Matthew Arnold's *Higher Schools and Universities in Germany* (1892) and Sir Philip Magnus's *Industrial Education* (1888). For the German universities there is F. Paulsen's *German Universities and University Study* (1885) and J. Conrad's *The German Universities for the last fifty years* (1885). W. H. G. Armytage in his *Civic Universities* (1955) deals with the development of the English civic universities and an interesting account of the ideologies underlying their development is Sir Eric Ashley's *Technology and the Academics* (1958). These works on the English universities should be supplemented by the histories of the individual universities — in particular J. Thompson's *The Owens College* (1886) and H. H. Bellot's *History of University College, London, 1826–1926* (1929).

There is a wealth of material concerning the industrial struggle between Britain and Germany in the second half of the nineteenth century. R. C. K. Ensor's *England 1870–1914*, vol. xiv of the Oxford History of England Series (1964) serves as a background to this, while standard works are W. Ashworth's *Economic History of England 1870–1939* (1960) and J. H. Clapham's *Economic Development of France and Germany 1815–1914* (1928). Further statistical material is found in G. D. H. Cole's *British Trade and Industry, Past and Future* (1932) and Ingvar-Svennilson's *Growth and Stagnation in the European Economy* (1954). Contemporary accounts include

The Emergence of a Scientific Society

Arthur Shadwell's *Comparative Study of Industrial Life in England, Germany and America* (1906), Sir Swire Smith's *The Real German Rivalry, Yesterday, Today and Tomorrow* (1918) and E. E. Williams's *Made in Germany* (1896). The two industries whose productivity was most closely related to scientific and technical efficiency — steel and chemicals — are covered by D. L. Burn's *Economic History of Steel Making* (1939) and F. Haber's *Chemical Industry during the Nineteenth Century* (1958). The latter contains an account of the beginnings of organised chemical research in Germany under von Liebig and Bunsen.

The post-1914 era is not so well catered for in the way of books, the most significant work, perhaps, is J. D. Bernal's *The Social Function of Science* (1942). In technical education there is P. F. R. Venables's *Technical Education* and S. F. Cotgrove's *Technical Education and Social Change* (1958). Useful outlines of further education are found in the Board of Education *Annual Report* for 1935 and the Ministry of Education *Annual Report* for 1950. There are, too, Ministry Circulars, University Grants Committee reports and the reports of the Central Advisory Council for Education.

There are several comprehensive analyses of scientific and technical manpower in the post-1945 era, beginning with the Barlow Report in 1946. Others are E. M. McCrensky's *Scientific Manpower in Europe* (1958), Richard Fort's *Scientific and Engineering Manpower Survey* (1959), Joyce Alexander's *Scientific Manpower* (1959) and G. L. Payne's *Britain's Scientific and Technological Manpower* (1960).

Some notable reports of the nineteenth and early twentieth centuries are listed below.

REPORTS

1. Select Committee on Scientific Instruction, *Parliamentary Papers*, 1867–8, xv.
2. *Reports of the Royal Commission on Scientific Instruction and the Advancement of Science* (Devonshire Commission), 1872, 1873, 1874, 1885.
3. *Reports of the Royal Commission on Technical Instruction Abroad*, 1882, 1883.
4. *Reports of the Royal Commission Appointed to Inquire into the Depression of Trade and Industry*, 1886.
5. *Report of the Royal Commission on Secondary Education*, 1894–5, H.M.S.O. (Bryce Commission).
6. *Chemical Instruction and Chemical Industries in Germany*. Diplomatic and Consular Reports. Foreign Office, 1901.
7. *Trade and Technical Education in Germany and France*. Report by Mr J. C. Smail to London County Council. 1914.
8. *Report of the Deputation Appointed to visit Technical Schools, Institutions and Museums in Germany and Austria*. City of Manchester Technical Instruction Committee, 1897.
9. *Report on a Visit to Germany with a view to Ascertaining the Recent Progress of Technical Education in that Country*. A Letter to the Duke of Devonshire by P. Magnus, G. Redgrave, Swire Smith and W. Woodall, 1896.

INDEX

Aberdeen, Earl of, 28
Advisory Council on Scientific Policy, 74, 75, 83, 87
America, 3, 5, 55, 56, 71, 72, 76, 78, 80, 83, 85, 86
Arkwright, Sir Richard, 15
Arnold, Matthew, 33
Arnold, Thomas, 33

Babbage, Charles, 13, 14, 15, 34, 35, 56, 82, 92
Bagrit, Sir Leon, 77
Bailey, Rev. R. S., 31
Bell, Charles, 11
Bernal, J. D., 63, 67, 68, 72
Bessemer, Sir Henry, 39–41, 101
Beyer, Frederick, 27, 28
Birkbeck, George, 31
Birmingham Lunar Society, 12
Board of Education, 54, 65
Boulton, Matthew, 12
Bowden, Lord, 69, 72, 78, 80
Brain Drain, 83–85
Brewster, Sir David, 11, 34, 93
Bristol:
  College of the West of England, 50, 97, 107
  Pneumatic Institute, 17, 96
British Association for the Advancement of Science, 14, 34, 38, 47, 59, 89, 92, 93
Brougham, Lord Henry, 20

Cambridge:
  Mathematical Tripos, 32, 53
  Natural Science Tripos, 32, 52, 105
  University, *see* Universities
Cavendish, Henry, 15, 93
Cavendish laboratories, 52, 53, 62, 64, 66, 94
China, 60, 79
City and Guilds of London Institute, 53, 82
Clarendon laboratories, 52
Clifton, R. B., 21
Cobden, Richard, 22
Cole, Sir Henry, 34
Colleges of Advanced Technology, 72, 81
Computers, 14, 70

Dalton, John, 12, 96
Darwin, Charles, 36, 98
Darwin, Erasmus, 12, 99
Davy, Sir Humphry, 15, 16, 17, 18, 56, 58, 96
Department of Education and Science, 87
Department of Science and Art, 34
Devonshire Commission, 1872, 38, 51
Devonshire, Duke of, 52, 58
Dewar, Sir James, 17, 18, 47
Disraeli, Benjamin, 28
Dissenting Academies, 11, 12, 97
Dyes, 40–41, 43, 47, 70

Edinburgh, 81
  Heriot-Watt College, 31
  Review, 15
Exhibitions:
  The Great, 1851, 19, 35, 53
  The Paris, 1867, 36

Faraday, Michael, 15, 17, 18, 56, 57, 96
Finsbury Technical College, 53, 54, 96
Fleming, Sir Alexander, 66
Florey, Sir Howard, 66
Forbes, Edward, 26, 99
Foster, Carey, 21
Foster, W. E., 28
France, 9, 13, 36, 70
Frankland, Sir Edward, 25, 27, 49, 96, 107
Franks Commission, 84

Galileo, 9
Gaskell and Deacon, Widnes, 45
Geological Survey, 65, 99, 100
Germany, 9, 10, 13, 19, 21, 23, 25, 40–42, 43, 44, 45, 47, 48, 50, 55, 60, 70
Gladstone, W. E., 28, 61
Glasgow, 81
  Royal College of Science and Technology, 31
Gore, George, 43
Graham, Thomas, 11, 97
Grammar Schools, 32, 60, 61, 73, 78, 79
Granville, Lord, 28
Grey, Lord, 28

Herschel, Sir John, 15, 56, 93
Hirst, T. A., 21
H.R.H. Prince Albert, 23, 24, 34
Hofmann, August Wilhelm von, 20, 24, 25, 27, 104, 107
House of Commons, 20, 27
House of Lords, 26, 72
Hurter, Ferdinand, 45, 47
Huxley, Sir Julian, 68
Huxley, Thomas Henry, 10, 18, 19, 27, 32, 35, 36, 37, 39, 50, 59, 61, 87, 99

Industrial revolution, 15, 19
Iron and steel industry, 40, 41, 42

Jefferson, Thomas, 20
Joule, James Prescott, 94

Kelvin, Lord, 11

Leblanc soda industry, 45, 46
Leeds, 56
  Yorkshire College of Science, 12, 50
Lockyer, Sir Norman, 59, 94
London, 56, 81
  Government School of Mines, 25, 26, 27, 93, 95, 99
  King's College, 50, 52, 94, 99, 104, 106
  Museum of Economic Geology, 25, 26, 96, 105
  Royal College of Chemistry, 20, 23, 24, 25, 29, 48, 96, 97, 107
  Royal College of Science, 25, 27, 40, 94, 98, 106, 107
  Royal School of Mines, 20, 25, 27, 29, 30, 48, 95, 97, 99, 102, 105, 106
  University College, 11, 20, 21, 22, 23, 27, 49, 50, 51, 93, 97, 98, 100, 104, 105, 106
Lowe, Robert, 28, 29

Manchester, 21, 29, 30, 56, 81
  College of Arts and Sciences, 12
  Examiner, 30
  Guardian, 30
  Institute of Science and Technology, 31, 76, 77
  Owens College, 12, 20–23, 27, 28, 30, 49–51, 95, 96, 97, 98, 102, 108
Mason, Sir Josiah, 50, 94, 107
Mason's Science College, 50
Maurice, F. D., 31
Maxwell, James Clerk, 11, 32, 52–53, 94
Mechanics' Institutes, 30, 31, 34, 40, 56, 76, 77, 103
Meldola, Raphael, 54
Mill, J. S., 37
Ministry of Technology, 87
Morgan, Augustus de, 11, 33, 93
Muir, Ramsay, 63
Muspratt, James, 31

Nasmyth, James, 15, 101
National certificates, 64, 81, 82
National diplomas, 64, 81

Index

Newcastle College of Physical Science, 50, 105
Newcomen, Thomas, 15
Newton, Sir Isaac, 9
North of England Council for the Education of Women, 50, 56

Owens College, Manchester, *see* Manchester
Owens, John, 21

Peel, Sir Robert, 20
Percy, John, 11, 27, 102, 107
Perkin, Sir William Henry, 40, 97
Playfair, Sir Lyon, Bart., 27, 30, 35, 36, 58, 97, 104, 107
Polytechnics:
  École Polytechnique, 9
  German and Swiss, 50, 53, 54, 55
  London, 54
Priestley, Joseph, 12, 15, 97
Public Schools, 15, 16, 20, 30, 32, 33, 78, 79

Rankine, William John, 11
Rayleigh, Lord, 18, 52, 53, 94, 104
Research:
  Agricultural Research Council, 65
  Department of Scientific and Industrial Research, 65, 87
  Expenditure on, 67, 68, 71, 74, 75, 85, 86
  Government research bodies, 65
  Industrial Research Association, 65, 67
  Medical Research Council, 65
  National Physical Laboratory, 65
  Natural Environment Research Council, 87
  Science Research Council, 87
Reynolds, Osborne, 22, 28, 102
Robbins Report, 74, 79
Roscoe, Sir Henry, 23, 49, 104
Royal College of Chemistry, *see* London
Royal College of Science, *see* London
Royal Military College (Sandhurst), 99, 100
Royal School of Mines, *see* London
Royal Society, 9, 13, 14, 34, 35, 38, 57, 82, 83, 95, 96, 99
Ruskin, John, 89
Russell, Lord John, 28
Russia, 60, 68, 70, 78, 79, 80, 85, 86

Sadler, Sir Michael Ernest, 54
Scientific and technical manpower, 47, 72, 74, 79, 84
Scientific and technical manpower (*contd.*)
  Honours graduates in science and technology, 73
  Membership of professional institutions, 84
  University students in science and technology, 44, 64, 73
Scientific societies, 13, 14, 18, 34, 35, 56, 82, 92
Sheffield, 56
  Firth College, 50, 93, 102, 108
Siemens, Sir William, 38, 40, 102
Smyth, Sir Warrington, 100
Snow, Lord, 69, 70
Southampton,
  Hartley Institute, 50, 109
Spencer, Herbert, 29, 37, 59, 75
Statutes:
  Education Act (1870), 19, 53
  Local Taxation (Customs and Excise) Act (1890), 53
  Technical Instruction Act (1889), 54
Steel, *see* Iron and steel industry
Stewart, James, 56
Stokes, George Gabriel, 27, 95, 107
Strange, Colonel Alexander, 38, 87
Sulphuric acid, 43

Technical education, 19, 34, 53–55, 64, 65, 81, 82
Thomas, Sidney Gilchrist, 31, 39–40, 103
Thomson, Benjamin (Count Rumford), 16–17
Thomson, Sir Joseph John, 18, 21, 32, 53, 64, 95, 104
Todd, Lord, 69, 72
Treasury grants, 50, 61. *See also* University Grants Committee
Turner, Edward, 11
Tyndall, John, 18, 56, 95, 107

United Alkali Co., Widnes, 45, 47
Universities:
  English, 50, 62
    Birmingham, 50, 63, 105. *See also* Mason's Science College
    Bristol, 50, 107. *See also* Bristol, College of the West of England
    Cambridge, 10, 11, 12, 15, 16, 20, 30, 31, 32, 35, 49, 50, 53, 56, 58, 61, 63, 74, 92, 93, 94, 95, 98, 99, 100, 102, 104, 105
    Durham, 11, 50, 107
    Exeter, 50
Universities (*contd.*)
  English (*contd.*)
    Leeds, 49, 50, 107. *See also* Leeds, Yorkshire College of Science
    Liverpool, 50, 108
    London, 21, 29, 38, 50, 56, 106
    Manchester, 12, 50, 63, 74, 75, 77, 108 *See also* Manchester, Owens College
    Newcastle, 50. *See also* Newcastle, Newcastle College of Physical Science
    Nottingham, 50, 108
    Oxford, 10, 11, 15, 16, 20, 30, 31, 32, 35, 49, 50, 56, 61, 63, 74, 83, 84, 94, 101, 105
    Reading, 50
    Sheffield, 50, 93, 102, 104, 105. *See also* Sheffield, Firth College
    Southampton, 50, 109. *See also* Southampton, Hartley Institute
  Scottish
    Aberdeen, 10, 37
    Edinburgh, 11, 36, 93, 94, 97, 98, 99, 102, 103
    Glasgow, 97
    St. Andrews, 92, 97
  German, 16, 31, 37, 49, 63, 65
    Berlin, 20, 23, 25, 95
    Bonn, 23, 24, 98
    Heidelberg, 45, 97, 98
    Giessen, 20, 23, 96, 97, 98
    Göttingen, 23, 95, 102
    Leipzig, 23, 96
    Marburg, 95, 96, 97
    Tübingen, 97
  French, 16
    Paris, 98, 99
  American, 63, 75
    Virginia, 20
University Grants Committee, 61, 81, 83
University population, 44, 64, 78

Watt, James, 12, 15, 103
Wedgwood, Sir Josiah, 12
Whewell, William, 31, 95
Whitworth, Sir Joseph, 28, 103
Widnes, 45, 46, 47
Williamson, A. W., 20, 98
Willis, Rev. Robert, 95
Wilson, Harold, 69
Wissenschaft, 10, 16, 37, 75

Young, Thomas, 15, 17, 95

SOURCES OF HISTORY

The Emergence of a Scientific Society in England 1800-1965

MACMILLAN