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IMPACT of Science on Society
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TERCENTENARY OF THE ROYAL SOCIETY, LONDON

Address delivered by
Mr. VITTORINO VERONESE
Director-General of Unesco

The United Nations Educational, Scientific and Cultural Organization is honoured to associate itself with the tributes and expressions of admiration addressed to you on the occasion of the tercentenary of the foundation of your illustrious Society. The bonds which unite our own youthful Organization with your Society date from the foundation of Unesco; for its first Director-General, the eminent scientist and thinker Sir Julian Huxley, and the first Director of our Department of Natural Sciences, Dr. Joseph Needham, are both Fellows of your distinguished Society. It was they who guided our first efforts in the realm of science, their influence, true to the tradition of your great scholar Newton, extending to many branches of human knowledge.

We are further indebted to your Society for its inspired initiative in founding the International Association of Academies, which has now become the International Council of Scientific Unions. You were among the first to have the universality of science at heart and it is through your efforts that we have in the successor to the former Association a real means of action, which has proved its worth on many different occasions and recently in the outstanding success of the International Geophysical Year.

Unesco’s brief records already include the names of many famous Fellows of your Society. We mention those of Professor A. V. Hill and Lord Russell. Special mention, too, should be made of Sir Alexander Fleming, that benefactor of the human race, whose powerful intellect gave an impetus to the early activities of the Council for International Organizations of Medical Sciences; he was one of the first members of the Council’s Executive Board.

The services which The Royal Society has rendered, throughout its existence, to the cause of science have done much for the promotion of that international co-operation which is so greatly needed; and they are a never failing source of inspiration to Unesco. In this task, in which all must lend a hand, Unesco is anxious to maintain close co-operation with The Royal Society, in a common aim of service to peace and to the welfare of mankind.

Through our representation at the official celebration of the tercentenary

1. Copies of this address were presented by the Director-General of Unesco to the President and members of the Royal Society at a reception held in Burlington House during the official visit to London of the members of Unesco’s Executive Board as guests of the United Kingdom Government from 2 to 4 May 1960.
of the foundation of your Society we wish to convey our admiration and gratitude for the inestimable worth and the high moral quality of the work The Royal Society is performing in the world today. Your glorious past is the best pledge of success in the future. May your far-reaching influence and your unrivalled independence of outlook continue to illuminate the advances of science everywhere.

London, 2 May 1960
THE ROYAL SOCIETY

by

EDWARD HINDLE

Dr. Edward Hindle, Fellow of the Royal Society, zoologist, has held professorships at the School of Medicine, Cairo, and the University of Glasgow, and was lately Scientific Director of the Zoological Society of London. He has specialized on insect-transmitted infections, especially yellow fever, Leishmania and spirochaetoses, and was the first to produce a vaccine against yellow fever. He is Founder-President of the Institute of Biology (United Kingdom).

This year delegates from all parts of the world will be arriving in London to take part in the celebrations in connexion with the three-hundredth anniversary of The Royal Society, the oldest scientific society or organized scientific academy which had been in continuous existence since its foundation. The society was founded by Charles II, and its Charter of Incorporation passed the Great Seal on 15 July 1662. Meetings had been held for some time previously, however, and in 1660, after hearing a lecture on astronomy by the famous Christopher Wren, a group of those present decided to form a ‘Society for promoting Physico-Mathematical Experimental Learning’. It is this first inception of The Royal Society which is now being celebrated.

The formation of the society is generally considered to be one of the practical results of the experimental method of research so strongly advocated by Francis Bacon against the deductive method then still in vogue, at least in Britain. His New Atlantis, published posthumously in 1626, attracted so much attention that 10 editions were issued in the next 43 years. The Civil War followed by Cromwellian and Puritan tyranny did not, however, favour the development of this conception of a carefully planned and well-endowed college with a company of 36 fellows divided into groups, each charged with a special department of inquiry and research.

Nevertheless, by the middle of the seventeenth century a remarkable group of pioneers had taken up experimental investigation and held meetings in London. Robert Boyle in a letter to his French tutor M. Marcombes, dated 22 October 1646, alludes to his studies in natural philosophy, the mechanics and husbandry according to the principles of ‘our new philosophical college which values no knowledge but as it hath a tendency to use’. He asks his French correspondent to bring to England ‘good receipts or choice books on any of

1. The writer would like to express his indebtedness to an article by E. N. da C. Andrade, issued by The Royal Society, 1960.
these subjects which you can procure, which will make you extremely welcome
to our invisible college’.

The Royal Society was very fortunate in its first generation of life for it
attracted a galaxy of men of genius seldom seen in history and never surpassed
in Britain, each with a strong claim to be the founder of a new department of
science. John Wilkins, the Bishop of Chester, who foreshadowed the telephone
with his ‘secret messenger’ and anticipated Esperanto with his Universal Char­
acter; William Petty, statistician, economist, physician, inventor, musician
and later poet; Christopher Wren, the famous architect, but of extraordinary
versatility in a wide range of subjects; John Ray, one of our greatest naturalists;
Isaac Barrow; Nehemiah Grew; Robert Hooke; John Evelyn; Samuel Pepys,
diarist and President of the Society; and Isaac Newton, the greatest name in
the history of the society, who was elected a fellow in 1671 in recognition of
his presentation of a reflecting telescope made with his own hands. He became
president in 1703 and held office until his death in 1727. The society also in­
cluded members of the aristocracy, for in its early days persons of the degree
of baron were admitted as supernumeraries in addition to the number of 55
ordinary fellows which had been adopted as the total membership. The great
majority of the fellows were graduates of Oxford or Cambridge or fellows of
the College of Physicians; most of them were of independent means and many
had made the ‘Grand Tour’ and established contacts with leaders of scientific
work in other countries. This favoured the international relationships which
became established between The Royal Society and all parts of Europe within
a very short time after its foundation. The first Secretary, Henry Oldenburg,
originally came from Bremen and, after acting as German Consul in London,
became tutor in various families and also studied at Oxford. Oldenburg
aroused the suspicions of the government of the time by his voluminous corres­
pondence with foreigners. In 1667 he was arrested for ‘dangerous designes and
practices’ but in fact, it was probably because he had criticized the manner
in which Charles II was conducting the war. He was conveyed to the Tower
of London, but the authorities were soon convinced of his innocence of ‘car­
rying on political correspondence with parties abroad, obnoxious to Charles II
and the Government’ and after a few weeks he was released.

This correspondence with continental philosophers formed an important
part of the society’s activities and furnished material for the early issues of
The Philosophical Transactions as Giving some Account of Present Undertak­
ings, Studies and Labours of the Ingenious in many Considerable Parts of the
World, which were first published in 1664-65. In 1776 the title was abbreviated
to Philosophical Transactions of the Royal Society of London, and in 1887,
the method still in use of dividing publications into Series A for papers dealing
with mathematics, physics and chemistry, and Series B for those dealing with
biological subjects was introduced.

The Philosophical Transactions were distributed by Oldenburg to all parts of
Europe and as the publication contained scientific articles and observations from writers of many different nationalities, it contributed to the surprisingly rapid spread of information. The society was also empowered by its charter to appoint a printer and engraver, and it either published or sanctioned the publication of separate works on natural knowledge. Before A.D. 1700 it had issued nearly thirty monographs, including such classical work as Robert Hooke’s *Micrographia: or some Physiological Descriptions of Minute Bodies made by Magnifying Glasses*, 1664; Thomas Sprat, *The History of The Royal Society of London, for the Improving of Natural Knowledge*, 1667; Marceli Malpighi, *Dissertatio epistolica de Bombyce; Societati Regiae Londini dicata*, 1669, also *Anatome Plantarum*, 1675 and *Opera Posthuma*, 1697; Francis Willughby, *Ornithologiae libri tres; totum opus recognovit digessit, supplevit Joannes Raius*, 1676, and also *Historia Piscium*, 1686; John Ray, *Historia Plantarum*, 1686-88; and especially Isaac Newton, *Philosophiae Naturalis Principia Mathematica*, dedicated to the society, 1687. This publication of separate works has continued down to the present time, but in later years these ‘occasional publications’ were restricted to catalogues and reports, or important scientific memoirs not suited for the pages of the *Philosophical Transactions* or the *Proceedings of The Royal Society*.

The publication of work by the Italian, Malpighi, at such an early date and the inclusion in the *Philosophical Transactions* of extracts of the Dutchman Leeuwenhoek’s letters to The Royal Society from 1673 onwards, are only two examples of the way in which the development of science was encouraged irrespective of nationality. The almost universal use of Latin among scholars also favoured the spread of new discoveries. Like many young institutions The Royal Society suffered from lack of funds and even the publication of Isaac Newton’s great *Principia Mathematica* was held up until Edmond Halley undertook to defray the cost. The publication of this great work established Newton’s reputation throughout the learned world and The Royal Society gained in prestige during his long presidency from 1703 until his death in 1727. An idea of how highly Newton was regarded in the Western world may be gathered from the remarks of Marquis de l’Hôpital, a distinguished mathematician, who asked whether Newton ate, drank or slept like an ordinary man—‘for I picture him to myself as a celestial genius’; and Queen Anne who said that she thought it a happiness to have lived at the same time as, and to have known, so great a man. This esteem for Newton did not extend to the body of fellows, at least so far as the general public was concerned, for the wits of Queen Anne’s reign continued to satirize the society and its works. Addison, for example, wrote in the *Spectator* in 1711: ‘Among those advantages which the public may reap from this paper, it is not the least that it draws men’s minds off the bitterness of party, and furnishes them with subjects of discourse that may be treated without warmth or passion. This is said to have been the first design of those gentlemen who set on foot The Royal
Society; and had then a very good effect, as it turned many of the great geniuses of that age to the disquisitions of natural knowledge, who, if they had engaged in politics with the same parts and application, might have set their country in a flame. The air-pump, the barometer, the quadrant, and the like inventions were thrown out to those busy spirits, as tubs and barrels are to a whale, that he may let the ship sail on without disturbance, while he diverts himself with those innocent amusements. 'For neither Prince nor People appeared to be curious in any Part of Knowledge, except Mathematicks & Musick, wherein I was far their inferior, and upon that Account very little regarded.'

However these popular misconceptions did not hinder the society's progress and in 1710, the president and nominees of the council were appointed visitors and directors of the Royal Observatory at Greenwich, for the society took an active part in its creation and lent various instruments. The President of The Royal Society is still chairman of the visiting body and continues to take an active interest in the Royal Greenwich Observatory, now at Herstmonceux, and in the Isaac Newton Observatory which is in course of being constructed there. J. Flamsteed was the first 'Astronomical Observator', the title later being changed to Astronomer-Royal.

Sir Hans Sloane whose collections formed the basis of the British Museum was the next president and his life is a good example of the international character of science in the early days of The Royal Society. Sloane was born in Ulster, then came to London and studied chemistry under the German Nicolaus Staphorst, at the Royal College of Physicians. Subsequently he went to France and studied anatomy under Duverney and botany under Tournefort at the Jardin des Plantes and met the chemist Nicolas Lémery. He took a doctor’s degree at Orange and went to Montpellier to continue his studies under Pierre Chirse and Pierre Magnol, following in the footsteps of many of his English contemporaries, including Thomas Sydenham, Robert Boyle, John Ray and John Locke. Hans Sloane became physician to the Duke of Albermarle and sailed with him to the West Indies in 1687, where he started making the collections which formed the basis of the British Museum. The friendly correspondence between Sloane and Tournefort continued even when France and England were at war, and included not only exchange of information but also of scientific objects such as seeds of plants from the Far East. It is not generally realized that until the last century scientists did not cease to communicate with each other even though their respective countries were at war. A recent book, *The Sciences were never at War*, by Sir Gavin de Beer, contains an interesting collection of communications between men like Sir Hans Sloane, Réaumur, Benjamin Franklin, Sir Joseph Banks and others, dating from the foundation of The Royal Society in 1660 to the downfall of Napoleon, which
The Royal Society illustrates the manner in which friendly co-operation was maintained between those whose first aim was the promotion of science irrespective of nationality.

The succeeding presidents in the eighteenth century were not of outstanding distinction until the election, in 1778, of Joseph Banks who held office for 42 years, the longest period on record. As a young man, in 1766, he had accompanied Lieut. Phipps to Newfoundland and Labrador and made extensive natural history collections; and in 1768 he joined Captain Cook in his first voyage in the *Endeavour* which was undertaken through the efforts of The Royal Society to observe the transit of Venus and also to make geographical observations. Banks was a rich man and at his own expense got together equipment and engaged a staff, including Dr. Solander, for the collection of animals and especially plants. He accompanied a scientific expedition to Iceland in 1772, which he had had fitted out, and made extensive collections of natural history specimens and purchased numerous Icelandic books and manuscripts. He acquired great fame as a result of his activities and became a friend of King George III, and thus was able to engage his support in many of the projects undertaken by The Royal Society. He was a very dominant personality and did much to raise the scientific and social standing of the society and improve methods of election. It is recorded of him that on one occasion hearing that the council intended to remove him from office he dismissed the council. He entertained lavishly and maintained relationships with a very wide circle of friends and acquaintances, including not only scholars but also political leaders in other countries, ministers, ambassadors and leading aristocrats. He was largely responsible for the establishment of Kew Gardens and arranged for the collection of plants and seeds from all parts of the world. His portrait, by Thomas Phillips, hangs in the Council Room at Burlington House and still seems to radiate his masterful and vigorous personality.

After his death in 1820 a certain amount of discontent was expressed with the affairs of the society and eventually a revision of the statutes was enacted in 1847. The tenure of office of president was gradually restricted and since the term of Sir Edward Sabine, 1861 to 1871, the most distinguished (polar) magnetician of his day, the period has never been longer than five years. Moreover, with the exception of the Duke of Sussex, president from 1830 to 1838, the holders of this office have all been distinguished in some branch of science and indeed for the last 45 years have all been Nobel Laureates.

During the nineteenth century the composition of the society gradually changed, the members with an amateur interest in science who previously formed the majority being largely replaced by men—and more recently also women—devoted to a scientific career.

The presidents since Sir Joseph Banks include such famous names as Humphry Davy, Sabine, Huxley, Kelvin and Lister, down to the twentieth century with Huggins, Rayleigh, Geikie, Crookes, J. J. Thomson, Sherrington, Rutherford, Hopkins, William Bragg, Dale, Robinson, Adrian, and finally Sir Cyril
Hinshelwood—the present holder of office. It has long been customary for presidents to be elected alternately from among the A and B groups of science.

The Royal Society has constantly been consulted by the Government for advice on scientific problems of national importance and has been responsible for the foundation of many important organizations. Reference has already been made to the Royal Observatory and Kew Gardens, but these are only two examples among a very large number of scientific activities. Their technical advice was engaged in connexion with the change of the calendar in 1752, following the passage of the Calendar (New Style) Act in 1750, and the consequent adoption of the Gregorian reckoning still in use, in place of the old Julian calendar.

In 1765 Mason and Dixon were engaged by the Government to survey and describe some boundary lines in America and the Council of The Royal Society asked them to obtain the precise measure of a degree of latitude. They charged £200 for the survey and Maskelyne, the Astronomer-Royal, drew up instructions and sent various new instruments to them in New York. This is the origin of the famous Mason-Dixon line of which so much has been heard in recent times.

The founding of the Geodetic Survey in 1784, and the General Trigonometrical Survey, begun in 1791, are among the early geographical problems studied. The Society has also been concerned with the scientific arrangements of numerous expeditions, including four to observe the transits of Venus, among them Cook’s first voyage in the Endeavour; the Antarctic Expedition of 1772, also under Captain Cook whose voyage included circling the globe; Ross’s Expedition of 1839; the Antarctic Expedition of 1817, in search of the North-West Passage, of 1819 (Parry), of 1827 (Parry and Ross), of 1845 (Franklin), of 1874 (Nares), in addition to expeditions for the observation of eclipses of the sun. The Royal Society Expedition to the Antarctic in connexion with the International Geophysical Year, and the establishment of a station at Halley-Bay in 1955 still in progress, has attracted wide publicity, but perhaps one of the most famous of all, from a scientific point of view, was the voyage of the Challenger, 1872-76.

In recent years the society has taken an active part in the investigation of various tropical diseases including the tsetse-fly disease (Trypanosoma nagana); malaria; Mediterranean fever; and sleeping sickness (T. gambiense). Their Kala Azar expedition to North China, 1925-27, was financed by a special bequest for tropical diseases received in 1924.

An undertaking which has been of great assistance to scientific workers throughout the world was the preparation of The Royal Society’s Catalogue of Scientific Papers; this was the outcome of a movement started by the British Association for the Advancement of Science in 1855. The catalogue contains the titles of all scientific papers in libraries other than that of The Royal Society and was completed up to the end of the nineteenth century, when
the work was continued by the *International Catalogue of Scientific Literature*. An *Author's Catalogue* was completed in seven volumes, but only three volumes of the *Subject Catalogue* (1800-1900) have been published, dealing respectively with *Pure Mathematics, Mechanics* and *Physics*. This work has involved the indexing of more than 1,500 journals and transactions, and about 800,000 titles for the indexes of the century, as well as about 413,000 titles for the years 1883-1900 of the catalogue of authors.

The society still exercises a variety of important public functions. It provides 11 representatives on the Joint Permanent Eclipse Committee; it controlled the Meteorological Council from 1877 until the reconstitution of the Meteorological Office in 1906 and, since this office became attached to the Air Ministry, the society has had two representatives on the Meteorological Committee. The society also has the custody of standard copies of the imperial standard yard and pound weight. The president and council have the scientific control of the National Physical Laboratory, an institution established in 1899 as a result of their representations.

The society had always favoured the development of international relations and after the first world war arranged for a meeting of the International Association of Academies to be held in the rooms of The Royal Society to discuss future international co-operation. After much discussion this organization was dissolved and replaced by the International Research Council which set up a number of international unions in various countries to deal with the different branches of science. These had become established when the second world war resulted in the breakdown of all such international organizations. After World War II, The Royal Society again took a leading part in attempts to restore international relationships in the scientific world and appointed delegates to visit various countries. As a result the international unions were re-established and there are now 12 of them officially recognized by the Royal Society—astronomy, biochemistry, biology, chemistry, crystallography, geodesy and geophysics, geography, mathematics, physics, physiological sciences, scientific radio, and theoretical and applied mechanics.

British national committees for each of these subjects have been appointed by The Royal Society, and also for geology, in view of proposals to establish an International Union for Geology. In addition national committees on antarctic research, for oceanic research, and on space research have been appointed to correspond with special committees set up by the International Council of Scientific Unions. A Royal Society Unesco Committee under the chairmanship of the Foreign Secretary of the Society and including also members nominated by the Minister for Science and the Ministry of Education, has been set up to co-operate with Unesco in the field of natural sciences on behalf of the United Kingdom, and to make recommendations to the council of the society and to the Ministry of Education.

These various activities might lead to the assumption that The Royal
Society was a government institution, like the academies of science in so many other countries including France, the USSR, Rumania, Czechoslovakia, etc. Such is far from being the case. The society fulfills in Britain the functions of a national academy of sciences and for more than a century has received a gradually increasing government grant, but from its foundation down to the present time it has always remained an entirely independent organization under the patronage of the ruling monarch and it is made up of fellows who pay an annual subscription. Membership of the society is open to all the countries of the British Commonwealth and each fellow must be a British subject or a citizen of Eire.

Entry into the society is governed by an elaborate mechanism which has gradually evolved in the course of years in order to ensure the election of suitable candidates essential to its effective continuation. Every candidate must be proposed by at least six fellows and his or her name is submitted to one of eight sectional committees representing the several branches of natural knowledge. Each committee recommends names to the council and after discussion this body draws up a list of 25 names which are submitted to fellows at an ordinary meeting and elected by ballot. In addition the council may nominate up to four persons a year for election as foreign members. Princes of the blood royal may be elected at any time as royal fellows and also not more than one person a year may be chosen for conspicuous service to the cause of science or because his election would be of 'signal benefit to the Society'. The society has thus become generally acknowledged as the representative body of pure science in the country and it plays an ever-increasing role in all scientific activities.

The funds at the disposal of the society long remained quite inadequate and severely restricted its activities and limited its accommodation. For some time the fellows met at Gresham College, Bishopsgate, in the City of London—a private foundation with seven professorships, still in existence, in astronomy, geometry, physics, law, divinity, rhetoric and music. The quarters were then removed to Arundel House in the Strand, where Henry Howard, Duke of Norfolk, provided rooms and offered part of his grounds for the erection of a college, a plan which unfortunately did not materialize. In 1673 the society returned to Gresham College for some years, but in 1710 it moved to quarters of its own in Crane Court off Fleet Street. From 1780 to 1857 it occupied premises provided by the Crown in Somerset House, after which it moved to Burlington House, although not to the rooms it occupies at present. The absence of any settled premises restricted the society's possessions, and its museum, at one time the most famous in London, was dispersed, the majority of the collections being presented to the British Museum in 1781. A certain number of instruments and models of historical interest were retained, some at Burlington House, but the majority are now either in the Victoria and Albert Museum, or the Science Museum, South Kensington.
The society gradually accumulated limited funds of its own as a result of private benefactions, but had rarely been in a position to finance any scientific work except on a comparatively small scale. However, in 1849 it began to receive an annual grant from the Government of £4,000 for the promotion of scientific research, subsequently increased to £5,000 for some years. During the present century and especially in recent years the parliamentary grants administered by The Royal Society have been greatly increased and, during the fiscal year 1958-59, they amounted to £127,000, allocated as follows: scientific investigations, £6,000; scientific publications, £15,000; libraries assistance, £1,000; international research and scientific congresses, £30,000; grant to Gassiot Committee (research in meteorology and magnetic observations), £7,000; grant for rocket research, £14,000. In addition £106,000 is being received for the International Geophysical Year for the fiscal year 1958-59. Another welcome feature is an increase of private benefactions and the capital value of the research funds is now well above £1,000,000. In addition there have been special grants such as a grant of £2,000 a year for five years from the Wellcome Trustees for the support of scientific publications in the field of medical and allied researches. All these research funds enable the society to make a number of research appointments, including one professorship and 15 fellowships and studentships. Within the last few months the most munificent donation in the history of the society has been received from the Isaac Wolfson Foundation to mark the tercentenary of The Royal Society. This is a donation of £200,000 to provide funds for a research professorship to be known as the Wolfson Research Professorship of The Royal Society, the endowment being calculated to provide an annual income of £10,000 a year.

Perhaps in the twentieth century Francis Bacon's conception of a well-endowed college of research fellows may be realized under the sympathetic direction of a society which for three hundred years has striven nobly to fulfil the objects aptly expressed in its full title—The Royal Society of London, for Improving Natural Knowledge.
We have only to come near to a river which flows through a large city to be struck at once by the greyness of its waters with their pallid sheen of oily film, and by the stale odours they give off. We have only to breathe the air of a crowded street to experience a sensation—at once respiratory and olfactory—which can sometimes almost reach the degree of suffocation. Pollution of water, pollution of air, these remain imprinted on the mind after even this fleeting examination, and are at once contrasted with those symbols of a healthy environment, pure water, pure air.

This leads us to a definition that at first sight would seem to be legitimate: 'pollution is the deterioration to which an environment—whether air or water—is subjected under conditions such that any living being dwelling therein suffers a physiological disturbance'.

This definition can be used, if need be, as a basis for technical investigations designed to determine local causes of pollution, to measure its intensity and lead to suitable proposals for reducing if not eliminating it. For scientific purposes, it is a much less satisfactory definition, being based on a far too static, empirical idea of the purity of the various environments favourable to life.

The history of the earth, as retraced by Urey and other authors, shows that these environments underwent great changes in the past, and that it is useless to imagine that there was ever an original purity which could have been maintained until the time when present forms of life suddenly tainted it.

On the contrary, the atmosphere during the first geological ages saturated as it was with gaseous hydrocarbides, carbon dioxide and ammonia, could be considered according to our present standards as extremely polluted. Only after a certain phase of evolution—that is, after chlorophyll-possessing plants had released pure oxygen—could the air and water environment more or less approximate to our fleeting notion of purity.
Atmospheric and water pollution

We can be quite certain that in the course of time the process of the freeing of oxygen, and that of the utilization of their environment by living organisms, did not come about without difficulty.

PREHISTORY OF POLLUTION

These introductory remarks must not make us lose sight of the geochemical and biological episode we are at present witnessing, in which man, employing all the resources of industrial civilization, is contributing in great measure to a modification of the terrestrial milieux. We are, however, justified in giving this episode its proper place among the natural phenomena which have led and still lead to conditions of pollution.

In their studies of fresh water, hydro-biologists have often described the successive stages of lakes: in their early period, thanks to a constant renewal of their water supply, they are relatively poor in nutritive matter. Flora and fauna develop sparsely, but enjoy an environment all the more favourable because there is an ample supply of oxygen for each organism. Lakes at this stage are called oligotrophic. But these favourable conditions constantly attract new species which multiply, and the dead matter of which accumulates, increasing the food reserves, which are likewise augmented by the contributions of other forms of life in the environment. Gradually the lake becomes eutrophic, a term which defines a situation in which the abundance of food, wealth of living matter and the resulting quantity of waste matter have combined to create chemical and biological conditions differing greatly from those prevailing at the start. At the end of the eutrophization period, the organic matter at the bottom is attacked by anaerobic bacteria which release hydrogen sulphide: a fairly frequent form of natural pollution, but which, as we shall see, becomes considerably intensified owing to the human contribution.

A comparable process occurs in the sea. There, too, life may become so concentrated within limited areas that accumulations of dead matter are mineralized and create gigantic submarine reserves of phosphates and nitrates. Under certain meteorological conditions, these food elements rise to the surface and completely modify the habitat of fish. There then occurs a rapid breeding of microscopic algae of the dinoflagellata group which secrete toxic substances; this is the origin of the phenomenon called the 'red tide' (dinoflagellata have chromatophores that change from yellow to red) which causes a mass destruction of marine fauna. Such paroxysms of natural pollution have been observed in the Gulf of Florida and at several points along the west coast of Africa.

If to these two examples one adds that the intense fermentation of dead vegetable matter in humid equatorial forests and its effect on the atmosphere it seems legitimate to link pollution with a changeless biological law: any excessive concentration of life tends to denature the environment where it
Atmospheric and water pollution
develops. As a consequence the species responsible for this pollution eliminate other species which can no longer survive. Even the 'polluters' may prove unable to adapt themselves to the conditions they have created and thus suffer a decline.

It cannot be denied that man from the very time of his appearance on earth has upset the evolution of the natural environments at many points of the globe. Wherever man has brought other species (whether vegetable or animal), under his control he has influenced these evolutionary processes in ways which might not have been expected.

The earliest forms of his intervention have been overshadowed by the more massive action of the later industrial phase, but they should not be ignored.

From neolithic times, man has been clearing land for the growing of food crops. In doing so, he has thinned out the plant covering of shrub and forest which, before it was cleared away, ensured a maximum chlorophyll exchange with the atmosphere, i.e. absorption of carbon dioxide by plants which, in turn, release oxygen. Surfaces cleared for agriculture bear only annual plants or scattered fruit trees which can by no means keep up the same degree of exchange. Soil bacteria also tend to free carbonic acid gas. Man's activity has thus increased the carbon dioxide content of the atmosphere, with important consequences for fresh and salt water milieux. According to Arrhenius, a chemical balance is automatically established between the atmosphere and the oceans, lakes and rivers.

In the course of this human intervention which has become steadily more widespread a large part of the forest cover has either been burnt off to clear land quickly or used as fuel for various purposes: there again the carbonic acid stocked by plants has been put once more into circulation in the air and water.

Taking the fullest advantage of his increased food resources, man experienced the expansion which is reserved for the dominant species, and this led him inevitably to form the population groups which prefigured the modern city. There is no need to describe these groups, which still exist in the least developed countries where pollution of the ancient or medieval type can easily be studied. It is sufficient to call to mind not only the crowds of human beings with their domestic animals, and in addition the other dependants and parasites (rats, stray dogs, carrion-eating birds), but also the accumulation of every kind of refuse, the dust raised by the wind on the beaten-earth tracks, and the trampling and wanderings of all these multitudes. There can be no doubt that the pollution of the air and water was entirely the result of the excessive concentration of life. This pollution was of a type to which we are tempted today to give only secondary consideration; the association of solid particles in suspension in the air with the bacteria for which these particles serve as a support, the uncontrolled dumping of refuse into rivers and the contamination of the ground-waters.
The epidemics which are so frequent in the Orient and sporadic in the West give irrefutable evidence of this kind of pollution.

**THE INDUSTRIAL AGE**

The new forms of civilization which emerged after the mechanization of transport and industry have quite rightly been accused of developing, spreading and diversifying pollution. One should be fair. Attempts were made and are still being made to remedy some of the causes of the deterioration of the environment. In any case, measures have been taken against the bacterial pollution of the air and water by means of methods and processes which the earlier periods were not in a position to apply.

As against this we must go back to Arrhenius' theory in order to describe additional profound changes to which the intensive use of energy has subjected the whole atmosphere of our planet. The crucial fact—and for a long time its consequences passed unperceived—is that the reserves of fossil fuels (solid, liquid and gaseous) are being rapidly dissipated by heat appliances of every kind. Such massive combustion results in a carbon dioxide production recently estimated at 6,000 million tons per annum, a much higher figure than that for the burning of the forests and the clearing of the soil.

Oddly enough, industrial civilization tends to restore to the atmosphere and oceans a mass of carbon compounds which had been accumulated, during the primary era, by luxuriant vegetation on the continents and rich marine plankton. There appears to be no doubt about one effect of this, namely the progressive reheating of the surface of the globe; an atmosphere with a heavier carbon dioxide content is better able to absorb the infra-red rays of the sun.

But such a phenomenon cannot be called pollution for the dose of carbon dioxide remains comparatively low, despite everything, and its presence is in no way harmful to life. It is none the less true that this corollary of human activity is necessarily accompanied by a profound change in the natural environment; indeed, we may reasonably expect a biological adaptation resulting in a new balance between animal and plant species.

In addition to these geochemical effects of the spread of industrial civilization, which are little known despite their importance, there is the much more evident phenomenon of population growth.

Wherever this civilization is in full swing, the population is attracted to urban centres, and censuses show that 50 per cent of the population, as against 2 per cent a century and a half ago, are concentrated in cities of over 100,000 inhabitants. It is obvious that this population growth and concentration have been made possible by a substantial increase in food resources; and on the whole, the human race, powerfully aided by its machines, is reproducing for
Atmospheric and water pollution

its own benefit the phenomenon of eutrophization from which the humble
inhabitants of the lakes first profited and then suffered.

Henceforth one can 'forget' this linking of the human groups to the general
laws of biology, and consider separately the environment in which they are
condemned to live. It is therefore the picture of industrial, or rather, of pre­
dominantly industrial, pollution that we shall examine.

Must we consider this rather gloomy picture as definitive? Certainly not,
for there are factors working in opposite directions to bring about rapid
changes. On the one hand, the process of urban concentration is accelerating
and becoming more widespread, whereas the limit of food resources (what­
ever may be said) is far from being reached. On the other hand, the evils of
pollution are now known and are producing good defence reactions. It is
not impossible that a marvellously equipped industrial civilization may even
be able to alleviate somewhat the dangers of pollution while, at the same time,
the human body may adapt itself to a theoretically unfavourable environment.

There still remain to be examined the two milieux which have been subjected
to pollution, the atmosphere and water, at the same time noting their frequent
interaction.

ATMOSPHERIC POLLUTION

Everyone who has been stirred by the problem of pollution without being able
to analyse it closely has dreamt of imposing very simple, categorical solutions.
Royal edicts under the French monarchy forbidding coal and peat fires are
often cited. Later, local authorities frequently issued regulations almost as
drastic which, naturally, could not be enforced. Industrial civilization would
not be denied. The best it could do was to try to find non-restrictive remedies,
but that became possible only after the phenomena of pollution had been
investigated methodically.

Thus was born the science of pollution, a 'cross-roads science' where met
such diverse disciplines as medicine, hygiene, bacteriology, haematology,
optics, chemistry, meteorology, aerodynamics, not to mention statistics and
the many other branches which have been omitted from this long list.

But it is still a young science and in many cases its application has been
delayed by the scruples of the research workers who readily admit their uncer­
tainty.

For this reason any ideas one may gather on this complex subject must
necessarily remain theoretical. Then, too, among the supporters of 'anti­
pollution' there are always a number of prominent persons advocating or
offering some particular material for the elimination of certain forms of pol­
lution. In spite of the somewhat commercial character of their efforts and
campaigns, it cannot be denied that in the long run they do useful work,
although it is obvious that their action is frequently conflicting, and is liable to cause confusion in a domain which, on the contrary, requires rapid clarification.

Indeed, complexity and confusion face us in any attempt to tackle the subject by dividing it into chapters. Since there is no other way of proceeding, we shall merely point out that such divisions as we have made should not be taken as implying the existence of watertight compartments.

**Solid pollution**

The most evident phenomenon of atmospheric pollution is the presence of dust. Dust, it must be noted, is by no means an exclusive product of industrial cities and centres; deserts and plains subject to erosion experience formidable dust storms. But cities enjoy, if one may so put it, the privilege of emitting a special kind of dust (some of which is harmful in itself) and mixing it with the biological elements of pollution.

The presence of dust in our civilization can best be revealed by the following figures for dust content, in milligrammes per cubic metre of air: urban centres, 3 to 7; shops, 5 to 8; cinemas and theatres, 16; steel mills, 16 and over; foundries, 25 to 52; cement works, 105 and over.

Figures of this magnitude show the problem faced by factories such as cement works where dust extraction is not only a sanitary need but the means of recuperating a considerable amount of the product manufactured. A less extreme case is that of modern thermal works equipped with powerful dust extraction apparatus; yet, burning less than 2,000 tons of coal a day, they give off solid particles which amount to 50 tons daily and fall within a radius of three miles.

Progress has been made, however, since the days when industrial centres used to scatter phenomenal quantities of smoke and ashes. Careful measurements in several manufacturing cities showed the quantities of dust that were deposited annually on 1,000 square metres, for instance: 539 tons at Leeds, 820 at Glasgow, 1,031 at Pittsburgh.

Wherever the atmosphere is saturated with dust, attempts have been made to determine its chemical composition. Naturally there are variations from one city to another but, on the whole, solid pollution consists of about equal shares of inorganic substances such as potassium, sodium, calcium, iron and aluminium salts, and organic particles (carbon and hydrocarbons).

The physical characteristics of the particles have also been examined. Most of them are about a micron in diameter. This unfortunately enables them to invade the lungs, since the nasal mucous membranes usually stop only particles measuring at least five microns. The study of their behaviour when in suspension in the air has shown that they are in continuous, confused motion; this is known as the 'Brownian movement'. Microscopic examination shows
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also that in their mass they are honeycombed with air-filled cavities which help to keep them in suspension.

Diseases such as silicosis and other pneumoconioses are produced by the inhalation of dust, especially siliceous dust. The exact nature of this attack is still not well understood, but there is every reason to believe that some hydrocarbon particles in soot play a part—jointly with liquid and gaseous substances—in the aetiology of cancer.

In considering the direct harmfulness of dusts, stress must be placed on their contribution to the spreading of bacteria. Bacteria cannot sustain themselves physically in air which, in a state of total purity, would be completely sterile.

The particles of dust give them the necessary support, enabling them to invade the atmosphere and move constantly from place to place. Biological pollution due to the association of bacteria and dust would, however, remain limited if solid particles circulated in a dry medium.

The association is really tripartite, for dust, especially in cold weather, is capable of condensing the humidity of the air into tiny drops of liquid which usually contain nutritive matter in solution such as phosphorous, sulphur and carbon. Physically speaking, we have mist, more or less light or dense, which has recently been given the name of aerosol. Biologically speaking, each drop of liquid, whether or not it is associated with a solid particle, constitutes a kind of culture medium, a food medium where bacteria have every chance of prospering.

This characteristic of urban pollution has many consequences: while it is recognized that most bacteria are saprophytes, i.e. parasites living on organisms without harming them, the presence among them of several types of pathogenic germs such as staphylococci, streptococci, diphtheria and tuberculosis bacilli and cholera vibrios must not be overlooked. To these agents of infection we must probably add several viruses, including the influenza virus.

Bacteria carried by polluted air also cause meat to spoil and contaminate milk: the difficulty of conserving food in cities has long been observed.

This alone is justification for putting the aerial transmission of several bacterial or virus diseases and the maintenance of certain infectious or subinfectious states down to atmospheric pollution. To this, however, must be added the allergenic properties of many substances which are disseminated among dust particles: the 'classic' allergens responsible for asthma, hayfever and a whole range of dermatoses, that is, the spores of Mucor, Penicillium, Aspergillus, and other moulds, down, hair, feathers and animal danders are the result of the concentration of population rather than the proximity of industry. But the fact has been recognized that many diseases caused by allergies are the result of the aerial dissemination of chemicals (disinfectants and detergents) and medicinal products. (It is true, of course, that this cannot be laid to the door of solid pollution.)
Doctors and public health specialists have often laid stress on one of the most disastrous effects of air pollution: dust in suspension, together with droplets of water, forms a screen which greatly reduces luminosity and, in particular, stops ultra-violet radiations. These radiations help the various tissues, especially bone tissue, to fix calcium. Insufficient sun, which is the lot of city dwellers, is above all harmful to children: there is probably no other cause for the many cases of rickets observed among growing children in cities.

It is in winter that the darkness in the towns is most severe; this can be explained by the condensation of the humidity and by the oblique angle of the sun's rays which compels them to penetrate a greater thickness of polluted atmosphere. In January, luminosity is about one-third less than in the surrounding countryside. That can only be taken as an average: great daily variations are to be observed in the degrees of darkness. Throughout the year, this darkening reaches its maximum intensity twice a day: between seven and nine in the morning, the city area, being more quickly heated than its surroundings, creates a slight barometric depression which makes the dust screen contract and thicken; towards five or six in the evening, activity in the factories and the dense traffic again causes this screen to thicken.

The screen of solid pollution generally takes the form of a flattened cupola, the radius of which in Paris is about twelve and a half miles. Its height varies between 1,600 and 3,000 feet in winter and can reach 6,500 feet in summer.

Chemical pollution

It is curious to note how the scientific approach to a problem such as atmospheric pollution can be subject to passing vogues and fashions. Research workers at the beginning of this century were more exercised concerning the association between dust and bacteria. Today, on the contrary, they dwell on the chemical aspects of pollution.

This tendency, occasionally perhaps too exclusive, can of course be justified to a certain extent. Life in urban environments has been undergoing extensive changes: industries have spread and have become more diversified, the heating of an ever-increasing number of dwellings contributes increasingly to pollution, and automobile traffic becomes heavier every day, while animal traction has almost disappeared. There can be no question that this last factor has greatly reduced the bacteria population of cities.

It may be added that some chemical pollutants—carbon or sulphur compounds—are bactericidal, but it would be over-bold to claim that this gain had an appreciable relative value. All that we can say—once more—is that it is the destiny of civilization, being in a perpetual state of evolution, to correct some of its vices by creating new ones.

Turning to the chemical aspect of pollution, the phenomenon may be divided into two main branches: specific pollution and generalized pollution.
Specific pollutions are essentially the emanations of the chemical industry, considered in the widest sense, that is, all undertakings where chemical products are manufactured or used. Their number is unlimited for, obviously, not only the workers in these establishments but persons living in the neighbourhood are compelled to breathe air charged with substances that are more or less evil-smelling and irritant, and frequently toxic.

It must be emphasized, however, that the zone of dispersion of these substances is generally limited, and that beyond this area the dilution is sufficient to obviate any danger of noxiousness. Factories which are operated carelessly and fail to exercise strict control over the emanations they produce are soon faced with complaints and obliged to adopt the necessary measures to keep pollution down.

Episodic conflicts of this kind tend to restrict the volume of specific pollutions which are all the easier to contend with since they are localized and clearly distinguishable. Nevertheless, it is difficult for some industries to avoid spreading toxic gases to a considerable distance: this is particularly true of the electrolytic methods of producing aluminium in which cryolite (sodium-aluminium fluoride) is used as flux. During the electrolysis operation, the cryolite is partially vaporized and escapes with aluminium fluoride and hydrofluoric acid in the factory smoke. Pollution by fluorine compounds is particularly harmful; and in view of the usual location of electro-metallurgical mills its effects are felt above all in the rural areas.

The number of similar cases is too great for enumeration here and it is, perhaps, more appropriate to stress the sporadic character of specific pollution, and to deal at greater length with the kinds of pollution resulting from the general phenomenon of combustion.

If combustion were always complete, the chemical reaction between the solid, liquid or gaseous fuel and the oxygen of the air would produce only anhydrous carbonic acid ($\text{CO}_2$). As we have seen, the massive emission of this gas brings about a radical transformation of the atmosphere, with consequent effect upon the oceans. Yet it is not considered that a relative increase in the quantity of $\text{CO}_2$ in both these media has the character of a specific pollution. Specific pollution is brought about by two main causes: the impurity content of the fuels and incomplete combustion, which produces all kinds of combustion wastes.

Sulphur is the impurity most frequently found in fossil fuels. It is encountered in nearly every kind of coal, and it is generally admitted that it may be used for heating purposes without too much danger provided that the sulphur content does not exceed 1 per cent. Yet consider the effects of even this slight dose if the furnace is that of a large thermal station on the edge of a city. Take, for example, a plant in the Paris area which burns about 50,000 tons of coal a month: a minimum of 500 tons of sulphur are burnt at the same time, and this combustion ends with the dispersal of 1,000 tons of sulphurous
anhydride in the atmosphere. A photo-chemical action may take place in this gas, each molecule of which will absorb an atom of oxygen: it will then become transformed into sulphuric anhydride which when subjected to the humidity in the atmosphere, becomes converted in its turn into sulphuric acid. Finally there is a risk that this series of reactions may result in a daily production of some 50 tons of sulphuric acid. But we have mentioned only one plant; and thousands of other thermic apparatuses are also spreading sulphur pollution. It has even been found that this form of pollution reaches its maximum in the western quarters of the city, where central heating boilers burn fuel oil mainly from the Middle East, which has a sulphur content of from 3 to 4 per cent.

On the national scale, it is estimated in Great Britain that the annual emission of sulphur converted into sulphuric acid is 9 million tons. The world figure is thought to amount to 130 million tons. Sulphur pollution has noticeable effects on the surfaces of limestone buildings and monuments. The blackening of facades is a well-known phenomenon in most large cities; it can easily be seen that in smaller places not subject to atmospheric pollution, the same building materials remain light in colour.

This chemical action has long been studied in western Europe, and it has been observed that walls usually sheltered from the rain—i.e. those facing north or east—become covered with a layer of gypsum (calcium sulphate) which soon becomes irregular, forming slabs that collect soot and dust. On the southern and western sides the streams of rain dissolve the gypsum, thus only the sheltered sides of the walls are blackened.

The same inequalities appear on limestone or even marble (metamorphic limestone) statues, which never keep an evenly distributed patina for long.

Plants are likewise sensitive to sulphur pollution, which does not, however, seem to be the principal cause of their decay in urban areas.

Where human beings are concerned, the very many medical studies published since 1954 would appear to attribute a highly responsible role to all types of sulphur pollution in starting a number of affections. Nevertheless, the authors of these studies have had to take into account the fact that pollution is usually complex: it is possible, therefore, that the effects of sulphur may be combined with those of other pollutants in what is usually called a synergy.

Whether or not it acts alone, highly concentrated sulphur pollution produces the following symptoms: irritation of the eyes and the respiratory system followed by coughing, nausea, vomiting, headache and breathing difficulties. Among predisposed subjects, fairly numerous cases of circulatory failure, cardiac decompensation and oedema of the lungs have been observed.

Attempts to define the chronic effects of pollution meet with still greater difficulties; and it has not yet been possible to establish a perfectly clear relationship between habitation in polluted areas (where sulphur is prevalent) and the frequency or gravity of respiratory, cardio-vascular and eye diseases.
Atmospheric and water pollution

More specific conclusions have been reached about the presence in the atmosphere of substances resulting from incomplete combustion. Heat engineers are constantly at work on this problem, a full utilization of fuel being desirable in order both to avoid waste and to safeguard public health.

The matter involves more than the layman might imagine. Under ideal conditions it could be assumed that during combustion carbon and hydrocarbon molecules would simply react with atmospheric oxygen molecules to form anhydride carbonic acid and water (the hydrogen of the hydrocarbides combining with oxygen).

In reality, every flame in a fire is the scene of a great number of successive or simultaneous reactions, during which the constituents of the fuel are changed into a series of other compounds. Even if ideal combustion, as we have defined it, is finally obtained, this phenomenon will have been preceded by pyroge- nation, cracking, and other physical transformations of the fuel. These processes vary in character according to the area where they occur: at the surface of the flame, contact between the gasified fuel and the air is as complete as possible; it is much poorer in the heart of the flame. Thus, taking into account the great variety of fuels employed (coal more or less rich in hydrocarbides, coal mixed with peat, fuel and gas oil, types of petrol, gas), and the wide range of heat appliances—from large boilers in electric power plants to the more modest engines of motor vehicles—there is an almost infinite variety of chemical compounds, some of which escape combustion while others are produced during combustion.

The commonest and the best known among them is carbon monoxide, the molecule of which contains a single carbon atom. There are also the unburnt hydrocarbides such as methane and benzene, heavy aromatic gases, nitric oxide and nitrogen peroxide, aldehydes, and ethyl compounds.

Soot (complex unburnt residue) must be added to this list, which is far from including all chemical pollutants released by combustion.

Emphasis must, in any case, be laid on the admitted harmfulness of most of them. The effects of carbon monoxide due to its particular affinity for the haemoglobin of the blood have often been described. The union between these two substances produces carboxyhaemoglobin, the presence of which in the blood deprives the red corpuscles of their power to convey oxygen through the body tissue. Carbon monoxide is therefore an asphyxial agent resulting in death for any person who stays more than half an hour in an atmosphere containing one-fifth of 1 per cent of this gas.

Such concentration is never reached in the open air. Nevertheless, most forms of combustion, especially in internal combustion engines, produce a constant flow of carbon monoxide. According to recent estimates, motor traffic in the Paris area discharges tens of millions of cubic metres of carbon monoxide into the atmosphere every day. The gas is lighter than air and normally rises; frequent samplings have shown a carbon monoxide content of...
from 9 to 31 parts per million. Unfortunately, the average proportion has been increasing year by year: 10 parts per million in 1956, 12 in 1957, 16 in 1958. Another interesting analysis made by the Laboratoire d’Hygiène de la Ville de Paris is that of carbon monoxide in the blood of motorists who drive in crowded streets; 50 per cent of them have a dose in their red corpuscles higher than that which corresponds to the threshold of intoxication. In other words, the denaturing of the haemoglobin is irreversible: these drivers, who are typical of the urban population, are suffering from chronic oxycarbonism.

The influence which carbonic acid gas, though inoffensive in itself, exercises over carbon monoxide intoxication should be mentioned. According to Deckert, the presence of CO₂ accelerates respiratory movements and thus, in a polluted atmosphere, increases the volume of carbon monoxide absorbed.

Blood tests of urban populations would no doubt prove that many city dwellers suffer from latent oxycarbonism. A number of habitual ailments which wear out the organism prematurely might be explained in this way.

Keeping in mind the notion of synergy, according to which a disease is not necessarily brought on by any one pollutant, one is nevertheless justified, in agreement with many authors in noting the presence of benzopyrene in the atmosphere of cities. This substance, one of the by-products of combustion, is specifically cancergenic. It was isolated several years ago in a filtrate of polluted air by Dr. Kotin of the United States of America and has been used in experiments on mice; of a number of mice subjected to an application of benzopyrene 50 per cent contracted skin cancer. This is not an absolute proof of its cancergenic effect on human beings, mice being exceptionally vulnerable to cancer. Nevertheless such an assumption is supported by statistics: between 1950 and 1957, the annual proportion of deaths from lung cancer among French males rose from 13 to 24.5 per 100,000 inhabitants. This increase is part of the general progression of all forms of cancer, which is even more marked in countries like the United Kingdom. It remains to be seen whether pollution is the dominant cause of cancerization of the lungs, which has often been attributed to the use of tobacco: in recent years, cancerologists in the United States have tended to consider pollution as by far the most important factor.

In the pathology of pollution which has not yet been well explored an important place should be reserved for its attacks on vegetable life. It is not sufficient to mention the general harm done to plants; attention must be given to certain particular effects on their organs which are easily detected and from which it may be inferred that similar injuries are done to human beings.

This research, conducted by Haagen-Smit in California and by Chouard in Paris, has gone far beyond the early observation that pollution is responsible for depositing a coating of grease and dust on leaves that occludes the stigmata and thus prevents the plant from breathing. We may fairly suppose that something similar happens in the alveoli of the lungs. The attack against plants, however,
Atmospheric and water pollution

is not limited to this physical phenomenon. Among the volatile substances disturbing their life are the ethylenic compounds responsible for a kind of 'vegetal fever' and the premature fall of leaves and buds. In California the study is being carried out on a series of complex phenomena, which involve ozone, nitric oxides, hydrocarbides and certain free radicals and which lead to the formation of olefins and organic acids likely to have toxic effects on plants even at concentrations of less than one in a hundred million.

**Meteorological factors**

Several local paroxysms of atmospheric pollution have revealed the influence of weather conditions on the phenomenon. The most terrible examples have been those of the Belgian cities of the Meuse valley in 1930, the industrial centre of Donora in Pennsylvania in 1948 and the London area in 1952.

The fact that hundreds of thousands or even millions of people have suffered from intoxication to a more or less serious degree and that there have been numerous deaths (more than 4,000 in London) has struck the imagination of city-dwellers most vividly. Many feel threatened by a recurrence of the meteorological situation to which has been given the portmanteau word *smog* (combined from 'smoke' and 'fog').

Their fears are maintained by the fact that Los Angeles in California is almost permanently subject to smog, though the invasion has not meant anything exceptionally serious until now. The idea of a 'smog' is also somewhat erroneous. There is no specific type of situation but several different situations which are capable of 'imprisoning' and concentrating pollution.

Meteorologists have not yet been able to obtain complete detailed analyses of temperature, pressure and hygrometric conditions which, together with topography, determine the greater or lesser degree of intensity of the pollution. For meteorologists, the atmosphere is a fluid mass in a perpetual state of thermodynamic turbulence. This turbulence consists of movements which may be either strictly localized or spread over a whole region. Observation of this uninterrupted succession of transitional phenomena is difficult, and it has not yet been possible to determine constant factors with precision.

It is possible, nevertheless, to describe in somewhat simplified terms a situation which is favourable to a concentration of toxic fog. This has been called temperature inversion. Although city air is normally warmer at ground level than in the upper atmospheric strata, the situation is sometimes reversed: for example on 16 December 1951, the temperature at the top of the Eiffel Tower, in Paris, was 14°C. (57.2°F.), while in the gardens of the Champ-de-Mars directly under the tower, it was 0°C. (32°F.).

In such a case, it is easy to see that polluted air will not be carried away in the usual manner by rising currents. On the contrary, it is maintained at or
brought down to ground level. This local inversion is part of a general meteorological situation due to an anticyclone and characterized by an almost complete absence of wind.

This gives some idea of the impasse which our civilization has reached as a result of having concentrated so many human beings and industries within such small areas. There is, however, even a further possibility where the 'pollution cloud', instead of being maintained captive is forced to migrate towards the rural zones. This situation has already been observed on several occasions; one may even wonder whether the result of the plans for urban decentralization will not be to extend the pollution phenomenon and make it uniform over wide tracts of territory.

**Distribution of the causes**

It is important to know the part played by the various sources of pollution in the life of a city. Such a study has been made for the Paris area by Grisollet and Pelletier. The conclusions, which the authors themselves consider to be provisional, are unexpected: domestic heating is responsible for more than 50 per cent of winter pollution; over the whole year, motor traffic, responsible for 49 per cent, heads the list. Industrial plants come only third.

This result is less paradoxical than it would seem at first glance. The French capital is mainly an administrative, commercial and residential centre and cannot be compared with cities where industry is more clearly predominant. The heating installations of buildings often leave much to be desired. The heavy motor traffic imposes on motors a disordered cycle of running which increases the emission of carbon monoxide and combustion wastes.

None the less, Paris is a very significant example. Although factories—at least those with experienced technicians—know how to choose their fuel and regulate their heating apparatus, and are often required to adopt effective dust extraction systems, yet their surroundings together with their urban prolongations are far from having attained the same stage of perfection.

There are means of reducing pollution: collective heating, use of smokeless fuels (coke or gas), devices to make internal combustion engines more efficient, new layout of cities in order to regulate and accelerate the flow of traffic. All this however, calls for heavy investments which must in any case be spread over a considerable period.

The conclusion is disheartening as far as atmospheric pollution is concerned: the technical difficulties can be or soon will be solved, but for the moment, there is no solution for the financial problem. Clean air is much too expensive; we cannot afford it now!

The same thing is true, unfortunately, of pure water, aggravated by the fact that water pollution spreads inexorably from place to place.
WATER POLLUTION

Only quite recently have highly industrialized nations become aware of an unexpected threat, the shortage of water. Until then this difficulty had been encountered only in arid zones, and it was not easy to understand how countries with a normal, regular rainfall could ever suffer from thirst.

Water from the clouds does, in fact, give the illusion of being unlimited. But a close examination of the water cycle shows that man uses or controls a relatively small portion. According to Keller and Clodius, about half the precipitation received by Western Germany (annual average: 771 millimetres, or approximately 31 inches) is given directly back to the atmosphere through evaporation from the ground and plant evapotranspiration. The other half (384 millimetres, or approximately 14 inches) flows to the sea—either on the surface or underground—under conditions such that, in the present state of technology, man can capture less than one-tenth of it.

We might almost be glad if that tenth left the rest intact. Unfortunately such a general view is Utopian: as the distance from the source increases, steadily heavier doses of polluted water are mingled with the pure water. There are even areas where almost all the water reaching the sea has been used and contaminated several times.

Now in contrast to the case of atmospheric pollution, industry itself, and not its urban surroundings, is directly to blame for the excessive proportions of water consumed and usually polluted.

Statistics published in the United States of America in 1959 show the gradual increase in needs over the past decades, and strictly calculated forecasts indicate the figures which may be reached within the next 15 years. The volumes of water are given in thousands of millions of cubic metres per annum:

<table>
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<th>Year</th>
<th>Irrigation</th>
<th>Public works</th>
<th>Household needs</th>
<th>Industrial needs</th>
<th>Steam production (energy)</th>
<th>Total</th>
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<td>4.5</td>
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<td>9</td>
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<td>10.8</td>
<td>173.1</td>
<td>196.5</td>
<td>685.6</td>
</tr>
</tbody>
</table>

In this table, we should not confine our attention to industrial needs properly so-called, which, in 1975 will be 11.5 times what they were in 1900. We should also remember that irrigated farming is very largely integrated with the industrial sector, which supplies fertilizers (considered today by hydro-biologists as pollutants by eutrophization), insecticides, anticryptogamic products, weed-killers, hormones and antibiotics. All these industrial products do much to contaminate the water medium.
As regards thermal energy, the water needs of which have been multiplied 26 times, there is no need to stress that industry is the principal user. It might be claimed that water consumed by electric power plants is mainly used for cooling and is therefore not contaminated. This assumption is easily refuted: water restored to the river after going through condensers has been deprived of most of its oxygen. As there is usually a large flow the result is to rapidly eliminate certain species such as the salmonides, which require an oxygen content of more than 7 milligrammes per litre. Deoxygenization also favours the development of anaerobic bacteria which are very harmful to the environment.

There is another disquieting source of disturbance for which industry is also responsible: the large-scale household use of synthetic detergents.

Thus, viewed from the most diverse angles, industry appears to exercise a veritable supremacy in water pollution, which should now be examined in greater detail.

**Specific pollution**

The same distinction must be made in hydrous pollution as in the case of atmospheric pollution. On the one hand are the specialized factories for different specific purposes, using processes which involve a series of chemical or biochemical reactions, and on the other, the industrial and urban centres which are responsible for general pollution.

In this medium, specific pollution has not the same characteristics: specific pollution in the air affects only the immediate environment but when it contaminates rivers and underground water, it spreads far and wide and may even threaten to become permanent.

There are innumerable cases: industries of every kind use 'strong acids' like sulphuric, hydrochloric or nitric acid; some use violent poisons like cyanide of potassium; coking installations and synthetic resin factories release phenolated water. In this last case, a characteristic phenomenon of the industrial age occurs. Localities taking water farther down the river often use a germicide with a chlorine-base in order to obviate the risk of contamination; harmful substances, chlorophenols, are then formed which also give water a very disagreeable taste.

A classic example is that of mills treating wood and other cellulose substances for the manufacture of paper or artificial textiles. They use great quantities of alkali or acid cleansing agents containing soda, sulphates, sulphides or sodium bisulphite. These products are extremely toxic for fish; the outflow carries them away, mingled with lignin in a kind of black liquor. Ironically enough, the cellulose industries require a supply of particularly pure water.

The greatest pollution difficulties are those presented by sugar mills, distilleries and dairy works which discharge waters full of several kinds of sugar.
Atmospheric and water pollution

(lactose, glucose, saccharose). These sugars ferment and produce acids such as acetic, lactic and butyric acid, and the pollution is frequently prolonged by the formation of hydrogen sulphide. The river then becomes a special medium which fosters the growth of Leptomitus lacteus, a fibrous alga which often collects at the surface and gives off repulsive odours.

The means of fighting this form of pollution long remained a most perplexing problem. The factories discharge a very large quantity of waste, the treatment of which is difficult. If the outflow were directed to vast settlement basins where the fermentation process could complete itself that would mean setting aside an area where the atmosphere would be permanently polluted, with the further danger of infiltration which in the end would contaminate the underground water.

A recently adopted process is to pump the wastes and spread them like rain over several acres of forest or tilled soil. This merely enriches the microbe population of the soil—without, it would appear, entailing any great disadvantage.

But that is only one example among many. Each specific form of pollution has to be treated by a special process which is rarely simple and frequently demands a large increase in the factory's operating costs. Here, too, pollution becomes an economic problem.

General pollution

The difficulty crops up again when evacuating wastes from urban areas. Let us not forget that the excessive expansion of cities is due to industrial civilization which, moreover, is almost everywhere very hard pressed to keep things in order.

Economic studies have shown that the water supply and disposal budget is relatively very small for average cities, i.e. those of about 50,000 inhabitants. As the population increases towards that of a giant city of several million inhabitants, the proportionate cost becomes steadily heavier. The supply of relatively pure water and the disposal of 'used water' certainly represents a large share of municipal expenditure. Apart from the building and maintenance of sewage systems, we need merely consider what happens to the wastes discharged by the main collector, whose flow is often that of an average-sized river.

The complexity and diversity of the wastes carried by this river need not be stressed. However, most of it is organic matter; and if it were restored, without being treated, to the waterway bathing the city, it would inevitably start a much quicker and more intense process of eutrophization than that which develops under natural conditions.

It is depressing to observe that although methods of treating wastes exist,
few cities in the world are financially or technically able to apply them as fully as they should be applied.

The classic method is that of the sewage farm, but the very large amount of space it requires constitutes a difficulty. The sewage water is emptied over fields which it helps to fertilize, if the ground has the right degree of permeability and if the bacteria of the humus have time to oxidize wastes and transform them into mineral substances. But it has been calculated that this type of automatic purification is successful only if the volume of waste water does not exceed 40,000 cubic metres per hectare per year. We may again take the example of the Paris area where the daily flow of waste is already more than 850,000 cubic metres. Would it be possible to turn 75 square kilometres into a sewage farm in an overcrowded suburb where, moreover, the water-retention rate of the soil is often greater or less than the optimum?

Highly elaborate techniques have been devised to obtain equivalent or even better purification with a smaller surface; removal of solids from sewage water by screening sand filtering, or by sedimentation and decantation; fermentation of sludge in metal vats expressively named digesters, from which methane gas (an energy source) is recuperated; oxygenation of the water by activated sludge treatment or trickling filters, through bacterial action.

All these operations call for very expensive industrial equipment functioning with a great array of motors and pumps, supervised by teams of specialists. At Chicago, the investments amounted to approximately $80 million, and the annual cost of operating the installation, which employs 1,100 workers, is approximately $3.2 million.

Processes frequently become complicated. Oily water requires special treatment and during the past few years a serious obstacle has come to light; the wide use of synthetic detergents has increased the surface tension of the water to such a point that oxidation processes are hampered and purification is infinitesimal.

Great discretion has been exercised in informing the public of this disturbing fact, while chemists are struggling to modify the formulae of detergents, and formidable mountains of soapy bubbles are accumulating down river from each great city.

The search for remedies

The pathological effects of water pollution have been less accurately defined than those of atmospheric pollution. We know, however, that water is often a vehicle for infectious germs and that chemical pollutants also play a part in the aetioloxy of certain diseases. Nor must we exclude the possibility of even more serious disorders which we cannot at present foresee. Ideally speaking, is it possible to suggest an organization which would canalize all contaminated
Atmospheric and water pollution

... water as it leaves factories and cities for appropriate treatment wherever possible? From the strictly technical point of view, this happy ending of the pollution tragedy is not completely Utopian. But two great obstacles stand in the way: money and time. In France, the cost of only the most urgently needed installation is very roughly estimated at NF50 million and no one can say whether the work would take 10, 20 or 30 years.

Meanwhile, both in France and elsewhere, attempts are being made to give a legal context to the question of financing this work. The situation, when viewed in detail, is a curious one: at first sight one might think that the 'polluters' should cease to pollute or pay the necessary costs. Many legal actions have in fact been taken on these grounds; the almost automatic reaction of the obvious or presumed guilty party is 'to take his case to a good lawyer' or to subsidize an angler's club. His reasoning is that not he, but those living farther down the river will benefit from the money he will have to spend. Should not they share in the cost?

There is thus a trend towards setting up basin associations, in which the maintenance of the purity of water is considered a collective task in which all the industries and municipalities along the river participate, with the advice of engineers and specialists. This method has not yet received a precise statutory definition and is only slowly being applied.

There are many cases where the total purification of the main river and its affluents would seem very difficult to achieve. One approach which has been adopted with promising results in the Ruhr basin and is now being used more widely, consists in concentrating efforts on a limited number of cases where success is possible even if sacrifices must be made on other fronts. For example, in a particular hydrographic area, one of the waterways is carefully protected against all sources of pollution, particularly by prohibiting factory construction along its banks. But the rest of the waterways in the area are left open to the various large industrial complexes which draw from them a water supply of doubtful quality which frequently has been used more than once; these rivers that have been sacrificed thus become, to all intents and purposes, open-air sewers.

Even if such a solution is locally acceptable, it does not solve the problem of pollution on a continental scale. For several years, a European commission under the chairmanship of Professor Otto Iaag has been studying the alarming state of the waters of the Rhine. After receiving the effluents from the heavily populated industrial Swiss plain, the river passes through several cities, and, what is worse, collects along the way the sodium compounds contributed by the potash works of Alsace, those of the Lorraine basin brought in by the Moselle, and those of the Ruhr basin.

By the time it reaches the Netherlands, the Rhine transports a largely mineral pollution which has been estimated at 15,000 tons of salts a day. The underground waters in the Netherlands are invaded by these substances, and elec-
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Trodialysis or some other demineralization process will soon have to be used in order to obtain, for distribution purposes, water which is drinkable if not pure.

Marine pollution

Many cities, including some of the largest in the world, are built along roadsteads or estuaries leading to the sea. It used to be thought that an advantageous situation of this kind annulled any effects of pollution. Recent studies have shown the undue optimism of such a notion. It is true that the great ocean surfaces are constantly stirred by currents and winds and lend themselves perfectly to automatic purification processes (through the rapid oxidation of organic matter); however, ‘contrary effects’ must also be taken into account. Winds and tides have a tendency to block the dispersion of polluted water and even send it back to points along the shore where it is decanted spontaneously and creates particularly unhealthy zones.

Oceanographers also remind us that estuaries are prolonged by submarine valleys where pollution sludge can accumulate. Explorations of the abyssal regions of the sea have made it necessary to rectify the formerly-held belief that fauna living near the surface do not communicate with the deep-sea fauna. Certain crustacea and many forms of zooplankton migrate vertically from time to time. The food material deposited through pollution undoubtedly attracts a number of species.

All these phenomena, about which little is known as yet, seem to indicate that chemical or bacterial intoxication, attributable in great part to oysters and mussels, is directly related to pollution. Intestinal bacteria of the species Escherichia Coli have been found outside the Rance estuary (in Brittany) as far 3,000 metres from the coast. This proves that the wastes discharged by localities near the river mouth (about 50,000 inhabitants) are not, by any means, diluted as quickly as was believed.

To this marine pollution which is the continuation of fresh water pollution must be added pollution by ships. This question has been actively studied by several countries since 1953 and was the subject of a conference at Copenhagen in July 1959. The conference reviewed the results obtained by an international convention regulating the dumping of petroleum products (grease, oil and combustible hydrocarbons) in the sea. This form of pollution often produces spectacular effects. Long stretches of beach are soiled by hydrocarbons, on the west coast of Denmark, on the periphery of Newfoundland and, generally, on shores facing important maritime routes where there is a prevailing wind.

Marine animals are frequent victims of pollution by hydrocarbons which deposit an isolating film on the surface. The harm done to fish has not yet been exactly determined; it may unfortunately be very great in an exceptional fishing area like the North Sea. As far as birds are concerned, the Dutch
Atmospheric and water pollution

estimate that tens of thousands of individuals belonging to fifty different species die every year of the effects of pollution along their coasts.

Still, this whole danger does not seem very great. The world’s shipping fleet is only a limited source of contamination. A more serious prospect for the marine environment is the daily increasing trend towards moving industries to the coasts. In the United States, where the water shortage has become a cause of national alarm, there are plans to install several thermal plants along the sea-coast where they will have plenty of water for cooling purposes. In Italy, France and Algeria, large steel mills are being or will be built along the coast. The aluminium industry is following this tendency.

In Great Britain, nuclear energy plants are being systematically located at points along the seashore. The decision to do so was obviously taken in order to spare the country the dangers of radioactive pollution. Here we have still another problem which is the subject of frequent discussion, although the elements are still matters of conjecture. In the present list of atmospheric and water pollutions radioactivity only takes up a very small space (unless bomb tests are to continue).

Will this always be the case? To this we may give a prudently optimistic answer. The heads of the new nuclear industry seem prepared to study seriously, and in advance, means of circumscribing the dangers of radioactive pollution, whereas those responsible for ‘classic pollution’ foresaw nothing and have had a posteriori to face situations which only a gigantic effort can improve.
CURRENT TRENDS IN SCIENCE POLICY IN THE UNITED STATES

by

DON K. PRICE, J. STEFAN DUPRÉ, W. ERIC GUSTAFSON

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GOVERNMENT AND THE SUPPORT OF SCIENCE

Historical background

The remarkable advances made in the natural sciences and their involvement in issues of national defense during the past twenty years have given science a new status in American society. The new patterns of scientific policy have been influenced, however, by the ways in which science and technology have been associated with government and public policy in the United States of America over the past century and a half. The keen interest of political leaders like Franklin and Jefferson in scientific progress led to the use of science in many of the governmental programmes concerned with the exploration of the new continent and with its agricultural and industrial development. The young Army and Navy were called on to support science and engineering in many ways which were of direct benefit to the civilian economy. In a country without an established bureaucracy, scientific personnel became the nucleus for the development, in the late nineteenth century, of the higher ranks of the civil service. The support by military services of research affecting civilian interests and the advancement of scientists to high rank in the civil service hierarchy remain familiar features of government policy today.

Until World War II, the scientific activities of the Federal Government were developed not as a part of a general scientific policy, but in connexion with specific programme responsibilities of various departments and agencies. The Department of Agriculture gradually built up a network of agricultural colleges and experiment stations not by direct management, but through grants to the states. In other fields, federal agencies carried on their own research directly; for example, the National Bureau of Standards, with its responsibility
for basic research and the maintenance of standards for weights and measures, concentrated its work in its own laboratories in Washington, while the Geological Survey operated extensively in the frontier areas. Although the actual conduct of government research programmes was greatly decentralized, Congress chartered the National Academy of Sciences in 1863, and the academy, at President Wilson’s request, set up the National Research Council in 1918 for the purpose of providing central machinery by which scientific advice on public problems could be made available to government agencies.

At the outbreak of World War II, science was supported by the Federal Government, but only in connexion with the operating programme of a variety of departments and agencies. The result was heavy emphasis on applied research, but little on the support of fundamental science. Most scientists indeed shared the general assumption that the support of basic research was not properly the responsibility of government.

The impact of World War II

The awesome achievements of science during World War II were supported by an unprecedented expenditure of public money through new patterns of co-operation between the Federal Government and private institutions. It was at this time that the major lines of contemporary science organization were laid out, and some of the present problems developed.

First, the defence agencies loomed overnight as the principal supporters and consumers of research and development. Secondly, the procurement by government of research and development through contracts with private institutions became a major feature of science policy, as the Federal Government through its emergency Office of Scientific Research and Development directly mobilized the scientific resources of business and the universities. Thirdly, research centres were founded and were supported exclusively by government money, but operated by industrial and educational institutions under contract. (The Los Alamos Laboratory of atomic bomb fame, set up under an Army contract with the University of California, provides one of the more spectacular examples.) Finally, the release of atomic energy as the most striking example of the scientists’ power dramatically changed the attitude of the public toward science. From the change in public attitude came both increased interest and support, and novel problems of security and personnel policy.

The most far-reaching effect of the war on science policy, however, was that officials and legislators came to recognize that science had to be given general support for its own sake, and not as a mere instrument to be applied to the solution of practical problems. Such post-war government reports as Dr. Vannevar Bush’s *Science, the Endless Frontier*, and the five-volume *Science and Public Policy* by the President’s Scientific Research Board urged that science be looked on as a major national resource, and be considered in the development
of public policy as a phenomenon with far-reaching social and economic consequences. It was immediately accepted that continuing government expenditure for the support of science on a large scale was both necessary and desirable, that non-governmental institutions must be encouraged to continue to play the major research role that they had successfully filled during the war, that science should be given higher status in the governmental hierarchy, and that provisions be made to ensure an increasing supply of highly trained manpower. These have thus been continuing (if fluctuating) objectives of contemporary government science policy.

The American scientific establishment

America's present scientific establishment can be described as a partnership among the Federal Government, business and the universities. Each of the three carries on research and development work which it finances with its own funds. But a large proportion is carried on by transfers of funds (by grants or contracts) to business corporations from government agencies, or to universities from government or from business; thus the agency which is the source of funds is often not the performer of the work (see Table 1). The magnitude of the present enterprise, and the prominence of the Federal Government within it can best be appreciated through a comparison with the pre-war situation. In 1938, total national expenditure on research and development was $264 million, of which the Government contributed $48 million (18 per cent), industry $177 million (67 per cent), universities $28 million (11 per cent);

Table 1. Research and development in the United States by sources of funds and performers, 1953-54 and 1956-57 (dollar figures in millions)

<table>
<thead>
<tr>
<th></th>
<th>As sources of funds</th>
<th>As performers</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1953-54</td>
<td>1956-57</td>
</tr>
<tr>
<td></td>
<td>$m.</td>
<td>%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>5 150</td>
<td>100</td>
</tr>
<tr>
<td>Federal Government</td>
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<td></td>
</tr>
<tr>
<td>agencies</td>
<td>2 740</td>
<td>53</td>
</tr>
<tr>
<td>Industry</td>
<td>2 240</td>
<td>44</td>
</tr>
<tr>
<td>Colleges and universities</td>
<td>130</td>
<td>2</td>
</tr>
<tr>
<td>Other non-profit institutions</td>
<td>40</td>
<td>1</td>
</tr>
</tbody>
</table>

Source. National Science Foundation. Figures are provisional for 1956-57, and revised for 1953-54.

1. Includes funds from the Federal Government for the conduct of research and development at research centres administered by organizations in this sector under contract with federal agencies.
2. Includes all state and local funds, received by public institutions of higher education, which were used for research and development.
3. Includes state and local funds, received by such non-profit institutions as museums, zoological gardens, and academies of science, which were used for research and development.
Current trends in science policy in the United States

and other institutions, including foundations, $11 million (4 per cent). Total spending has since multiplied by more than thirty-fold, with government now providing over half the funds and industry about two-fifths. The bulk of the work, however, is done in the development laboratories of business and industrial corporations, the greater part of it under contract to the Government.

As to all-important basic research, which accounts for approximately 8 per cent of total research and development funds, government money is again predominant, with universities performing the bulk of the work (see Table 2).

TABLE 2. Basic research in the United States by sources of funds and performers, 1953-54 and 1956-57 (dollar figures in millions)

<table>
<thead>
<tr>
<th></th>
<th>As sources of funds</th>
<th>As performers</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1953-54</td>
<td>1956-57</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$m.</td>
<td>%</td>
</tr>
<tr>
<td>Federal Government agencies</td>
<td>443</td>
<td>100</td>
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<tr>
<td>Industry</td>
<td>212</td>
<td>48</td>
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<tr>
<td>Colleges and universities</td>
<td>62²</td>
<td>14²</td>
</tr>
<tr>
<td>Other non-profit institutions</td>
<td>28²</td>
<td>6²</td>
</tr>
</tbody>
</table>

Source. National Science Foundation. Figures are provisional for 1956-57, and revised for 1953-54.

1. Includes funds from the Federal Government for the conduct of basic research at research centres administered by organizations in this sector under contract with federal agencies.
2. Includes all state and local funds, received by public institutions of higher education and such other non profit institutions as museums, zoological gardens, and academies of science, which were used for basic research.

The new role of the Federal Government in science, then, is to provide financial support for research in private institutions, as well as to maintain government laboratories. And all indications point to a continuing increase in the Federal Government’s relative importance, especially as spectacular achievements in the Union of Soviet Socialist Republics emphasize the success of publicly supported research.

Decentralization is the principal characteristic of government financing of research and development. Some idea of the manifold sources of financing may be gained from Table 3, which shows estimated expenditure by the leading federal agencies for the fiscal year 1959, and, indeed, each of the major agencies cited in the table further decentralizes its work. (The Department of the Interior, for instance, sponsors research through no less than eight

subdivisions.) The result is that individual agencies have retained their traditional freedom to tailor research programme to their widely differing needs and situations. Thus, for instance, the relatively long-established bureaux of the Departments of Commerce and Interior perform the bulk of their research and development in their own laboratories, while the Atomic Energy Commission, both because of its need for non-governmental personnel and its recent inception, carries out nearly all of its research programmes through privately-operated facilities.

Types of research and development work both within and among agencies differ as widely as do methods of financing and organization. Activities range from basic research in the pure sciences to the applied engineering involved in the production-oriented problems of development. The latter requires more money because of its greater need for materials and capital equipment, and therefore the dollar figures tend to exaggerate the scientific contributions of certain departments and agencies (80 per cent of the total expenditure shown in Table 3 is for development.) This picture is corrected in Table 4 which omits development expenditures, and classifies research by field of science. In research as such, there is less variation in the relative importance of the various agencies.

### Table 3. Total Federal Government obligations for conduct of research and development, fiscal year 1959 (as estimated in The Budget, 1959—Reflecting congressional action) (dollar figures in millions)

<table>
<thead>
<tr>
<th></th>
<th>Total¹</th>
<th>Intramural¹</th>
<th>Extramural¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$m.</td>
<td>%</td>
<td>$m.</td>
</tr>
<tr>
<td>TOTAL</td>
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<td>100.0</td>
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</tr>
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<td>Department of Defense</td>
<td>5581.2</td>
<td>77.2</td>
<td>1312.2</td>
</tr>
<tr>
<td>Atomic Energy Commission</td>
<td>773.4</td>
<td>10.7</td>
<td>8.7</td>
</tr>
<tr>
<td>National Aeronautics and Space Administration</td>
<td>302.8</td>
<td>4.2</td>
<td>128.0</td>
</tr>
<tr>
<td>Department of Health, Education and Welfare (including National Institutes of Health)</td>
<td>244.0</td>
<td>3.4</td>
<td>74.6</td>
</tr>
<tr>
<td>Department of Agriculture</td>
<td>119.4</td>
<td>1.7</td>
<td>87.8</td>
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<tr>
<td>Department of Interior</td>
<td>61.9</td>
<td>0.9</td>
<td>52.7</td>
</tr>
<tr>
<td>National Science Foundation</td>
<td>57.4</td>
<td>0.8</td>
<td>5.9</td>
</tr>
<tr>
<td>Department of Commerce</td>
<td>27.9</td>
<td>0.4</td>
<td>20.9</td>
</tr>
<tr>
<td>Federal Aviation Agency</td>
<td>27.8</td>
<td>0.4</td>
<td>10.0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>36.8</td>
<td>0.5</td>
<td>22.6</td>
</tr>
</tbody>
</table>


1. Totals may not always tally exactly because round figures have been given.
2. Intramural research is carried on within government laboratories.
3. Extramural research is carried out by contract or grant in universities, industries, research centres under their management, or in independent laboratories.
Current trends in science policy in the United States

TABLE 4. Total Federal Government obligations for research by field of science, fiscal year 1959 (as estimated in The Budget, 1959—Reflecting Congressional Action) (dollar figures in millions)

<table>
<thead>
<tr>
<th>Total 1</th>
<th>Life 2</th>
<th>Physical 3</th>
<th>Social</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m. %</td>
<td>$m. %</td>
<td>$m. %</td>
<td>$m. %</td>
</tr>
<tr>
<td>1,443.5 100.0</td>
<td>432.1 100.0</td>
<td>963.7 100.0</td>
<td>47.7 100.0</td>
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<tr>
<td>Department of Defense</td>
<td>595.2 41.2</td>
<td>35.9 8.3</td>
<td>546.8 56.7</td>
</tr>
<tr>
<td>Department of Health, Education and Welfare</td>
<td>241.7 16.7</td>
<td>227.6 52.7</td>
<td>41.0 0.4</td>
</tr>
<tr>
<td>Atomic Energy Commission</td>
<td>178.1 12.3</td>
<td>40.1 9.3</td>
<td>138.0 14.3</td>
</tr>
<tr>
<td>National Aeronautics and Space Agency</td>
<td>164.2 11.4</td>
<td>— —</td>
<td>164.2 17.0</td>
</tr>
<tr>
<td>Department of Agriculture</td>
<td>113.9 7.9</td>
<td>76.4 17.7</td>
<td>20.7 2.1</td>
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<td>National Science Foundation</td>
<td>57.4 4.0</td>
<td>22.8 5.3</td>
<td>33.8 3.5</td>
</tr>
<tr>
<td>Department of Interior</td>
<td>50.2 3.5</td>
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<td>35.0 3.6</td>
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<tr>
<td>Department of Commerce</td>
<td>18.5 1.3</td>
<td>— —</td>
<td>15.5 1.6</td>
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<tr>
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<td>24.5 1.7</td>
<td>15.0 3.5</td>
<td>5.8 0.6</td>
</tr>
</tbody>
</table>


1. Totals may not always tally exactly because round figures have been given.
2. The 'life sciences' include the biological, medical and agricultural sciences.
3. The 'physical sciences' include the physical sciences proper, mathematics, and engineering.

The Department of Defense remains America's principal consumer of research and development services. By no means, however, do the armed services finance research and development that is of value only for military purposes. It is impossible to discuss the support of pure science, or its application to industrial or social purposes, without noting the heavy contribution of the military services to the programmes of independent civilian institutions. This is particularly true in the case of research as distinct from development. The military services have always been interested in the general advancement of science and technology; indeed the nation's first engineering school was the United States Military Academy at West Point. In the years since World War II, the military departments have sponsored much basic research of fundamental scientific value. Particularly in the post-war years preceding the creation of the National Science Foundation, the Office of Naval Research took the lead in the support of basic research, financing a wide variety of university projects with no limitation on the conduct of the research or on its publication. Further, a number of industries, particularly in aeronautics and electronics, perform military-financed research, the results of which are applicable to civilian purposes.

The line of demarcation between civilian and military interests and purposes is equally blurred in the programmes of the Atomic Energy Commission and
the National Aeronautics and Space Administration. The latter is so new that its exact relation to the armed services has yet to be clearly worked out. The Atomic Energy Commission and the Federal Aviation Agency, meanwhile, are charged with responsibilities related to both civilian and military purposes. Thus their research programmes in particular will often tend to benefit both. It is, of course, a truism in all these cases that the more 'pure' the research, the more difficult it becomes to identify any objective other than an intellectual or scientific one.

The remaining agencies are more predominantly civilian in purpose. The Department of Agriculture continues its tradition of research in all scientific fields relevant to its mission, from entomology to nutrition. The departments of Commerce and of the Interior carry out research in such diverse areas as fish and wild life, natural resources, meteorology and standards of physical measurement.

The Department of Health, Education and Welfare, through its National Institutes of Health, is of key importance to the nation's medical research programmes. There are seven institutes, each of which concentrates on a major problem area. These include cancer, mental health, heart, arthritis, allergy, dental research, and neurological diseases. Approximately one quarter of NIH expenditure is for research conducted within institute laboratories proper. The remainder is expended in the form of grants to universities, hospitals and medical research centres. The effect of the grants on medical schools in particular has been far-reaching, and has enabled these institutions to place unprecedented emphasis on research.

But the one agency set up to support science as such—not in relation to some specific action programme—is the National Science Foundation. It was created in 1950 to help support scientific research of a basic and fundamental nature and to deal with general problems of science policy. How the foundation has fared in relation to the second objective is discussed in a later section of this paper. What is particularly noteworthy is that the foundation has as its mission the financing of basic research in all branches of science; it receives proposals of research projects freely from any member of the scientific community, and evaluates them only in terms of their scientific merit, and that of the scientists who are to work on them. The foundation exemplifies the new status of science in the governmental system of the nation. The annual increases in its appropriations reflect a still mounting appreciation at the highest levels of government for the general value of science.

Government policy toward science is not limited to the financing of research and development projects. As the result of growing concern since the war regarding the availability and quality of scientific manpower, a number of federal programmes of aid to science education have been initiated in recent years.

Included in these programmes, which involve the Federal Government in
aid to education in unprecedented ways, are fellowships, loans, and training grants to support work at the university level, and miscellaneous programmes directed toward the improvement of science teaching in schools. Roughly $224 million will be expended for these functions in the fiscal year 1960, principally through the Department of Health, Education and Welfare and the National Science Foundation. The present budget of the former includes $57 million for grants to assist local secondary schools in equipping and remodelling laboratories, $31 million for student loans under the new National Defense Education Act of 1958 and some $60 million for fellowships and training programmes in the medical sciences. National Science Foundation expenditures totalling $67 million are budgeted for fellowships and the training of science teachers. The massive support of scientific research programmes led logically to the decision by Congress that Federal Government financing was necessary to improve the number and quality of scientists produced by the nation’s educational system. With the National Defense Education Act, this concern for science has been broadened to include the education of teachers for elementary and secondary education, and of advanced students in mathematics, languages, and other important fields.

While expanding its support for science and scientific education, the Federal Government has made some efforts—although with less conspicuous success—to increase the attractiveness of the government service itself for scientists. It has put new emphasis on programmes for the recruitment and training of its scientific civil servants, and in a number of the new scientific programmes, especially those associated with space and atomic energy and military research, Congress has authorized grades of pay for scientists generally higher than those of the top administrative personnel within the civil service.

The last twenty years has seen a fundamental change in the policy of the Federal Government with respect to science. The Government no longer treats science merely as an auxiliary to the operating programmes of its several executive departments and agencies, even though most of the financial support of science is channelled through those programmes. It has come to recognize, both in principle and by the appropriation of funds, that the cultivation of basic science and the education of scientists are important aspects of national policy.

PROBLEMS IN NATIONAL SCIENCE POLICY

The present research partnership between the Federal Government, business, and education has numerous advantages. First, it has allowed the Government to finance greatly increased scientific activity through existing facilities and personnel thereby avoiding the dislocation which would have been caused by a rapid enlargement of government laboratories. Second, industrial corpora-
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tions and universities have been able to perform research with great speed and flexibility because of their experience and freedom from detailed regulation. Third, these institutions have generally maintained their operating autonomy, while their science programmes have benefited enormously from government funds. The system as a whole exemplifies the American preference for limiting the role of government, even in a situation requiring massive public support. Nevertheless, it is inevitable that problems arise in this vast network that has been improvised to connect the Federal Government with its partners in science. Let us try to identify some of the problems, and the major points of view about them.

Contracts and grants

The two principal legal instruments through which the Government engages outside services for research and development are the contract and the grant. The research contract was derived from contractual conceptions long applied to government procurement of goods and services. The grant, on the other hand, was adopted by virtue of its successful record in the support of science by private foundations. Contracts are used both for specific research projects and for setting up large organizations charged with broad missions. The big research centres like the Los Alamos Laboratory are established and tied to the Government through broad master contracts. Grants are normally limited to the support of specific projects, but also pay for the construction of facilities and certain training programmes. In general, the contract is used more widely than the grant, which is primarily an instrument for supporting university research. Recent legislation, however, has authorized a number of government agencies previously limited to contracts to make grants at their discretion. This move is an indication of the growing concern for the sponsorship of basic research.

The research contract is a distinctive form of government contract. First, since what is contracted for in research and development is necessarily a product of uncertain nature, the contract must be written in general rather than in specific terms. Second, since the Federal Government is procuring highly individualized talent, the general rule of open advertising for bids by prospective contractors is not followed. But while the Government goes this far in recognizing the special features of research and development procurement, many of the researchers and administrators in private institutions argue that the standard contractual regulations should be further relaxed. Reports at frequent intervals, spot checks by government field administrators, the inclusion of standard regulatory clauses (e.g., the 'Buy American' clause), detailed accounting for purchases and property, and similar requirements are

often criticized as superfluous and restrictive in research matters. While admin­
isters have done much to ease the situation by discretionary action, many
scientists believe there is much room for statutory improvements.

Similar criticisms have been made of research grants. While they do not
include standard regulatory clauses, the requirements for fiscal and technical
reports are frequently similar. But it should be noted that the conditions at­
tached to grants can differ considerably from agency to agency. University scien­
tists are keenly interested in the policies and administrative procedures by
which grants are provided; some of them advocate the institutional or ‘block’
grant on the British model, as distinct from present project grants.

But some serious obstacles stand in the way of such broad grants. From the
governmental point of view, block grants would involve a departure from tra­
ditionally close accountability for public funds. Perhaps even more important,
many scientists fear that institutional grants would come to be allocated either
according to rigid formulae (e.g., by states, or in proportion to population) or in
response to political influence. These difficulties are now avoided by the tests
of competence which can be enforced when individual projects alone are
supported.

*Loyalty-security requirements*

During World War II, the strategic importance of science to the nation’s
defence led to the erection of a number of security barriers within or around
the scientific community. These barriers were designed both to keep research
of military importance secret and to ensure the loyalty and reliability of the
scientists involved in it. There is little disagreement about the need for security
restrictions on military research, but many scientists have objected to procedures
that seem to hamper their work unnecessarily. For example: (a) secrecy
requirements frequently prevent or delay publication of research findings,
thereby impeding the free flow of ideas necessary for rapid scientific progress;
(b) a certain loss of scientific manpower in some key areas of research results
from the government’s fear of taking on security ‘risks’; (c) loyalty and security
requirements are open to the caprices of unscrupulous or prejudiced politicians
and administrators.

The secrecy in which much research remains shrouded continues to be a
source of considerable complaint. While many universities have chosen to
overcome this barrier by refusing to perform classified research except in
unusual circumstances, both industry and independent research centres must
cope with it on a large scale. The principle of keeping certain research or deve­
lopment secret is agreed upon, but many scientists think that standards of
secrecy do not discriminate sufficiently between work of obviously military
significance and that having general scientific application.

The most acute difficulties arose in the years immediately following the
discovery of celebrated cases of espionage in the atomic energy centres of the United States, Canada, and Great Britain during the war. Since the passions aroused by controversy over these cases have subsided, and since the Government has introduced more equitable procedures into its system of dealing with loyalty and security investigations, the difficulties experienced by research scientists because of government investigations and hearings have substantially diminished. More important, a more discriminating line has been drawn between those situations in which the Government should impose requirements of secrecy or insist on tests of loyalty or security and those in which it should not. In 1955 the National Science Foundation took the lead among government agencies in asserting that no loyalty test should be imposed on persons receiving government funds for research in non-military areas.¹

Then in 1956, as a result of a study by the National Academy of Sciences, an announcement by the President’s office clearly laid down the principle that ‘an allegation of disloyalty should not by itself be grounds for administrative action on a grant or contract for unclassified research by scientifically competent investigators’.² Thus personal loyalty checks are now limited to performers of secret research.

In spite of such relaxations of administrative procedures, personal loyalty requirements still have distasteful overtones for many scientists and scholars, particularly in the academic community. Recent examples are the loans and fellowships under the new National Defense Education Act and those financed by the National Science Foundation, which may be given only to those who sign an affidavit that they have neither supported nor been a member of certain organizations defined as subversive. A number of colleges and universities have seriously questioned their connexion with such programmes, and some have altogether refused to participate in them.

Government-university relationships

The network of relationships which has sprung up over the last two decades between the Federal Government and university research laboratories has led to new high levels of financial support and also raised many policy problems. In 1953-54, 55 per cent of all university research was directly financed by the Government through contracts and grants for specific projects. This does not mean, however, that government agencies have unlimited influence over research in the universities. The Government, in its own internal processes, makes use of university scientists who thus have a substantial impact on policy. Since government agencies generally finance specific research projects rather than institutions, each project must be individually evaluated. The agencies sponsoring research call on outside scientists to sit on advisory panels to

². White House press release, 4 April 1956.
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examine individual proposals. In effect, then, scientific specialists from private institutions have major responsibility for allocating funds although the final authority remains with the granting agencies.

Inevitably both the size of the programme and the intricacies of government-university relationships are sources of serious problems. These difficulties concern not only scientists and government officials, but also university administrators who must formulate the business and organizational policies of their institutions as a whole. The following are a few of the pertinent problems.

**Maintenance of an atmosphere for basic research.** Among the many requirements for successful research is an environment which promotes creativity and independence in investigation. The traditional university atmosphere has often been said to nurture these intangible qualities most effectively. But extensive governmental work may be a source of unfavourable influences on the university environment. (a) Researchers complain that a greater proportion of their time is being taken up by administrative work related to obtaining or accounting for government grants. (b) Because government money is readily available for research in certain areas, these are often over-emphasized at the expense of scientific problems which might otherwise attract attention because of their pure intellectual interest. (c) Personnel policies of university scientific departments are complicated by a need for many more researchers than can possibly be given academic positions.

No matter how effectively the grant policies of the Federal Government are adapted to suit universities, an upper limit undoubtedly exists beyond which universities cannot conduct additional government research without interfering with their traditional functions. For this reason, perhaps, the Government has helped create new research centres (some as separate corporations, others as autonomous units managed by universities). The National Science Foundation has recently shown interest in such centres, especially in research areas now being neglected. But it seems clear that problems will be involved in keeping the centres from competing unduly with universities for needed manpower and in successfully creating in such centres an atmosphere favourable to research. The experience of existing research centres suggests that additions to their number might intensify the problems just mentioned.

**Teaching versus research.** With the growing demands of government programmes for research, it has become more and more difficult to maintain a proper balance in dividing faculty time between teaching and research. This difficulty is evidenced in several ways: (a) senior faculty members whose research services are in high demand tend to hand over an increasing portion of undergraduate teaching to junior staff; (b) graduate students are pressed to conduct their research on problems closely connected with their supervisor's governmental research; and (c) members of a department who concentrate
on teaching resent the higher incomes of colleagues engaged in research supported by government contracts. While most universities are coping with the last of these problems by refusing to inflate the salaries of scientists whom they pay out of government contracts or grants, the first two are causing considerable concern in the academic world.

Concentration of funds among large institutions. As is to be expected, government funds for scientific research tend to gravitate towards the larger universities that are known for the quality of their faculties, facilities, and students. As a result, several hundred good, but less well known, colleges and universities are put at a disadvantage. For one thing, the faculties of these institutions are given little research encouragement, which results in less than optimal use of scientifically trained manpower. In addition, the availability of federal money in the form of fellowships and loans tends to direct the flow of the best students to the larger universities.

The problem of over-concentration is extremely difficult to assess. To be sure, there is a strong argument for allowing public money to flow freely into the channels of greatest value in terms of talent and resources, especially since (as some argue) it is hard to train students in the newer fields of science without the large and expensive facilities which can be found only in the great university centres. But over-concentration of funds and students in large universities could result, others argue, in an eventual weakening of both the large and the small institutions. The Federal Government is becoming increasingly conscious of the intensity of the argument and the practical and political difficulties involved. The National Science Foundation accordingly has incorporated a Cooperative Fellowship Program into its policies which, by allocating fellowship quotas among a wide range of universities, tends to favour the smaller institutions. But in general, all federal agencies still prefer to give research grants to institutions where they think the best results will be achieved.

Indirect costs. Whether through contracts or grants, federal agencies strive to cover all direct costs of research projects, in so far as funds permit. But a whole range of costs exist in universities which are not directly attributable to any given research project, but which nevertheless are affected by its presence in the university. Such costs, ranging from the maintenance of buildings and grounds to the library and accounting services, are normally known as indirect costs or overheads. They are normally covered by assessment of the various programmes within the university on the basis of a percentage of direct costs. One matter of continuing controversy is whether the Federal Government should be charged with the full indirect costs of its sponsored projects. On the one hand, it has been argued that the universities should shoulder some of the expenses of federal projects on the grounds of the prestige and stimulation they gain thereby. And research scientists are not eager to see limited govern-
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ment funds diverted from the direct financing of research to the general university budget. But on the other hand, university administrators reply that anything less than full reimbursement of indirect costs means that other academic areas not sponsored by government money must sacrifice their own programmes.

At the prompting of the National Science Foundation, the Government has given greater attention to this problem. Thus recent policy statements have allowed a number of agencies, including the armed services, to liberalize their overhead policies considerably. But room for improvement still exists. The National Science Foundation remains restricted to overhead payments equal to 15 per cent of direct costs, a rate which the foundation itself regards as inadequate. And legislative provision which would have authorized the increase of the allowance of National Institutes of Health from 15 per cent to 25 per cent of direct costs has on three occasions failed to pass the House of Representatives.

Government-business relationships

Industrial research has grown tremendously in the United States in recent years. Spending for industrial research has doubled since 1953, and governmentally-financed research and development in industry has increased to the point where it now represents more than half the total industrial spending for research and development. Although government research and development contracts are primarily for defence or defence-related research, these programmes also have a substantial impact on the non-military side of the economy. The increasing importance of spending for research and development has led to a growing awareness of the influence of these expenditures on the economy. Indeed, a number of economists have maintained that research and development expenditures are one of the principal motive forces behind economic growth. At a National Science Foundation conference, for instance, one of the nation’s leading economists stated: ‘... research gives the economy the capacity to bring about planned increases in the demand for goods—both by creating new demands for consumption goods and by creating new investment opportunities.’

Economists are becoming more and more interested in the effect of government research and development on the total processes of economic growth, even though not all of them are in agreement regarding the effect of government research spending.

Quite aside from the effects of the volume of research and development expenditures, important policy problems arise with respect to the manner in which the Government chooses to spend its funds. Many economists and students of government-business relations argue that the contracting system is tending to foster the concentration of American industry in the hands of large corporations.\(^1\)

It is unquestionable that the greater part of research and development money is spent by the larger corporations. The National Science Foundation estimates that in 1953, 72.6 per cent of spending for industrial research in manufacturing was concentrated in the hands of firms with more than 5,000 employees. (In 1954, the average American manufacturing firm employed 65 workers.) These same companies accounted for only 39.3 per cent of manufacturing employment in the country. Overall figures for the amount of governmentally-financed research and development performed by large firms are unfortunately not available but the main outlines are clear. The bulk of government research and development support (77 per cent) goes to the aircraft and electrical equipment industries. In these two industries, 89.8 and 69.6 per cent, respectively, of the research and development expenditure is made by companies with over 5,000 employees.\(^2\)

There are many perfectly natural reasons why this should be so. In particular, the peculiarly uncertain nature of the research and development process makes it difficult to use a system of open bids for contracts. In addition, large corporations find it easier to maintain offices in Washington to keep in touch with current requirements in the field. Finally, much research and development contracting must necessarily depend on the contracting agency's knowledge of the capabilities of the firms which might handle the contract—and the bigger companies are obviously better-known. But nonetheless, in the view of many, much more should be done to enlist small firms in the government's programmes, even at the expense of a somewhat higher cost in seeking out performers for research and development work. (Indeed, the Air Force is already beginning to move some distance in this direction.)

Somewhat apart from these procedural aspects there is the question of the sheer size of the contracts. In the view of some critics, part of the concentration of government research and development funds in large corporations is the result of the tendency of the Department of Defense to plan research and development programmes from the beginning in terms of integrated weapons systems rather than in terms of smaller weapons-system components. Defence research and development contracts, largely executed through the Air Force, deal with new aeronautical and electronic systems on such a complex scale that the problems of management lead the Air Force not to arrange for all

the individual projects by direct contract, but instead to set up broad contracts for entire systems and then to permit extensive subcontracting for component parts of those systems. The critics object to this approach primarily on grounds of the efficiency of the military research and development system, but its effect may be equally serious in promoting concentration of contracts in the hands of large firms.¹

Although most of these contracts are for defence items, some defence ‘commodities’ have closely related peace-time counterparts, and companies which have participated in military research and development work naturally have an advantage in production for the civilian market. An additional factor of considerable importance is the fact that the accumulation of ‘scientific capital’ is extremely important in enhancing a firm’s position in the research and development field, and governmentally-financed research and development enables its recipients to profit from the by-products of government research conducted in their own laboratories.

GOVERNMENTAL MACHINERY FOR SCIENCE POLICY

By the end of the war, the American scientific establishment had changed into something entirely different from what it had been in 1939. Non-governmental laboratories, while maintaining their independence of action, had nevertheless become critically dependent on federal funds for their existence, especially in the fields calling for expensive capital facilities. Continuation of government support was an obvious necessity if American science were to continue to advance. On the other hand, problems of governmental co-ordination were obviously substantial, especially after the demise of the wartime agencies which had exercised some measure of central control.

During the last year of World War II, the scientists who had taken the lead in wartime research proposed the establishment of a National Science Foundation with a dual function: (a) to administer federal support for basic scientific research, and (b) to make recommendations on national science policy and to provide some measure of co-ordination for federal scientific programmes. The scientific community, although it changed its traditionally opposed attitude to favour government support for basic research in principle, was far from united in its views on the nature of the proposed organization.

As far as the financing of basic research was concerned, the scientists were not altogether convinced that centralization of government efforts would necessarily provide the best of all possible worlds. With support for this research scattered among the multitude of agencies, many scientists believed that the wide variety of policies for contracts and grants worked in their favour

¹. See the works by Klein, and Klein, Meckling and Mesthene listed in the bibliography.
and that centralization of support within the government might lead to an undesirable loss of flexibility in the administration of funds for science.

Even though they frequently criticized the lack of co-ordination in grant policy and in the broader areas of national science policy as well, many scientists were afraid to give centralized authority over scientific grants to non-scientist administrators, insensitive to the needs of the scientific community. Some were even more afraid of the possibility of giving political influence over science to the President or Congress. Some scientists—perhaps most of them—wanted the proposed foundation to be directed by a board of private citizens made up for the most part of scientists; this proposal was unacceptable to the President, who wanted a greater measure of central executive responsibility.

The proposal was debated hotly for four years while the relationship of the proposed foundation to central political authority was considered. With the final establishment of the NSF in 1950, the issue was settled by placing the foundation under the control of the part-time National Science Board, appointed by the President and composed of eminent scientists and educators from outside the Federal Government. (The NSF Act does not restrict membership in the board to people outside of government, but with one exception all members have been in private life.) The approval of the full 24 member board was originally necessary for all grants made by the foundation, although authority has recently been delegated to the director to approve grants of up to $250,000, provided that they do not involve basic policy issues. The director is the full-time administrative head of NSF, appointed by the President and responsible to him. In order to make the process of appointment as nearly non-political as possible, the Act requires the President, in appointing the board, to take due consideration of the recommendations of such educational and scientific organizations as the National Academy of Sciences and the Association of American Colleges. The board, in turn, makes recommendations to the President on the selection of the foundation’s director.

As it finally emerged from the Congress, the National Science Foundation Act provided that the NSF was to become the government’s principal disburser of aid for basic research, and was to develop national policy in basic research. In addition, its mandate included the responsibility to ‘evaluate scientific programs undertaken by agencies of the Federal Government’.

Some of the original backers of the foundation expected a great deal more from it in the way of direction of the scientific programmes of the Government, but the foundation itself was the first to come to the conclusion that it should not try to be a co-ordinating agency in the sense of exercising directive authority. The foundation had deliberately been somewhat removed from the executive centre of political force in the Presidency and the President’s Cabinet. It had no authority over the agencies represented there, and would have met strong opposition from the powerful interests which stood behind them.

The foundation has exercised a great deal of influence within government,
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however, in the direction of more effective science policy in its advisory capacity. It has issued a number of policy studies of major importance,¹ and has assumed the responsibility for collecting statistics on the manpower and funds devoted to scientific research and development both inside and outside government.

In the meantime, a body of quite a different sort had been set up to help in the problem of co-ordinating governmental scientific programmes. The Interdepartmental Committee on Scientific Research and Development was formed in 1947, to be composed of representatives from the principal departments and agencies performing research and development. The committee was composed principally of scientists rather than of high-level administrators within the departments involved. The report of the President’s Scientific Research Board (the Steelman Committee) in recommending the establishment of this group indicated that ‘one of the finest spheres of usefulness from this committee of scientists and administrators would be its contribution to liaison of the spontaneous type.’²

As the quotation indicates, the committee was given no authority but was conceived as a forum through which the various departments could achieve some measure of informal co-ordination in their work. Obviously it suffered from lack of authority and from the fact that it did not involve high-level administrators, but this was perhaps a natural consequence of scientists’ mistrust of the administrative mechanism.

Nevertheless, the committee was able to achieve some significant work. For instance, it compiled an inventory of major equipment and facilities of Federal Government laboratories, and worked with the Committee of Specialized Personnel of the Office of Defense Mobilization to establish effective policy on the military service of technical personnel.

These arrangements suddenly seemed inadequate in late 1957, when the Soviet Sputnik led the American public to reconsider its complacent view of the comparative merits of its scientific and technological programmes. In this new perspective, it began to be evident that scientific matters in the Government were largely unco-ordinated. The only central administrative machinery was the Interdepartmental Committee, which was a discussion forum rather than a group with specific authority, the National Science Foundation, whose authority in matters of co-ordination had been (perhaps deliberately) left somewhat smaller than its responsibility, and the Bureau of the Budget, whose authority extended only to fiscal matters. A high official in the Bureau of the Budget commented shortly after the Sputnik went into orbit that ‘...it must be conceded that the art of public administration has not kept pace with the rise of scientific research as a public responsibility ...

¹. A number of these are listed under the various headings of the bibliography.
We have to develop within the Government a comprehensive view of research and development roughly similar to what we long ago devised in such areas of public policy as agriculture, land and resource conservation, national defense. Science in government continues in this critical age to prosper labor, and as a sideline of separate and unrelated departmental missions; it is not seen as a unity either in the executive or the legislative process.1

At this time, as President Eisenhower later wrote, 'a many-pronged effort was launched to underwrite the strength of American science and technology as one of our essential resources for national security and welfare'.2 Considerable action was soon forthcoming. The President appointed as his Special Assistant for Science and Technology Dr. James R. Killian, Jr., the President of the Massachusetts Institute of Technology. (Dr. Killian has since been succeeded by Dr. George Kistiakowsky, professor of chemistry, Harvard University.) The Special Assistant was to chair a Science Advisory Committee composed of a group of eminent scientists who would be available to mobilize scientific advice for the President and the various executive departments. Even aside from the value of the expert advice brought forward through the committee, the benefits have been great. The scientific community at large has acquired a sense of participation in the high-level formation of science policy. The presence at the President's right hand of a powerful emissary from the scientific community has, in the words of William Carey, worked against '... the disposition of citizens not only in science but in other occupations to absent themselves from the wedding feast unless and until the summons is delivered by a courier of their own persuasion. Perhaps this is harsh, but the difficulties of the President in securing skilled help are too well known to require elaboration. To the extent that Dr. Killian has moderated the problem with respect to science and technology, the benefits are considerable.3

The Science Advisory Committee has set up several standing and ad hoc panels, some of which include non-members of the committee. Some have recommended programmes which have since been carried into effect. In particular, the panel on research policy issued an excellent report entitled *Strengthening American Science* in which it recommended a Federal Council for Science and Technology, since established by Executive Order No. 10807 on 13 March 1959.

The Federal Council is a reconstitution of the old Interdepartmental Committee on Scientific Research and Development, but at a higher level. Whereas the ICSRD had been composed of scientist-administrators heading purely

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1. William D. Carey (Bureau of the Budget), 'The Support of Scientific Research', paper delivered before the American Association for the Advancement of Science, 30 December 1957.
scientific units (like the Geological Survey or the Bureau of Standards) within the various departments and agencies, the Federal Council is composed of an 'official of the Department of policy rank' from the Departments of Defense, Agriculture, Commerce, Interior and of Health, Education and Welfare, the Director of the National Science Foundation, the Administrator of the National Aeronautics and Space Administration, and a Commissioner of the Atomic Energy Commission. Most important, its chairman is the President's Special Assistant for Science and Technology.

In recommending the establishment of the Federal Council for Science and Technology, the Science Advisory Committee at the same time pointed out that within each of several departments having substantial scientific functions there was little co-ordination of science policy. The committee obviously hoped that each department would reorganize its own procedures and perhaps make the same man responsible for co-ordination of scientific work within the department and for representing the department on the Federal Council.

The Federal Council is an organization set up to study and advise, and like its predecessor has no direct authority in scientific matters. But in the light of its high-level composition, and of its direct channel through its chairman to the President—and vice versa—it is obviously intended that the council have more influence than previous bodies of this nature. Its mandate is extremely broad, including consideration of practically every aspect of government science policy, specifically including the overall impact of government programmes on science outside of the Government.

Although these interrelated moves creating the Science Advisory Committee, the post of President's Special Assistant, and the Federal Council have given the federal science programme more potentiality for unification and control than there has ever been before, some critics raise the question of how effective these organs can be, since they have only advisory powers and depend for their effectiveness on personal influence with the President—a relationship which may not prove as happy in the future as it is now. Such critics often suggest as an alternative approach for the co-ordination of science policy the creation of a Department of Science and Technology which would unify some (or all, depending on the proposal) of the government's scientific activities in a department headed by a secretary with cabinet rank.

The administration has indicated its opposition to the plan in unmistakable terms through the Bureau of the Budget. William F. Finan of the Bureau said before a Congressional Committee that '...considering the purposes and character of present federal programs, we doubt that there exists a workable concept upon which a Department of Science and Technology could soundly be based. The well-established approach to organization of the executive branch is the grouping of agencies into executive departments on the basis of major purpose... The bureau has been unable to identify any significant group of governmental activities which could be brought together under a
single department roof on the ground that their major purpose is "science and technology".\textsuperscript{1}

One of the fundamental reasons advanced for having a Department of Science and Technology has been that the Secretary of the Department would then 'represent science' in the Cabinet and provide a powerful advocate for the science programme of the Federal Government. The difficulty with this proposition is that a 'Secretary of Science and Technology' would in the nature of the case be unable to represent science in the Government, except partially. Most parties to the debate about the proposed new department admit that only part of the government's scientific activity could be centralized under it. The bulk of the government's scientific work is generally admitted to be too closely tied to the operating responsibilities of the departments in which it is located to be effectively separated from them without serious damage to the quality of the performance.

Consequently the secretary of any such department would be placed in the anomalous position of being expected to be 'spokesman for science', supposed to represent the broad interests of science and scientists in government, and yet at the same time forced into the position of representing only a part of the governmental scientific establishment, because of his responsibility for ensuring an adequate level of financing for those organizations under his direct control.

The proposal of this general nature which has attracted most interest in recent months has been for an amalgamation not of the major agencies that support scientific research in connexion with operating programmes, but of some government bureaux (for example, the Weather Bureau and the Naval Observatory) the purpose of which is to provide direct service to the scientific community and the country as a whole.\textsuperscript{2} Yet this proposal, like the other moves for a Department of Science and Technology, is unlikely to be adopted in the near future. A bill is now before Congress calling for the establishment of a commission to study the feasibility of such a department and its potential areas of responsibility. The administration has indicated its opposition even to such a study being made since it considers a Department of Science to be out of the question.

Yet there are obviously areas of governmental policy which still require co-ordination and policy guidance even if one does not think a Department of Science and Technology desirable. All have been subjects of concern to the President's Science Advisory Committee and his Special Assistant for Science and Technology.

\textit{Basic science.} By definition basic science—research conducted without immediate regard for practical application—is work which will tend to be neglected in the scientific programmes of operating departments. In preparing

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budgets for scientific research within an operating department, basic research is often neglected in favour of research which can be counted on to produce immediate concrete results that can be applied to the mission of the agency. The function of seeing to it that basic research is not neglected has been placed primarily in the hands of the National Science Foundation.

However, by Executive Order\(^1\) the President has made it plain that the National Science Foundation is not to have a monopoly on the performance of basic research. Each agency supporting research is expected to devote some fraction of its resources to basic research, both for purposes of maintaining the quality of its laboratories and of keeping them aware of new developments in their formative stages.

**Budgetary co-ordination.** This function is now performed by the Bureau of the Budget in its role as the President’s watchdog over the expenditures of the various departments. The President’s Special Assistant for Science and Technology, with the help of the two bodies of which he is chairman, is also concerned with the policy issues reflected in the budgets, especially when longrange capital expenditure or the construction of facilities are involved.

**Scientific information.** Under the provisions of the National Defense Education Act of 1958, Congress directed the National Science Foundation to establish a Science Information Service which would provide indexing, abstracting, and translating services, and which would develop improved methods for making scientific information available. This authority was further fortified in 1959 by amendments to Executive Order No. 10521 which directed the foundation to ‘provide leadership in the effective co-ordination of the scientific information activities of the Federal Government’. Both instructions simply gave further emphasis and support to a function which the National Science Foundation, with the support of the Science Advisory Committee, was already seeking to carry out under its basic statutory authority.

The scientific information activities which the foundation will seek to co-ordinate and supplement are scattered among various agencies of the Government and among a great variety of commercial and educational institutions. A report of a Science Advisory Committee panel in 1958 saw no advantage to be gained in trying to centralize their operations.

**Scientific manpower problems.** Since the dissolution of the President’s Commission on Scientists and Engineers at the end of 1958, there has been no agency in the Government concerned with formulating overall scientific manpower policy and programmes.\(^2\)

**International scientific relations.** As a reflection of the growing importance of international scientific relations, the State Department in 1951 established

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2. A partial exception is the Committee on Specialized Personnel in the Office of Civil and Defense Mobilization. It is concerned primarily with defence mobilization problems.
the Office of the Science Adviser to the Department and appointed a number of science attachés to the embassies in various European countries. Ten of these were on duty in 1952. But in 1954 the department let the Office of Science Adviser fall vacant and did not fill the posts of attachés as the incumbents resigned. The last attaché's post became vacant in 1956. After considerable urging by the House Committee on Government Operations and others, the Department in 1957 appointed Dr. Wallace R. Brode, then Associate Director of the National Bureau of Standards and President of the American Association for the Advancement of Science, as the new Science Adviser. He began recruiting a staff of science attachés, and by late 1958 seven had been selected.

Some of the main problems faced by the Science Adviser are the outcome of the general problems confronted by the Department of State in the American governmental system. For example, by contrast with many other countries, the United States permits its various departments a considerable amount of freedom in establishing missions abroad. Although these are technically subject to the ambassador in the particular country, in practice they often have a high degree of operating autonomy. Dr. Brode pointed out early in 1959 that ‘...some six major agencies of our Government are each requesting authority to establish offices in a single foreign country to provide basic research contracts in science, capability surveys, and exchange of basic scientific information. A cooperative program for this effort through combination of these agencies to work as a unit with respect to basic scientific research would provide a better impression on our host government as well as a more efficient effort.’

National scientific needs. The major programmes of scientific research during World War II led the United States Government to understand the necessity of maintaining a high level of basic science if it hoped to exploit the results of applied research for its various practical programmes. During the intervening years, that policy has been followed, with considerable fluctuation, but with a persistent increase in both the level of support and the degree of national commitment to continue it. But as a whole the scientific programmes of the country remained unplanned, partly because the programmes of applied research were carried on with a high degree of independence by individual government departments, and partly because many scientists, in and out of government, were committed to the belief that basic research cannot and ought not to be planned or directed.

Since the appointment of the Special Assistant to the President for Science and Technology, and of the two bodies of which he is the chairman, the Government has taken a significant step towards a system of planning more positively the fields of science to which major federal funds are to be committed. This is the effort ‘to identify research needs including areas of research requiring

1. Testimony before the Senate Committee on Government Operations, 86th Congress, First Session, Create a Department of Science and Technology: Hearings, Part 1, Washington, 1959, p. 73.
additional support—a responsibility formally assigned to the Federal Council for Science and Technology.¹

The Science Advisory Committee has called the attention of the public to fields of basic research which require more extensive support, among them meteorology, oceanography, geophysics, radio-astronomy, biophysics, linguistics, and social psychology.² The emphasis on meteorology and oceanography has been underlined by special reports from committees of the National Academy of Sciences, which urged (in the report on oceanography) the commitment of long-term funds to stimulate teaching and graduate study as well as research.

Such proposals go beyond the tradition of giving support only in response to research projects submitted by independent institutions; they amount to an effort to guide the nation’s scientific programme. And the need for such comprehensive guidance is reinforced, as the report of the President’s Science Advisory Committee indicated, by the impossibility of carrying on some types of modern research without complex and expensive facilities and equipment, and without research institutes specially organized to carry on particular programmes.

The first illustration of the former need came when the committee recommended to the President, and the President to Congress, the appropriation of $100 million to build a new linear electron accelerator at Stanford University in Palo Alto, California, as a national research facility. With expenditures of this order of magnitude in mind, the committee thought it essential for the Federal Council on Science and Technology to take responsibility for advising on the future national capital requirements for scientific facilities.

The Science Advisory Committee and the National Science Foundation have both been concerned with the problem of creating new research institutes outside the universities to make it possible to carry on large-scale research without distorting the programmes of teaching faculties. Both have called attention to the opposite dangers of failing to create such an institute when the situation requires it, or of establishing one at great expense in money and manpower if the job could be done otherwise.

The Executive Office of the President now includes among its most influential staff agencies a noted scientist as the President’s immediate adviser supported by eminent committees composed of scientists from private life and of scientific administrators from government agencies. Without intending to promote planning and government controls for their own sake—indeed, while remaining fully committed to the advantages of as much private initiative and decentralization as possible—top-level science advisers are recognizing that the magnitude of the expenditures required for new research programmes, and the pressure of government requirements on private institutions, now require a

¹ Executive Order No. 10807, 13 March 1959.
² The President’s Science Advisory Committee, Strengthening American Science, 27 December 1958.
more comprehensive co-ordination of government plans and programmes for
the support of science.

The decade that followed World War II committed the United States to a
policy of government support for science. The first few years of space explora-
tion seem to have committed the American Government equally to an effort
to plan the development of neglected fields of science, and to give comprehen-
sive guidance to the development of scientific facilities and institutions, in
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<td>Yugoslavia</td>
<td>Jugoslavenska Knjiga, Terazije 27, Beograd.</td>
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