3 January 1964, Volume 143, Number 3601 SCIENCE

The Fifth Estate in the Seventh Decade

The status of science and scientists in the 1960's is reviewed.

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My distinguished predecessors of the past few years who spoke on similar occasions as retiring president of the AAAS dealt with various substantive aspects of science. At Chicago in 1959 Paul Klopsteg, in a talk reminiscent of Bragg's famous essay on the contribution of British craftsmen to British science, depicted the role played by instrumentation in the development of science. The next year, in New York, Chauncey Leake described the development of a special area of science—that of pharmacology and physiology. Last year in Philadelphia Tom Park gave us an account of the origins, development, and outcome of his own research program as an investigator in biology.

Tonight, instead of talking of my own field of physical chemistry, I think it may be of interest if I say something of the present status of science and of scientists, as I see it, from my experience of almost a half century in scientific education, research, and administration. The reference in the title to the "seventh decade" is, of course, obvious. That to the "fifth estate" may not be familiar to some. This relates to the three estates of English history—the Lords Spiritual, the Lords Temporal, and the Commons. To these was added a fourth—by Edmund Burke, according to Carlyle. Burke is said to have observed, in a famous speech: "There were Three Estates in Parliament; but, in the Reporters' Gallery yonder, there sat a *Fourth Estate* more important far than they all." If he were speaking today I am sure he would enlarge the gallery considerably and provide ample space for the commentators and columnists who, obviously, know all about the world and its affairs, both scientific and otherwise. So much for the fourth estate.

The "fifth estate" of my title can best be described in the words of the distinguished scientist and technologist Arthur D. Little, who first used this term in an address in 1924 at the centenary celebration of the founding of the Franklin Institute.

> This fifth estate is composed of those having the simplicity to wonder, the ability to question, the power to generalize and the capacity to apply. It is, in short, the company of thinkers, workers, expounders and practitioners upon which the world is absolutely dependent for the preservation and advancement of that organized knowledge which we call "science."

The status of science and scientists in the 1960's is obviously a large subject, and here I will discuss four aspects of it which I feel should claim our attention, thought, and understanding. The first relates to the greatly expanded tempo, scope, and power evident in the development of science during the past quarter of a century. Secondly, I would like to consider the increasing role of science and technology as an instrument of national policy. A third area meriting attention is a changing pattern of scientific activities and some implications of this. Lastly, and most important, for the future advancement of science, is the place of science and scientists in our modern social structure and the interactions with that structure.

Changes in Tempo, Scope, and Power

Before elaborating on these topics, I think it desirable, even at the risk of covering ground familiar to many, to sketch briefly against their historical background some of the scientific developments familiar to us. In doing this I will attempt to emphasize not the content of science so much as the changing characteristics of scientific endeavor. For this purpose it will be convenient to have two reference points in time: the late 1800's just prior to the turn of the century and the decade from 1925 to 1935.

While the ranks of the fifth estate have grown rapidly in this century, it is still true that the number of scientists remains a small fraction of the total population. In the long years prior to 1900 the voice of science in national and world affairs was rarely heard, and the individual scientist working in his ivory-tower laboratory was a little-known member of society. Nevertheless, contributions of science and technology to human welfare and to the problems of the military, the growth of industry, and economic development in general were more important with each passing decade. Toward the end of the last century and in the early years of this one a new aspect of scientific activities began to emerge. This was the concept of highly organized team activity in scientific and industrial research. It was in Germany that this concept first appeared in any substantial measure, in the latter years of the 19th

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century. Its effective utilization gave Germany a leading position in producing such things as chemicals, pharmaceuticals, steel and machinery, and similar products of industries where scientific and technical knowledge was a prerequisite for effective production. This lead over other countries, including the United States, was retained up to World War I. Some of us can recall hearing the news in the early years of that war, before our entry, that the German submarine *Deutschland* had successfully eluded the British naval blockade and landed in Baltimore harbor. What may not be as well known is the fact that the cargo consisted of scarce pharmaceuticals and dyestuffs which sold at high prices in this country because of our almost total dependence on Germany for such synthetic chemicals. On the return voyage the cargo was mainly tungstic oxide, as tungsten was a critical raw material in many areas of Germany's advancing technology. Only after World War I and as late as the 1920's did the industrial research concept of today begin to appear as an important component of some of our own more technically based industries.

The world nitrogen supply and the fate of nations. Before this century much scientific thinking was still limited in its scope and heavily circumscribed by the walls of the laboratory. There were of course exceptions. Though the ranks of science were small in number, they included a goodly share of giants —such men as Maxwell, Rayleigh, Herz, and Röntgen, to mention but a few. One in the field of chemistry was Sir William Crookes, president of the British Association for the Advancement of Science at its Bristol meeting in September 1898. In his presidential address, after an excellent analysis of factors bearing on world food supplies, he spoke as follows.

> The fixation of nitrogen is vital to the progress of civilized humanity. Other discoveries minister to our increased intellectual comfort, luxury, or else convenience; they serve to make life easier, to hasten the acquisition of wealth, or to save time, health or worry. The fixation of nitrogen is a question of the not too distant future. Unless we can class it among the certainties to come, the great Caucasian race will cease to be foremost in the world, and will be squeezed out of existence by the races to whom wheaten bread is not the staff of life.

That these are still matters of vital interest today is seen by recalling current discussions of the population explosion, and discussions of this past fall relating to the sale of surplus wheat from this and other countries to help feed the millions in the Soviet bloc.

While we all have general awareness of the important role of organized industrial research in defense and in economic development, this can be focused more sharply by looking back at the events relating to the world's nitrogen supply that occurred after 1898. Based on fundamental research in Germany and Scandinavia, in the period between 1900 and World War I a new industry developed, that of nitrogen fixation. However, this was of only limited capacity at the beginning of the war. Since nitrogen is essential not only for agriculture but also for the manufacture of explosives, as war became imminent Germany began stockpiling Chilean nitrate. The first important naval engagement of World War I was fought not in the Atlantic but in the Pacific, off the coast of South America, in an operation in which British warships captured or sank a German merchant convoy carrying Chilean sodium nitrate back to Germany. With this event there were many predictions that Germany could not last long in the war, with her very limited domestic sources of nitrogen. As with many predictions, these proved quite wrong in the outcome. During the war years, the Germans, with their by then matured capability in industrial research, were able to build the first major nitrogen fixation industry in the world. Moreover, after her recovery from war and with the rebuilding of her commerce, Germany became the world's principal producer of nitrates and supplied these to Europe and the Atlantic seaboard at prices with which Chileans could not compete. The next step in this chain of economic events was a fiscal crisis in Chilean affairs, as a substantial part of the Chilean economy had been based for years on a tax on exported nitrates. Recovery from this crisis came only when, through research sponsored by American financial interests, more efficient ways were found of mining the Chilean nitre deposits and of extracting and marketing as a valuable by-product the significant amounts of iodine that they continued.

This illustration of changing conditions in the nitrate industry is but one of many that could be cited. In today's highly technological civilization the fate of nations will depend increasingly on their store of scientific knowledge obtained through basic research, and on their capacity and ingenuity in applying this knowledge to produce goods and provide services of all kinds. This is the basis of a sound economy and the key to its forward progress.

Rather than continuing with an account of more recent scientific and technologic events familiar to all, I will simply point out that greatly expanded basic and applied research between World Wars I and II and after World War II led to such results as the high state of development of the airplane for transportation, the whole electronics industry, the release of nuclear energy and its use for power and the propulsion of naval vessels, and, finally, the successful launching of orbiting satellites.

International Geophysical Year. More detailed review of similar developments would quickly reveal much to support the thesis that there has been a greatly expanded tempo, scope, and power in activities in science during the past quarter of a century. So far as scientists themselves are concerned, this could almost be regarded as the emergence of a kind of fourth dimension in scientific thinking. Justification for such a statement is evident in a number of directions—for example, in the thinking, planning, and execution that went into the project known as the International Geophysical Year. This was a bold frontal attack, involving international collaboration on a grand scale, which was made in an attempt to understand more fully the physical nature of the surface of our globe through a carefully planned survey of the scientific phenomena relating to the atmosphere, the oceans, and the input of radiation of all types to our near geosphere. The information gathered was vast, and the discoveries were many. Their significance for a better understanding of such important phenomena as weather changes and climatic cycles is already apparent. As the many scientists interested in this area continue working on the large number of data that were accumulated, a much deeper knowledge of the surface of our earth can be expected.

Another example of the type of thinking I have referred to, and one still on the scale of great dimensions, is the project currently under way which is known, for short, as "the Mohole." This is an attempt, fraught with great difficulty, to penetrate the earth's crustal layers to acquire a better understanding of the nature, composition, and behavior of its massive interior core. However, such scientific thinking and progress have not been confined to endeavors of large dimensions, even global in scale. In the past decade, work of a highly competent team of mathematicians, physicists, chemists, and biochemists at Cambridge University has led to a better comprehension of the basis of life processes, through discoveries of great significance in the field of molecular biology. The determination and unraveling of the complex molecular structure of giant molecules, such as ribonucleic acid (RNA) and deoxyribonucleic acid (DNA), have been major advances and outstanding illustrations of the effective collaborative, scientific teamwork so characteristic of much current scientific activity.

Possible modification of the climatic cycle. A final example of thinking of this sort is a proposal by Ewing and others for possible modification of the age-old climatic cycle which results in repetitive glaciation of continental land masses south of the Arctic Circle. The geologic and related evidence from prehistoric times for the existence of such a cycle of ice ages with a period of perhaps 30,000 years appears clear. Ewing's thesis, in broad terms, is that the occurrence of this cycle is related to the extent of accumulation of ice and snow on the polar ice cap within the Arctic Circle and also the ingress and exit of warmer waters from the Pacific and the Atlantic over the edges of the fairly shallow geologic basin which holds the Arctic Ocean. The conclusion of the argument, which I shall not develop fully, is that this cycle could be altered by stopping or at least modifying the flow of water through Bering Strait between the Arctic Ocean and the Gulf of Alaska in the North Pacific. This would indeed be a gargantuan project in applied science, execution of which could only have been thought possible—whether desirable is another question—with the availability of nuclear explosives. Thinking of this type would, in my judgment, have occurred but rarely in earlier periods of the development of science.

An Instrument of National Policy

Much that I have outlined is evidence of the increasing role of science and technology as an instrument of national policy—the second topic under discussion. An illustration from behind the Iron Curtain at once comes to mind.

Few of use like the tenets of Soviet ideology, though many take complacent comfort in the disparity between the present standard of living in Russia and our own. Nevertheless, Russia has forged ahead through the encouragement of science, through the systematic employment of the methodology of research and development, and through the extension to large segments of her population of free education oriented strongly toward rigorous training in science and technology. Nicholas DeWitt, who has studied the Soviet manpower and educational system intensively, states the situation in the postscript to his book *Education and Professional Employment in the U.S.S.R.*

> If the aim of education is to develop a creative intellect critical of society and its values, then Soviet higher education is an obvious failure. If its aim is to develop applied professional skills enabling the indivdual to perform specialized, functional tasks, the Soviet higher education is unquestionably a success, posing not only a temporary challenge, but a major threat in the long-run struggle between democracy and totalitarianism.

While DeWitt's first description of the aim of education may well give us pause when we think of values in relation to our own culture and society, and make us ask how well our own system of education has done, the validity of his concluding statement becomes apparent from the perspective of little more than a third of a century. In this short period Russia rose from the rank of a third-rate power to a position, today, second only to that of our own country.

National defense. There is a final element relating to the present role of science and technology as an instrument of national policy which must be mentioned. This concerns warfare and the preparation for warfare, or what is today euphemistically called national defense. From the first development of gunfire in the 14th century there had been little real innovation in the practice of warfare until this century, though the Civil War did bring the introduction of steel armor and the submarine. In World War I, gas warfare, tanks, and the aeroplane made their appearance. The development of the latter for military use between the two wars paced and enhanced the great development of commercial aviation, and this, in turn, has reduced passenger traffic on our widespread network of railroads to a fraction of its volume in the first third of the century. In World War II, radically new concepts such as the proximity fuse, the landing craft, and, of course, nuclear explosives were introduced. The war also saw the refurbishment and effective use of a very old device—the rocket. This was first used as a weapon by the Mongols about the middle of the 12th century, and it reappears from time to time in the subsequent history of warfare in various military versions. Francis Scott Key witnessed one of these occasions when he was a prisoner in a ship in the British fleet off Baltimore at the siege of Fort McHenry in 1814, and the spectacle inspired the line in our national anthem: "And the rocket's red glare, the bombs bursting in air. . . ."

The high state of effectiveness to which rockets were brought toward the end of World War II through intensive research and development and the advent of the German V-I's and V-II's provided the background for today's missile technology. Further development of long-range offensive missiles provided the launch rockets for orbiting satellites and for vehicles for space exploration. These are some of the advances that have completely changed the whole aspect of warfare in less than a third of a century. In this area there can be no doubt that scientific advance and capability are indispensable instruments of national policy.

Changing Pattern of Scientific Activities

What, then, have been the effects of this great expansion of science and technology, this changed scientific thinking, this involvement with national policy, on science itself, on its organizational patterns, and on scientists and their pursuit of scientific endeavor? The question brings me to my third topic. These effects have been both major in scope and diverse in direction. They have been both favorable and unfavorable for the sound advancement of scientific endeavor.

Consider first the positive side of the coin. Today, the nature and tempo of effective research requires ample funding for men, machines, and facilities, and funds have been made available in rapidly increasing measure during the past third of a century. A glance at one area, that of nuclear and high-energy physics, will quickly reveal the scale and pattern of support. From relatively small beginnings, in such laboratories as those of Rutherford and the Curies, nuclear physics in the 1920's and 1930's moved steadily but slowly ahead. Support for the first generation of high-energy machines, the early cyclotrons, came mainly from university funding and private giving by individuals or foundations. The demonstration, in the early years of World War II, of the feasibility of the nuclear chain reaction and of its significance for the release and utilization of nuclear energy in war and peace led quickly to federal support, first through the Manhattan District Project and later through the Atomic Energy Commission. The scale of this support was not in millions but in billions, and this pace continues today. However, the magnitude of expenditures, though indicative of the scale of modern scientific activity, is never a good measure of scientific achievement.

Astronomy. Nevertheless, a brief survey of several areas of science will reveal that great substantive progress has been made in recent years. A case in point is the field of astronomy. Next to mathematics, this is the oldest of the sciences, dating from Babylonian times in the 3rd century B.C., and it has a long history of achievement before 1900. The early years of this century saw the establishment, largely through private philanthropy, of a few observatories, such as that on Mt. Wilson, with telescopes and ancillary instrumentation larger and more effective, by an order of magnitude, than anything that had gone before. These were the forerunners of the large-scale scientific facilities familiar today—the giant cyclotrons, accelerators, and piles of nuclear physics. As astronomy moved ahead through the first half of the century, its progress was relatively slow by comparison with the burgeoning development of the laboratory sciences of chemistry and physics, which received much of their steadily increasing support from private, industrial, and government sources.

It was only after the establishment, at mid-century, of the National Science Foundation to support basic research that attention was turned to more adequate support for astronomy. In the middle 1950's the establishment by NSF of the Greenbank Observatory as a National Radio Astronomy Observatory marked a turning point in the character of federal support for basic science and fundamental research. From this beginning, federal funds became available for "national" basic scientific enterprises, such as the International Geophysical Year in 1957–1958 and, later, the Kitt Peak National Observatory in Arizona (near Tucson), the Mohole project, and the Atmospheric Sciences Center in Colorado. With this type of support, scientific progress in a number of relatively neglected fields, such as astronomy and various branches of the earth sciences, notably oceanography, was greatly accelerated, and the development of pure science for its own sake became, and now is, an acknowledged instrument of U.S. national policy.

The individual scientist and organized endeavor. It is of interest to consider the effects of these changes on scientists themselves. These are manifest in a number of directions, but here I mention only two, which appear to be the most significant. The first may be described as a type of dilemma with which the individual scientist appears to be increasingly confronted. In earlier periods the role of the individual scientist stood out clearly, and while the magnitude of his contribution might occasionally be large, usually it was small, though still real and discernible. Each small contribution was a piece in a growing mosaic of knowledge of the particular field involved. As this mosaic grew from initially few pieces of data and information, and as the basis for their interpretation and correlation became dimly recognized, there was ample scope for individual initiative, and there was wide freedom of choice and of action. As progress in the field increased, the few individuals with greater insight helped shape the pattern of the whole and made it part of scientific knowledge. Much of this was a seemingly random and quite haphazard process.

To this somewhat inadequate description of science in earlier years should be added the description given by Langley in his presidential address before the AAAS meeting in Cleveland in 1888. He characterized the pursuit of scientific research as "not wholly unlike a pack of hounds, which, in the long-run perhaps catches its game, but where, nevertheless, when at fault, each individual goes his own way, by scent, not by sight, some running back and some forward; where the louder-voiced bring many to follow them, nearly as often in a wrong path as in a right one; where the entire pack even has been known to move off bodily on a false scent. . . ."

Whether or not either of these descriptions is an adequate picture of earlier scientific endeavor, it is clear that, in spite of limitations of support, facilities, and equipment, there was ample room for individual freedom of choice and for the exercise of initiative, ingenuity, and resourcefulness. Out of this situation developed what we all inherit and cherish as the great tradition of freedom in science and of communication in science, both nationally and internationally. This may be stated otherwise by saying that science is universal and knows no bounds of geography, race, creed, or nationality. Many attributes characteristic of scientific endeavor in earlier periods still hold for the sharply quickened and greatly expanded domain of today's science. Unfortunately, there are signs that as this domain grows further, as it becomes more highly organized, more programmed, and more directed toward national and other ends, and as its impact on our culture and society becomes more widespread, some of this traditional freedom will be lost. An obvious example of this trend relates to freedom of exchange of information, so essential to the progress of science. In World War II it was found necessary to impose a cloak of secrecy and classification on research in the developing field of nuclear physics—research which led to the release and utilization of nuclear energy. All agreed that this secrecy was necessary in wartime, and it was imposed under the Manhattan District Project. In the early days of the activities of the Atomic Energy Commission these restrictions were still dominant, and it was only with the passage in 1954 of the "Atoms for Peace" modification of the original Atomic Energy Act that some of them were removed or considerably relaxed.

This is one aspect of the so-called dilemma that many see ahead as the role of science becomes more important in modern civilization. Another, perhaps more important but more subtle, aspect can best be illustrated by an example from the field of chemistry. One of the great discoveries by Rayleigh and Ramsey at the end of the last century was that of the existence of the family of rare gases, the description of their properties, and the characterization of their chemical behavior. As these gases were studied further by many investigators, it became a tenet of chemical thinking that they were unreactive and would not combine with the other elements and compounds. So strong was this belief that, as theoretical knowledge of chemical reaction and chemical binding developed through this century, an essential element of each new theory of chemical bonding was that it should account for the supposed fact that these gases would not combine chemically with anything else. The first crack in this inviolate image came from the work of Bartlett, who demonstrated the combination of the rare gas xenon to form one of the components in a coordination compound of complex structure surrounding a central platinum atom. As often happens in science, the initial breakthrough was followed closely by others. Soon after Bartlett's discovery became known, further research and experimentation quickly destroyed this image that had dominated thinking in chemistry for some two-thirds of a century. The experiments leading to this final event need not be described in detail, but the circumstances under which they were undertaken are relevant. While I cannot claim to know these circumstances at first hand, the account as it reached me, and as it is given here, is from a source I believe to be authoritative.

Under the system in AEC national laboratories which provides for research participation by scientists from outside the laboratory staff, a young physicist from a small college came to carry on research for a time at the Argonne National Laboratory. In discussing his proposed program with those responsible for general supervision of the Laboratory, he said he would like to attempt to react xenon and fluorine at an elevated temperature. Since most physical scientists were convinced that the rare gases were unreactive, and since this reaction had already been tried in the Argonne Laboratory at ordinary temperatures, it is reasonable to assume that in the discussion that ensued doubts were raised about the wisdom of devoting the investigator's time and the resources of the Laboratory to the attempt. If such doubts were raised, at least they did not prevail, and it was agreed that the young physicist should go ahead with the attempt. The result was a spectacular, unanticipated discovery in the field of chemistry.

When a mixture of xenon and fluorine was heated in a nickel container to 400°C and then cooled rapidly to room temperature, a deposit of white, colorless crystals of the compound xenon tetrafluoride was found, and the long-standing belief that rare gases are inert was shown to be a myth. These events came to their culmination in the summer of 1962. On learning of this discovery, many investigators at the Argonne Laboratory and elsewhere went quickly to work and made other compounds of xenon and fluorine, as well as of certain of the other rare gases. As of the end of 1963, there is already an extensive literature relating to such compounds. In passing, and somewhat out of context, I might note that *Science*, in its "Reports" section [**138**, 136 (1962)] carried the first general news of this important discovery through a communication from the Argonne group dated 2 October 1962. Incidentally, the interval of 10 days from 2 October to 12 October, the date of the issue in which the report appeared (which carried a striking picture of the crystals of xenon tetrafluoride on the cover), probably constitutes an all-time record in the rapid communication of new scientific information through the printed word.

More in the context of the present discussion of the environment in which today's scientists work was a very timely and thoughtful editorial in the same issue (p. 75) by the editor of *Science*, Philip Abelson, entitled "The need for skepticism." The last paragraph of this is well worth quoting.

> There is a sobering lesson here, as well as an exciting prospect. For perhaps 15 years, at least a million scientists all over the world have been blind to a potential opportunity to make this important discovery. All that was required to overthrow a respectable and entrenched dogma was a few hours of effort and a germ of skepticism. Our intuition tells us that this is just one of countless opportunities in all areas of inquiry. The imaginative and original mind need not be overawed by the imposing body of present knowledge or by the complex and costly paraphernalia which today surround much of scientific activity. The great shortage in science now is not opportunity, manpower, money, or laboratory space. What is really needed is more of that healthy skepticism which generates the key idea—the liberating concept.

Of serious concern under present conditions of highly organized and programmed scientific endeavor is whether the freedom, initiative, and originality of the individual will still be able to emerge to play their important roles, so evident in the history of science in earlier periods. It is disquieting to speculate on what the ultimate outcome would have been, in the case cited, if it had been decided not to make the experiment. How long would it have been before the proper conjunction of circumstances occurred again—the individual with faith in his idea and skepticism of established dogma; a laboratory with chemists experienced in handling potentially dangerous fluorine reactions; and last but not least, a supervisory group willing to authorize the trial? Here the conjunction of events was propitious, and the outcome was a brilliant success. Unfortunately, or perhaps fortunately for scientific morale, as science progresses the number of instances in which the circumstances are not propitious is unknown. We can only hope it is small.

Specialization. A subject of much current interest is the rapidly increasing degree of specialization in science, which has paralleled science's growth and expansion in the past 35 years. Consideration of this is important, because of its implications for sound scientific education and also because of the common reaction of the lay public to highly specialized activity of any sort. Specialization in the most general sense is not new. However, when we consider the complexity of our own social structure—the profusion of implements, machines, instruments, and devices—and its specialisms of all kinds, we tend to think the latter are characteristic of, and even in a measure unique in, our society and time. A moment's reflection will indicate that such is not the case. The thoughtful citizen of the great ancient metropolis of Rome, with a population of nearly 2 million persons in the 2nd century A.D., must have been confronted with something of the same situation. The highly organized civilization of the Roman Empire must have required a high degree of specialization on the part of its citizens to provide its food supply, build its aqueducts and public works, and maintain its roads and the government of its far-flung provinces and colonies—not to mention the high state of development of literature and the fine arts. It seems clear that elaborate specialization, comparable in scope to our own, has been a characteristic of all great civilizations, especially those which were highly urbanized.

Nevertheless, it is desirable to consider briefly the nature of specialization itself, particularly that in the realm of intellectual endeavor. Here the intense concentration of an individual on a limited area of special knowledge and his attainment of expertness in his field tend to break the broad pattern of uniformity of the social structure. This is especially true in a democracy. The resulting separation of the individual from the stream of the common affairs of man tends to make the average citizen uneasy. Shaw put this feeling succinctly, in *The Doctor's Dilemma*, when he said, "All professions are conspiracies against the laity."

Much of the extensive specialization in the sciences has some features that can be most clearly delineated by the following comparison: "A salesman is one who begins by knowing a little about everything and who goes on learning less and less about more and more until he ends up knowing practically nothing about everything." On the other hand, "A specialist is one who starts off knowing a great deal about very little and goes on learning more and more about less and less until he ends up knowing practically everything about nothing."

For our present purpose the description of the salesman can be ignored. That of the specialist will bear further scrutiny. The difficulty lies in the common lay conception that what is small or restricted in scope and dimensions is simple, and in its limits amounts to "nothing." Here is one clue, and a very significant one, not only to the common negative reaction to specialization in general but to the general public's understanding of specialization in science.

Scientists, unlike the lay public, have the privilege of appreciating the accomplishments of a truly great specialist as he reveals fascinating glimpses of things to come, when, from time to time, there is a breach in the ramparts that bar us from comprehension of nature. These ramparts are long and formidably complex, as Vannevar Bush implied in his description of science as "the endless frontier." Rarely do they succumb to attack along a broad front; when they do, it is only through the work of a genius—and geniuses are rare in the human race. If science is to move forward, it will be increasingly important that the general public acquire a better understanding and some appreciation of the true nature of scientific specialization.

As we look ahead to yet unconquered areas, we may confidently predict that soundly conceived specialization in science will continue to survive and multiply. Historically, much of the effort in science has related to inanimate things, or to relatively simpler organisms or functions. As our growing knowledge permits us to move more firmly to studies of human behavior and of its psychological, biochemical, physiological, genetic, and other bases, it is possible to envisage new coalitions between psychologists, neuroanatomists, and neurophysiologists; as they grow, these coalitions may develop as specialties, as is the case for present-day biochemistry and biophysics.

With this prospect confronting us, we shall have to consider the negative aspects of the further growth of specialization and to constantly appraise its soundness. This will be especially desirable in developing sound principles to be followed in future education in the sciences. Here the danger is that the form may be mistaken for the substance. To illustrate the problem and not invoke invidious comparison, let us imagine some future specialty that we call neurobehaviorism, for want of a better designation. On what will the validity and worth of such a field, both as a contributor to our knowledge and as a field of endeavor, depend? First, it will depend on how well those in the field are versed in fundamentals of the relevant derivative sciences, such as neuroanatomy, neurophysiology, and neurobiochemistry. Beyond this, and of great importance, it will depend on how well they understand, or can acquire understanding of, principles from the underlying basic disciplines of psychology, mathematics, physics, chemistry, biology, and physiology that are relevant and applicable to the field in question.

By this criterion, the validity and worth of an area of specialization would depend on the firmness and clearness of the pathways from the outer branch to the deep, sound roots of available scientific knowledge. Perry relates an episode that occurred at Harvard in the 1830's, about Ralph Waldo Emerson and Henry Thoreau, which has point in the present context. The then-young naturalist, who was an intimate of the Emerson household, sat quietly in a corner one day while Emerson expounded to English visitors on education at Harvard, saying, "At Harvard College they teach all branches of learning." At this point Thoreau, to the embarrassment of his patron, blurted out, "Yes, but none of the roots." Without vital and continuing sustenance from strong roots, the branches of specialism will bear meager fruit.

Science in Our Modern Social Structure

Let us now turn to the fourth topic of this discussion of the fifth estate in the 1960's—the impacts of these changes in science on our current culture and the response and reaction of the latter to the change. I have already mentioned many of these changes and need not review them, but two additional ones deserve attention. However, before considering these let us look at a few figures for the sake of perspective.

Scientists and technologists have been, and still are, a relatively small minority group in our total population. In 1900 they numbered perhaps 90,000, representing little more than 0.1 percent of a population of about 76 million. Federal expenditures for science in 1900, similar to the federal expenditures for research and development of today, were about $10 million, or between 0.5 and 1 percent of the annual federal budget. The corresponding rough figures for 1963 are, 2.7 million scientists in a population of 190 million and federal R&D expenditures of $14 billion, which now require about 15 percent of an annual federal budget of the order of $95 billion. Thus, scientists, though their number has increased 30-fold since 1900, still comprise a relatively small part, about 1.4 percent, of the total population.

Effects of the drain on federal resources. It is important, first, to consider some of the consequences of this increasing drain on federal resources that is caused by the recent, almost exponential growth of science and technology. Since federal revenues grow at a much slower rate than the economy does as the economy advances, it is obvious that some adjustment in the growth rate of federal expenditures for science must take place. Indeed, this is already occurring, as is evident to anyone who has followed recent hearings before Congress relating to the expenditures for science projected for the next annual federal budget.

One aspect of this adjustment poses a new and serious type of problem that scientists have not faced previously in any substantial measure. With limitation necessary, on what principles is the assignment of priorities to projects in the various fields of science to be made? What are the relative merits, both in a scientific sense and from the standpoint of the national interest, of a new, large accelerator for nuclear physics, costing perhaps $100 million for its initial construction and about a third of that amount for its annual operation; of the Mohole project for drilling through the earth's crust, variously estimated to cost between $50 million and $100 million; of the expenditure of similar sums annually for biomedical research on cancer or the diseases of the heart; and of landing a man on the moon by 1970, at an estimated cost of over $5 billion? There are no clear guidelines on which to base such priority decisions, and their formulation will require a higher order of statesmanship among scientists and those in the upper echelons of government than has existed heretofore.

Effects on health. The rapid growth of science has had a second type of impact on society in our greatly expanded technological and industrial civilization. This growth has been so great that it has already begun to alter man's traditional natural environment. The emerging problems involve such things as air and water pollution, radiation hazards, occupational hazards, and contamination of milk and food supplies, which are now classed under the general head of environmental health problems.

Several years ago I was asked by the Surgeon General to head a committee of 24 members from widely diverse scientific disciplines. The group was to analyze and survey the problems in the environmental health area and to make a 10-year projection of the nation's needs for scientific research relating to environmental health and of its needs for trained manpower to deal with the problems.

These problems are varied, complex, and serious. They range from the provision of adequate sewage disposal for large and growing metropolitan districts to the recently noted higher level of radioactive contamination of caribou meat, which is an important part of the diet of Eskimos in northern Alaska.

The origin of the high levels of radioactivity in caribou meat was relatively simple to trace and understand, though not necessarily easy to control. Certain lichens on which caribou feed were found to absorb relatively larger amounts than most plants of the radioactive trace elements which the soil had received from the debris of fallout.

A simple illustration relating to the matter of sewage disposal in large metropolitan areas will show the complexity of many of the problems involved in environmental health. A number of years ago, in order to handle its sewage disposal without contaminating Lake Michigan, Chicago built a drainage canal in which water from the lake ran across country to empty into the Mississippi. The sewage effluent from Chicago was fed to this artificial running stream. The dilution of the effluent by water from Lake Michigan reduced its concentration to the point where the organic sewage could be oxidized effectively by the dissolved oxygen in the canal waters, and well-purified water was delivered to the Mississippi. As the city expanded industrially, steam plants were built along the canal, and these discharged warm water from their condensers into the stream. Ultimately, the effect of these additions of warmer water was sufficient to raise the average temperature of the canal water by some few degrees throughout the year. With this development the phenomenon technically known as "heat pollution" became operative. Simply stated, the higher temperature reduced the concentration of oxygen in the water, and therefore the capacity of the flowing stream to oxidize the organic matter present. As of several years ago this "heat pollution" had reached such proportions that its effect on the sewage disposal problem of the Chicago area was estimated to be equivalent to the effect of adding a million people to that metropolitan area.

These are but a few examples of the many effects on the economy, on health, and on various aspects of our culture and society of the greatly increased endeavors of scientists. What has been the reaction to these great changes occurring in little more than a quarter of a century? Here two things are relevant—the status of the general public's knowledge of science and its methods and, even more important, the image in the public mind of the whole modern scientific enterprise. A realistic appraisal of these two factors does not give much ground for thinking that the public has a sound comprehension of science.

The nonscientist's view of science. For the great majority of our people, formal education terminates with high school. Sober reflection about our educational system, after the launching of Sputnik, clearly revealed the woeful inadequacy of the science education of most of our people as a basis on which to build any real understanding of modern science. Since Sputnik, real improvement has been made in science teaching in many of our lower schools, but the effects of this in the adult population will not be evident for another generation.

Given this lack of any sound comprehension of science, what picture can be drawn of the image of science in the public mind? This image is difficult to describe, for it is compounded of many diverse elements. These include respect and gratitude for the "miracles" of modern medicine; admiration for the know-how of applied science which can put satellites in predetermined orbits; and awe, verging on fear, of the results of the mysterious release of nuclear energy. Two events in our time must have contributed greatly to the building of such an image, since the public, as well as most scientists, had no warning and little preparation for their advent. The first was President Truman's unheralded announcement of the dropping of the atomic bomb—a spectacular but terrible demonstration of the power of modern science. The second was the sudden news, one day in October 1957, of a second satellite orbiting our planet. This was Sputnik, the first of a growing family which later included Echo I—a "star" whose rapid course across the night sky could be easily followed with the naked eye.

What is the significance of this image, and of this lack of real understanding by the general public, for the future of science and scientists? Some already feel that scientific endeavor must be controlled and circumscribed if it results in pollution of air and water, in contamination of food with pesticide residues, in the hazards of radiation and the development of nuclear weapons. Still others, left ever farther behind in their understanding of rapid scientific advance, take refuge in a polite, but neutral, type of anti-intellectualism toward all scientific activity. The emergence of attitudes like this among nonscientists is the basis of Snow's discussion of the Two Cultures, and of his warning that the rift may grow wider unless the trend is checked.

Conclusion

Faced with these possibilities, what should we, as scientists, do? We are in some sense a privileged minority group, and all of us should be ready to exercise the grave responsibility which we all share, "to increase public understanding and appreciation of the importance and promise of the methods of science in human progress." These words are quoted from a statement of the objectives of this Association. A second objective of our organization is "to improve the effectiveness of science in the promotion of human welfare." These two should be the articles of our scientific creed in the years ahead. Furthermore, as scientists we should not lose our perspective but should recall the history of science and remember that it has survived pestilence, wars, and disaster and has surmounted barriers of race, religion, and language. Beyond this, it is even more important to recall, in a gray period of international tension, that all members of the human race, throughout its evolution and long history, have had a common opponent. This is inscrutable nature with her seemingly inexorable laws, her hosts of organisms and parasites, her hurricanes and catastrophic events of all kinds. For our human race the central problem is still that of understanding nature and attempting to control it. Here the thinking and tools of modern science have a great contribution to make. May we use them well.

Much of what I have said of warnings, of impacts and reactions, and of grave concern may have the ring of pessimism for the future as science moves swiftly ahead in one of the great adventures of the human mind. That this is not my intent can be made clear by a closing quotation from Carlyle's great satire *Sartor Resartus*. In this he attributes to his fictitious author, "Professor Teufelsdröckh of Weissnichtwo," these words, in the promethean spirit of which I share: "Man's unhappiness, as I construe, comes of his Greatness: it is because there is an Infinite in him, which with all his cunning he cannot quite bury under the Finite."

Growth and Development of Cultured Plant Cells

Biochemical and morphogenetic studies with cells yield new evidence on their metabolism and totipotency.

F. C. Steward, with M. O. Mapes, A. E. Kent, and R. D. Holsten

The rapid advances in molecular biology (perhaps more appropriately called the chemistry of biologically important compounds) have rightly focused attention upon the DNA of the nuclei of cells and upon its various derivatives expressed as RNA's of the cytoplasm (see *1*). The roles of the nucleic acids in maintaining the constancy of self-duplicating structures and in transmitting likenesses from cell to cell, or from generation to generation, are fundamental concepts of modern biology. Impressive as all this is, it should not obscure the fact that, despite all that has been learned about the apparatus in genes and in cellular organelles which prescribe cellular capabilities, there is a great deal yet to be learned concerning the means by which these potentialities are either evoked or suppressed.

The fertilized egg of a flowering plant was originally thought of as a unique cell, maintaining continuity from generation to generation, while the elaborate apparatus of the embryo sac and of the ovule was regarded as necessary to foster division of the zygote and early development of the plant. But, if each cell of the plant, derived in lineal descent from the zygote by equational division, has the genetic complement which is necessary to produce the whole organism, then, it appears that the zygote is not unique and the environment of the embryo sac may be replaced.

However, the facts of morphogenesis and differentiation indicate that diploid cells in a plant do vastly different things with what is presumably the same genetic information. The capacity to divide may be inherent in cambial cells of trees for over 4000 years, even though this capacity is expressed only intermittently. Some derivative cells of the cambium rapidly lose their protoplasmic contents and die as they differentiate; others, closely adjacent, remain alive, although quiescent, and fulfill their role as living cells in the plant body.

There must, then, be some mechanisms of control, some obvious restraints, which allow cells in the plant body to do only a small fraction of that of which they are capable. To explore these problems of regulation one must recognize that cells have organization vastly above the molecular level; one needs to know how cells, as integrated structures, are constrained to function as they do.

One should look to more complicated systems than those which it is now fashionable to study. Studies of the ribosome or the virus particle, even of the gene-enzyme-protein sequence, cannot provide a complete explanation. The individual cell becomes the lower limit of organization in terms of which these problems should be discussed, for it is the cell which divides, which grows and differentiates. And, freely suspended, single cells may give rise to whole organisms. Simple molecules may transmit the stimuli which evoke

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