SCIENCE ON THE MARCH

By Frederick Seitz

THE various civilizations of mankind known to us are characterized both by remarkable similarities, stemming from the common problems of humanity in all environments, and by quite remarkable differences, related to differences in culture and environment. The differences may be of secondary importance, or they may be so important that they determine the fate of a given civilization in a major way.

Except for a brief period of expansionism at the time of the Han Dynasty, coincident with the Roman era, Chinese civilization has been characterized by an introspective or isolationist character. It is true that the Chinese "discovered" Persia and the Mediterranean world, and probably even Australia, and that they entered into extensive trade with foreign regions. It is also true that China was conquered by outsiders several times and, hence, was subject to outside stimulus. Nevertheless, the indigenous culture remained essentially isolationist until the very recent past. This trait of Chinese civilization has done much to help the people preserve unity and continuity for nearly 5000 years. On the other hand, it has prevented them from being colonizers on any major scale. One can well imagine what the status of North and South America would be at present if the Chinese civilization had been more extroverted in the past.

The ancient civilization of the Greeks, particularly the Athenian phase, placed enormous emphasis on the individual. The talented and individualistic young man with a highly trained body and an imaginative mind was the prototype of the ideal in early Greek society. This pattern of civilization led to an almost unparalleled artistic and philosophic development. Whatever the political weakness of the Greeks may have been, their unique emphasis on the development of the individual made Greek culture and, in fact, the Greek community a powerful force in the Mediterranean era long after the political institutions of Greece had decayed.

The Romans placed enormous value on organization in their civilization, particularly in military, political, and legal affairs. This quality of the civilization not only assisted in the establishment of the Roman Empire, but brought sufficient order to a chaotic Mediterranean world that even the conquered peoples were, for the most part, willing to assist in maintaining the Empire. Even the invaders from the north hoped to preserve the Roman institutions when they conquered Italy.

Except for a very brief period of Empire, the pre-Christian Hebrew civilization was characterized by an essentially unique emphasis on religious and spiritual matters. There is scarcely a population group which has enjoyed communication with this religious development that has not been affected profoundly by it.

The Christian West

The civilization of the Christian West has been characterized by two quite different and consecutive phases. The first, which extended from the fall of Rome to about the 14th century, was highly isolationist; the second, which has endured since, has been as nearly the opposite as it could conceivably be.

The rapid rise of the Arabs, inspired by Mohammed, bottled the northern Europeans in their own lands. Communication with the Mediterranean was essentially limited to that with an equally enlocked Byzantine Empire and a greatly impoverished Italy. Communication with the remaining world became almost negligible. In this phase of its history the Western World turned inward and devoted most of its attention to the cultivation of religion and to the more mundane issues of everyday living. There were several remarkable developments. Among them were the rise of the monasteries, with the attendant scholasticism, and the evolution of an economic system that did not rest upon slavery. However crude feudal society may appear to us now, the feudal bondsman felt that he was an integral part of the society in which he lived and that he was tied to it by something other than the chains of slavery. One of the most remarkable facets of this stage of the

Frederick Seitz, head of the Department of Physics at the University of Illinois and the recently elected president of the National Academy of Sciences, presented the address upon which this article is based at a convocation of science librarians at the Allerton Institute of the University of Illinois during the winter of 1960-61.

evolution of Western society was the encouragement given to the invention of devices and processes to increase the production of the farm and factory. Technology had begun to advance after the long period of stagnation that had started soon after the Roman Empire reached its peak.

Once the Arabs began to weaken in the thirteenth century (and many factors contributed to their collapse) the outlook in Western Europe changed quite rapidly, for opportunities opened for exploration and expansion. Ultimately, the dominating spirit became the one that we associate with Henry the Navigator rather than with the traditional recluse in the monastery. What is perhaps even more remarkable, the new prototype of leader was not willing to recognize any arbitrary limitation in his quest of the knowable. He was prepared to explore and use all of the world of mind or matter available to him. This had not happened to mankind since the days of the early Greeks. The new outlook was backed not only by a respect for scholarly knowledge that could be traced to the scholarship of the monastery but by an intense interest in practical affairs, including everyday matters of technology. The new quests attracted the curiosity of even the most brilliant minds, which proved willing to grapple with both the practical and the abstract problems which arose. No detail was considered to be too menial to deserve attention. This concern with inventiveness at even the mundane level soon began to bear rich fruit.

In a word, the West abandoned its introspective mood and began to examine and exploit the material world about it in a wholesale fashion. Moreover, Western society had the combination of intellectual and practical attributes which would make it possible to develop what we now call science.

It is very important to realize that the development of science required more than the philosophical or the practical mind alone, but depended upon a happy combination of the two. At their prime the Greeks had all of the philosophical depth one could hope for, but their leading minds lost interest in the practical once the more routine tasks of society were turned over to slaves. Conversely, the Romans had a rich appreciation of the practical, but lacked the philosophical interest required to probe for guiding theoretical principles. The uniqueness of Western civilization at the height of the Renaissance lay in the fact that it combined these attributes in a way that gave respect to both.

During the first three centuries of the development of science, say from 1500 to 1800, there is little doubt that the applied or technological aspects provided a richer harvest from the standpoint of practical gain than the theoretical, or fundamental, ones. It is true that the knowledge represented by the discovery of the laws of mechanics, the law of gravitation, and the laws of optics had its uses. However, the first great value of this knowledge lay in the fact that it demonstrated to the intellectually curious that there is an underlying order and regularity in nature. It seems safe to say that in the early stages of the development of science the intellectual value of the knowledge gained was probably much greater than its practical worth.

All of this changed in the course of the nineteenth century. By the middle of the twentieth century it can safely be said that fundamental science is well on the road to becoming the dominant force in determining not only the course of technology but the dynamics of our society. Any group of national leaders which does not appreciate this principle at the present time will encounter great difficulty in dealing with the tide of events in the future.

There are many ways of demonstrating the manner in which science has gained ascendancy. The electrical communications networks in use today depend upon ingenious combinations of electromagnetic radiations and atomic devices. While certain indispensable aspects of these systems have developed as a result of painstaking trial and error investigation requiring the work of skillful technicians, none would have been possible were it not for discoveries made by individuals who were primarily interested in understanding natural phenomena for their own sake. Probably none of the individuals involved was even reasonably close to guessing the practical importance of the world they revealed.

Several years ago when the University of Illinois was applying to the Federal Communications Commission for a broadcast channel with which to televise educational programs, the appropriateness of the application was challenged by an individual who asked by what right a mere university should be awarded such a commercially valuable item. The answer was, of course, clear to any scientist: the right lies in the names of Coulomb, Faraday, Weber, Maxwell, and Hertz, without whom radio and television would have been beyond practical conception.

Similarly, the controlled release of atomic energy, which promises so much for good or evil in the immediate future of mankind, rests primarily on discoveries which had far more meaning to the inquisitive scientists than to the practically minded individuals at the time they were made.

It seems safe to say that the overwhelming fraction of the advances in technology which will take place between now and the year 2000 will rest at their base on discoveries made in a quest for knowledge quite removed from immediate practical considerations. It should be added in haste, of course, that most of the discoveries will be possible only because of the timely development of equipment which depends enormously on the evolution of technology. Science and technology are very intimately wedded now. Neither one can flourish in the future without the other.

The Organization of Science

It is interesting to consider the changes in the organization of science which have accompanied its growth toward major importance in determining the course of affairs of the everyday world.

During the earliest period of science, let us say up to the beginning of the nineteenth century, scientists were few in number and were exceptionally individualistic. Moreover, they were tied into society in diverse ways. Many were independently wealthy and carried on their investigations as independent gentlemen. Some were attached to courts or to special offices of government. Such were the royal astronomers. Newton spent the latter part of his career as Master of the Royal Mint. A few were attached to universities, but such cases were almost the exception rather than the overwhelming rule. Our own Benjamin Franklin, the first really distinguished American scientist, was a man with a myriad of positions, but I doubt if he was ever a university professor.

The university became the home of science in the last century as a result of a movement which started in earnest in Central Europe, particularly in Germany. Here the academic institute of science with its laboratory, its library, its head and his disciplined assistants, and its enthusiastic students began to be commonplace. This organization proved to be so superior for attacking the problems of science that could be solved in the period between 1850 and World War I that it came to be the dominant one in the world of science. This is not to say that excellent research was not carried on outside universities; however, the overwhelming fraction of the most brilliant work emerged from universities after 1850.

The United States had great difficulty in establishing itself as a truly scientific nation until after World War I. When it did so, it introduced an important innovation into the organization of science—namely, the large university department of science.

The reason for the long delay in maturing of science in the United States provides an interesting subject of speculation on its own. Perhaps above all, the United States was primarily interested in practical matters before World War I, and was not willing to cater to the needs of its own scientists when the practical results could be imported from Europe so easily. In addition, our education tended to be slanted toward the everyday problems of an undeveloped nation with a moving frontier. All of this changed in the twenties and did so with remarkable rapidity. The change came about, of course, only because our country developed a genuine interest in science. Fortunately, the basic education had always been sufficiently good that those who emerged from it were not disqualified from becoming scientists, particularly if they were willing to spend a period of two years or so receiving a final polish in the best institutions in Europe.

Beyond the awakening of interest, the feature which made development in the United States so fast was the ability of the academic structure to absorb large numbers of individuals of closely comparable age and training. In order to suit the needs of mass education, the American university had in the nineteenth century developed the concept of the large department. In this unit a number of individuals concerned with overlapping aspects of the given area of science cooperated in lecturing on the essential topics into which the field could be divided. While there might be a chairman who had more or less distinction than his colleagues, most of the senior members of the department usually enjoyed similar rank and were prepared to work in relative harmony. This organizational unit was quite different from the European institute, which tended to have a single dominant leader who controlled it fairly completely. Once the United States started to take science seriously, most departments found themselves in a position to hire a number of young men of comparable age who shared similar understanding. This led to the evolution of the scientific team, which saw its flowering in the 1930's.

The emphasis on teamwork in science paid enormous dividends to the United States during World War II when the idea was brought to its logical climax by the formation of large laboratories composed of a number of teams which worked together on different aspects of one or more major problems. All members shared the joys and disappointments of the work much like a large family shares the ups and downs of its members.

It is interesting to note that the majority of the laboratories were attached to universities, probably because most of the members originated in universities and were more willing to work in an organization which they considered to be a simple variant of the normal academic pattern than in an industrial or governmental laboratory. This is not to say that the industrial and

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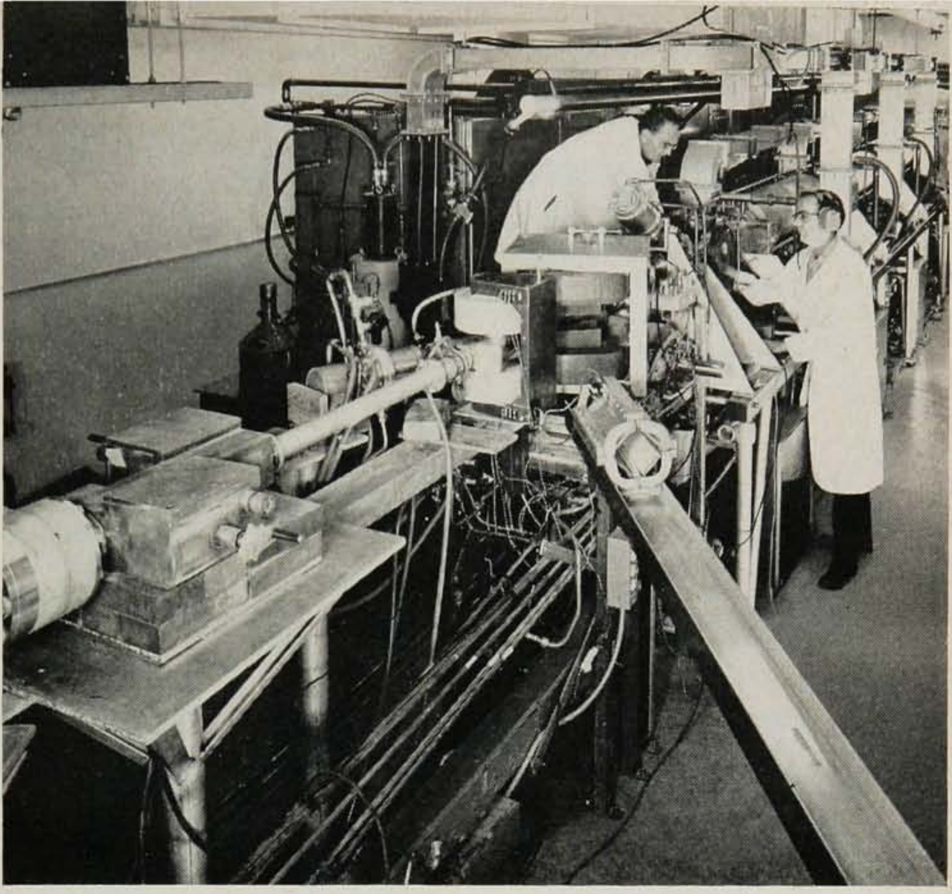

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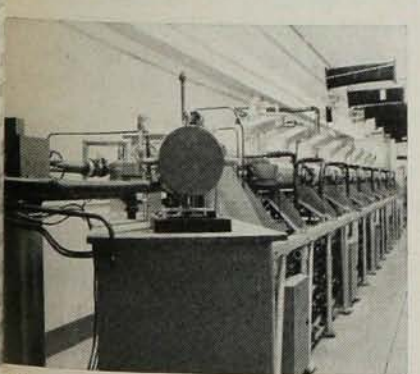

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governmental laboratories did not play a highly important role during the war, for the converse is the case. What is emphasized here is that in the main the concept of teamwork in science has evolved most rapidly and most effectively through university channels during the past forty years.

It now seems clear that whatever defects team enterprise may have because of the de-emphasis of individualism, it is far more effective in producing new results consistently than the old-fashioned European institute can be at the present time. It seems safe to say that the nations which value the fruits of science and which desire to have productive groups within their borders will have to adopt the American system or a variant of it.

Western Europe obviously was left behind the United States by the wartime development. Only the British had a direct hand in the most productive research. Unfortunately, their academic system was deeply entrenched in the past and responded only slowly to the many new ideas developed during the war. Happily, the British have now come to recognize the issues at stake and are making modifications which preserve the features of their own system that they value most. It is not yet certain that this compromise offers as effective an organization for producing science, but there is no doubt that the British will retain a position among the leading nations in science in the next generation.

France remained rather quiescent until a few years ago, relying upon inadequate traditions that dated to a period before World War I. The wise leaders within the country realized that there was a need for a reform; however, the rapid turnover in the national government, which has the primary responsibility for innovations, did not permit appropriate legislation to be enacted. Fortunately, the relatively stable conditions which have existed within European France since the summer of 1958 have made it possible for the French to make many important changes. They are developing new laboratories where teamwork is possible and are expanding the number of positions in the academic circles. It will require another generation to see the fruits of these changes. If all of the plans now being made actually are realized, France will probably emerge in another decade or so with a highly expanded body of young and creative scientists and assume a strong position in international science.

There is evidence that a somewhat similar development is taking place in Italy. Unfortunately, Italian industry is less highly developed than that in France or England, so that there is neither the wealth nor the diversity of technical enterprise to support a broad development of science.

For a variety of reasons, Germany has been less willing to accept innovation in the organization of science than any of the other technically advanced western nations of comparable size. The universities and related research centers still rely primarily upon the institute system which developed nearly a century ago. Both industrial and other nonacademic governmental

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The growth of this branch of photography proves it was just what the space age was waiting for; the reduction in weight of the age's playthings without sacrifice of strength is but one aspect of photography's importance as the newer kind of fabrication. The changes it has wrought in the whole art of electronics are now recognized in financial circles as profound. If it has gone that far, readers here addressed will have doubtless passed some time ago the stage of wonderment at it all. Nevertheless, guidance on technique may still be badly needed.

The new book doesn't so much guide as inform. (Let your conscience be your guide, assisted by a lawyer who closely follows the patent situation proliferating as a result of industry's heavy investment of brainpower in the field. Most important firms are reasonable about licenses.) The book brings together a lot of hot tips on preparing the many kinds of substrate, applying our various resists, preparing the coatings for exposure, developing them, choosing the proper etchants or electroforming solutions for use with stainless steel, glass, gold, germanium, etc. As for the strictly photographic information contained, we offer suggestions for determining correct exposure, where "correct" means maximizing the tolerances in all other steps of the process and has nothing to do with photography's traditional interest in tone reproduction.

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research laboratories focus attention on applied work. One suspects that the years lost between 1933 and 1945 lie at the heart of the difficulty. At the end of the war, the academic leaders, who were mainly older men, were anxious to shake off the political interference that they had had to countenance during the period of national socialism and, hence, turned the clock backwards to the best era they had known, namely, that before World War I. Neither the university leaders nor the government has yet gone very far in challenging the present state of affairs. Unfortunately, the present system does not permit Germany to absorb its product of young scientists into positions of appropriate responsibility and prestige. As a result, there is a steady loss of scientists to other western countries, particularly the United States.

In spite of the difficulties which science faces in Western Europe, it has one significant advantage which may compensate for the present difficulties in the course of time. In brief, specialization in science or technology is regarded as a thoroughly respectable pursuit in present-day European society. There may be splits between the classicists or the humanists and the scientists or engineers in individual academic institutions, but these are highly localized phenomena and do not affect substantial groups of populations or of leaders within the nations.

In contrast, there are significant segments of the American population which regard the pursuit of science or engineering as either queer or drab, or both. One can only pray that this trend is transitory and will soon vanish. Many of my friends in Ivy-League institutions state that substantial numbers of the brilliant students who enter with the intention of having careers in science or engineering are diverted by complex pressures that originate in social factors. Our country could pay a heavy price for such losses.

The Soviet Union

So much has been said about the attention being given to science and engineering in the Soviet Union that it is hardly necessary to dwell on the matter here. Suffice it to say that there are two major careers for the intelligent and ambitious person in the Soviet Union at the present time. He may become an active party member and, hence, an important individual in the organization of the government, or he may become a scientist or engineer. The Soviet equivalent of the man in the gray flannel suit falls in one of these two categories. At the present time, the number of scientists and engineers being trained in Russia is at least comparable to the number in the western nations. Since the Soviet leaders are interested in mass education, it is clear they hope to produce far more scientists and engineers than we in the coming generation. If the quantity is matched by quality, it would appear that the Soviet Union will eventually take the leadership in science and technology from the West. We cannot afford to let this situation go unchallenged.

The Financing of Science

It may be of interest to comment briefly on the financial outlay for science and technology at the present time. The United States is currently spending about two percent of its gross national product in the fields designated as research and development. Research is concerned with the discovery of new principles, whereas development is concerned with transmuting these principles into practice. One needs both aspects to convert knowledge into useful form in the ultimately practical sense.

Actually, development now takes a lion's share of this expenditure. Only about five percent of the total, that is, about 0.1% of the gross national product, goes into research.

It is difficult to know to what extent the combined fractional expenditure on research and development could be increased. Much depends upon the state of society. Perhaps I might put the issue in the following way. Under normal circumstances, the average individual is willing to accept a major innovation in a typical feature of his material life in a period of ten or twenty years. In fact, he has come to anticipate changes of this type at a rate to which he can adapt. It is true that there are certain areas in which he hopes for more rapid innovation. This is true, for example, in the field of medicine. However, he does not want to live in housing that changes rapidly and radically or to drive a radically different type of car every year or two. He is satisfied with changes that represent a significant total once every ten or twenty years. This means that he is probably prepared to pay on the average something near or about one percent of his total income for innovation. Five or ten percent might seem high. The facts show that he does accept two percent at present.

Of course we must recognize that about half of this two percent is for research and development of military interest. Here, as is the case for matters affecting health, the citizen is probably willing to pay a much higher premium for innovation than he is for matters such as communications. In fact, it is clear that the nation would be willing to pay a very large fraction of its gross product for innovation in the event of dire peril. Values such as twenty or thirty percent would not seem preposterous in wartime, provided they would appear to assure survival.

I am inclined to believe that the present fractional investment of public wealth in research and development for matters other than those affecting national survival probably is close to the upper limit which we might expect. Obviously, one must be cautious in making such a statement for it is conceivable that advances in science might have such public appeal because of the enhancement of national prestige or for cultural reasons that society would be willing to make a substantially heavier investment.

Unfortunately, our survival is now so intimately associated with the over-all progress in science that it is next to impossible to assess the relative merits of any

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given limit of support in a detailed way. Under the present circumstances, the Western nations have no choice but to do their all-out best in science. Nothing less is really practical.

It may be noted that there is no fundamental reason why only five percent of the national budget for research and development is spent on research. Development usually is costly for two reasons. First, it involves massive equipment, which is naturally expensive. Secondly, it may involve costly trial and error investigation made necessary for lack of precise knowledge. There undoubtedly are many fields in which more emphasis on research would cut the cost of development by substantially more than the cost of the research. Usually, in such instances, the waste arises not from lack of interest in research, but from the lack of talent to carry it through competently. This limitation on manpower represents the greatest bottleneck in our technological development at the present time and is one of the reasons why the fraction of brilliant minds devoted to science and technology should grow in the future.

It may be added that Great Britain and the Soviet Union are now investing about the same fraction of their gross national product in research and development as the United States. It is exceedingly difficult to get precise figures from the Soviet Union. However, there is little doubt about the general level of the support at present. The continental nations of Europe have, for the most part, a substantially lower fractional support. The French Government, which is undertaking a systematic survey of its own scientific potential, is completely aware of the problem in the sense that the issue is discussed openly and intelligently in the press. It seems likely that France will close the gap within the coming generation.

What of the Future?

Only a foolish individual would speak dogmatically about the future course of science. Nevertheless, some comments are in order. It is quite likely that the very great state of international tension in which we live will dictate the major course of scientific investigations in the foreseeable future, much as was the case during World War II. Any alternative course is almost certain to have suicidal consequences if there is no genuine relaxation of international tension.

Let us forget military matters for a moment and attempt to regard the problem of the future of science in a more dispassionate way. As one examines the many fields of pure and applied science, one sees no evidence that any given major field is reaching a limit through exhaustion of the knowable. Each advance in knowledge of nature serves to increase the profoundness of the questions which can be asked about the unknown. In fact, nature appears to be inherently so much more complex than the body of riddles which man seems capable of solving that one would gain the impression that the scientist is pursuing the end of the rainbow if it were not the fact that the harvest of information he already possesses is so exceedingly valuable.

Consider, for example, the quest of the physicist into the atomic world which began toward the end of the last century. Each victory has opened up another vast doorway into a world that could be explored appropriately only by increasing the effort of exploration several fold. As matters stand at present, I believe that it is safe to say that we are now passing into an era where a world-wide expenditure of the order of $500 million per year in the field of high-energy physics alone is warranted, if we are to explore this field at a rate which makes sense from the scientists' point of view. There is no reason to believe that the results of these investigations would close down the field because intriguing new problems would be exhausted. Rather one expects that still another vast world would be revealed in the process.

I believe the same principles are valid in all of the major fields of science. We need only look at the area of investigation opened up by the study of viruses or of biochemistry, for example, to know that the biological sciences are faced with an essentially inexhaustible universe for study.

Unfortunately, the essentially limitless opportunities for valuable basic research which do open up are accompanied by a very steep rise in the cost of the investigations. I believe that the restrictions that have been placed on the expenditures for really basic research in the United States from time to time in the past have not been founded on completely realistic analysis. They stem primarily from the lack of universal understanding of the practical value of science to modern society. You will recall that only about 0.1% of our national product is spent on basic research. Nevertheless, we probably shall reach a point in the not too distant future when the costs in money and manpower required to explore all available avenues of fundamental research will become prohibitive. I am inclined to set the date about twenty years hence if the world avoids war and returns to a less tense state. I would not attempt here to set a monetary figure on the limiting budget for research since the factors involved are far too uncertain. However, I am guided by the fact that the fractional expenditures for research are increasing with time at a faster rate than our national income.

When the period of limitation is reached, research will not stop. In fact, the expenditure will probably seem lavish by present standards, being perhaps ten times greater in terms of fraction of the national income. Nevertheless, there will be a need to appraise the areas of investigation very carefully, using whatever standards society may decide to establish. Viewed from the standards of our time, this appraisal will probably require more arbitrary and, hence, more difficult decisions than any judgments which are made concern-

ing the distribution of funds for research and development at the present time. At present, these judgments are based primarily on estimates of the value of the ultimate applications of the work. Since the amounts spent on the most fundamental work are still so small, almost any reasonable program of a basic kind made by competent individuals can expect support in the course of time. In the period in the future, of which I speak, society will have to decide which aspect of man's innate curiosity concerning the world about him deserves priority. Fortunately, these are problems for another generation which will approach them with its own terms of reference.

The general conclusion we may draw is that science will grow for at least another generation both on an absolute scale and relative to applied work whether or not the present world tensions relax. The emphasis will be different in the two cases, but the growth will be along a very broad frontier in either event. One may anticipate that the growth in importance will be appreciated in a general sense by the public.

The problems involved in correlating and disseminating scientific information will become even greater during the coming years both because of the rise in sheer quantity of material and because of the higher degree of specialization of individual programs in the various fields of science. Much of the product of science will appear in the traditional research journals of the various professions. Personally, I prefer to see these grow in size rather than to see a proliferation in the number of journals. Actually, it appears that both types of increase are fairly inevitable because of the lack of planning. Speaking again at the purely professional level, I have, for a number of years, advocated the principle that, parallel to the growth of the volume of scientific literature, it is essential to expand the development of review journals and books. These should be written by the most competent individuals in the fields and be edited with great care. This idea obviously is not new since we have had good review publications for many years. It seems evident, however, that the development will become increasingly more important as science becomes of age.

The means whereby the public should be informed of the course of scientific research represents a very intriguing problem. It seems obvious to me that the average individual can at best be profitably interested only in the broader and most general conclusions of science and then possibly only in the most dramatic areas. I am not one who feels the general public will ever show a profound interest in the detailed progress of science. Speaking generally, the details can be appreciated only by the highly trained mind which has become quite expert in a given field.

Perhaps the greatest hope for providing public information is that the great and articulate minds of science will devote some of their time to the task of apprising the public of the progress in science by both the written and the spoken word.