# THE CHALLENGE OF SCIENCE AND TECHNOLOGY

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**Here are some of the changes the science and technology of tomorrow may bring — and what we can do today to encourage these changes and insure that they will be for the best**

SCIENCE AND TECHNOLOGY have become so intertwined during the past few years that today we face the rather curious situation that many people—far from thinking of science and technology as two separate and distinct disciplines—are now inclined to regard the two as different forms of the same thing. Before we can understand the challenge of science and technology we must understand something of what science is and what technology is and in what respects they are alike and in what essential respects they differ.

First, what is science? It is easier to recite first some of the things that science is not. Science is not the development of new weapons of war. It is not the development of new or improved industrial products or processes. It is not even the discovery of new cures for human disease. Science is not the development of any device or technique. Science is simply knowledge. The goal of scientific research is to discover new facts and principles concerning the behavior of the physical world. The eventual goal of science is to build a conceptual framework of the physical world, a system of well established theories, if you wish, on the basis of which one can understand and interpret natural phenomena and can also predict what future events will occur under specified conditions.

This ability to understand and predict has during the past two centuries reached a high stage of perfection in certain areas of science. The laws of celestial mechanics are so exactly known that, for example, eclipses of the sun can be predicted with a high degree of precision for centuries to come. Quite adequate precision of prediction is also possible in great areas in the fields of mechanics, optics, electricity, and in certain fields of chemistry. However, as we enter the areas of more complex phenomena of organic chemistry and the biological sciences we find that we are only at the threshold of an understanding of the phenomena which take place here. The investigations of the past few years have shown pretty clearly that the first problem in these fields is the understanding of the nature and behavior of complex molecules. It is exciting to visualize what important progress can be made in this area in the coming years if suitable efforts are devoted to it. The basic techniques are now at hand so that an adequately extensive research effort may cause our knowledge to grow in snowball fashion.

But the point to be emphasized is that in all fields of basic science the goal of research is further understanding. The object is not to invent but to comprehend.

Now, of course, the goal of technology is very different. Each individual technological research project has as its aim the development of a specific device or technique which will be of practical use. In the days before the development of the scientific method technology proceeded largely by the trial-and-error method. The sum total of the achievements in the practical arts which were attained by human beings by this method over thousands of years of technological efforts is impressive indeed and culminated in the magnificent achievements of Edison. But the rate of progress during the past hundred years has been fantastically higher than that of any previous era, to the extent that in such fields as the development and use of power and in the fields of transportation and communication more progress has been made in the past fifty years than in all the previous thousands of years of human experience.

It is the interaction of science with technology which has made possible this accelerated rate of development. This interaction is of two forms. In the first place, the discovery of new phenomena and new laws in the field of science has given rise to new practical applications. The abstruse theoretical studies of James Clerk Maxwell on the nature of light and of electricity led to Hertz' experiments which uncovered the existence of electromagnetic waves. These discoveries stimulated the brilliant Marconi to establish a whole new area of technology which has given us among other things modern radio and television and radar.

The discovery of the laws of electromagnetic induction by Faraday eventually gave rise to the modern electric power industry and all of its ramifications. The discovery of the basic laws of thermodynamics by Carnot, Joule, Kelvin, Helmholtz and others made possible the many modern forms of heat engine, including the steam engine, the internal combustion engine, and now the jet engine and the gas turbine. Pioneering work of a whole host of physicists and chemists who studied the nature of atoms and molecules made possible the creation of modern chemistry and the chemical industry. Dozens of other examples from other fields could, of course, be mentioned, in which the discovery of a new law or new phenomena in science has made possible the creation of whole new areas of technology.

But technology has also grown by adopting in technological research the *methods* of science. Though the systematic trial-and-error method is still the mainstay of many areas of technology where the fundamental principles are still not fully understood, there are many other areas of technology where the method of the controlled experiment is not only possible but highly fruitful. The controlled experiment leads to an advance in understanding which, in turn, leads to the prediction of the results of new experiments. Practically the whole of the technology of the electrical and radio industries, for example, proceeds in this fashion—the method of science which came out of the science laboratories of the nineteenth century.

## Contributions of science to technology

In other words, science has contributed to technology not only new discoveries and a new understanding of nature upon which new practical devices and techniques can be based, but has also contributed a new method of research which has multiplied the rate of technological advance by fantastic proportions.

Now the very fact that the research methods used in a laboratory of technology or of applied science are essentially identical with the methods used in a laboratory of pure science has led many people, including some very well-known writers, to the conclusion that there is no real distinction between science and technology—between pure and applied science. This, it seems to me, is not only a very superficial view, but a very dangerous one.

This view is dangerous because it implies that the burden of scientific research, which was largely carried by the universities during the nineteenth century and the first quarter of the twentieth century, has now been largely assumed by the industrial laboratories, and more recently by government laboratories. All three kinds of laboratories, it is said, are working toward the same goal, and the great expansion in industrial and government laboratories will result in a great acceleration in the rate of growth of science. Even if the university laboratories should go out of business, some would conclude that science will continue to thrive in the laboratories of industry and government. There are even a few industrial leaders who have apparently subscribed to the thesis that what goes on in the university laboratories is of relatively small importance, in any case, for the only things of practical import will come from the industrial laboratories.

## Basic science vs. industrial research

I think what I have already said is sufficient to suggest the fallacy of this point of view. The laboratories of basic science in universities and the laboratories of applied science in industry do have much in common. But like the east- and west-bound sections of the streamliner, however identical they appear to be in their physical form, they are simply not headed in the same direction. The aim of science is to discover new knowledge and new principles. The aim of technology or applied science is to invent new devices, new machines, new processes, new techniques. Furthermore in the long run the new developments in technology will be based only upon the new knowledge uncovered by science. Only when totally new knowledge is discovered can a totally new technology arise.

I emphasize this situation because I believe that we in this country are approaching a real crisis in regard to the future development of basic science. The American people seem to be so imbued with the idea that the chief products of science are such things as jet-propelled planes, atomic bombs and television sets, that they have forgotten that all of these things rest upon basic scientific discoveries which were uncovered in research work which was not at all aimed at such practical results. The American people take such great pride in the fact that hundreds of millions of dollars of government and industrial money is going into research in applied science that they are unconcerned and even uninformed about the fact that but a tiny fraction of this amount is being fed into the laboratories of basic science, wherein will be made the discoveries on which future technology will be based.

The dangers of spending all our funds and effort on applied science to the neglect of basic science can, I think, well be illustrated by a consideration of the field of medicine. Many people, I am sure, believe that the one and only way to find a cure for cancer is to build many large medical research centers where hundreds of doctors try out hundreds of thousands of chemical compounds on thousands of animals and human patients until some day the miraculous compound is discovered which will remove the scourge of cancer from the human race.

## Finding a cure for cancer

Now I admit that there is a possibility that a cure for cancer will be found in this way. The trial-and-error method in applied science has led to many spectacular practical achievements. Nevertheless, it would surely seem to be good sense not to place all our bets in this direction. Rather we should, give some support to those scientists who are trying to understand the basic processes that go on in the biological systems, the basic processes which give rise to the normal growth of cells and tissues, as well as to the abnormal growth which we call cancer. It is quite possible, in fact it is almost inevitable, that if we really understood the basic nature of cell growth, the conditions which give rise to abnormal growth would become evident and the methods of preventing such conditions might be immediately obvious.

It is not impossible, for example, that the cause of cancer may lie in the fact that molecules of the wrong shape somehow get synthesized under certain conditions in the human body. Recent research by Dr. Pauling and his associates at the California Institute of Technology has shown conclusively that one human disease, known as sickle-cell anemia, is in fact a molecular disease. These workers have found that the hemoglobin molecules, which are present in the red blood cells of patients suffering from sickle-cell anemia, differ in structure from normal hemoglobin molecules. Because of this difference in structure, the molecules tend to clump into small crystals, producing a condition which, in turn, causes a change in shape in the red blood cells themselves in such a way that the blood no longer flows freely through the blood capillaries and lack of proper circulation results.

It appears likely that this abnormal formation of abnormal hemoglobin molecules can be made normal again by some method of increasing the oxygen supply to the blood. At least the development of a cure for this disease is now a straightforward development program, and the cure which eventually comes about would possibly not have been reached in a hundred years of trial-and-error experimentation.

## Basic research — a practical investment

What I am driving at is simply this. Great centers of medical research are fine, just as are great centers of research in other areas of applied science, such as the great industrial laboratories working on industrial technology and the great government laboratories working on military technology. But the fuel which will eventually keep all of these laboratories going is the scientific knowledge which will come out of the laboratories of basic science. At the very least, for every hundred million dollars spent on medical technology, I wish that at least ten million dollars could be spent for basic research in biology, biochemistry, chemical biology and medical chemistry. I believe that one can say with confidence that out of the studies in this broad field of what is often called molecular biology will come the basic knowledge on which better health for the human race can be built.

The same remarks might be made about many other fields of applied science. The most impractical thing we can do as a nation is to devote all our efforts and funds to so-called practical research to the neglect of more basic investigations.

Let us now turn to the question of what we may expect the science and technology of tomorrow to bring. What kinds of things dare we predict?

Looking to things which might come to pass in the next fifty years we find that these fall into two classes. First, those which, while not impossible, have no basis for achievement in presently available scientific knowledge. When the scientific discoveries which might render them attainable will be made, if ever, it is of course impossible to forecast. For example, it is not impossible that we may some day be able to observe directly whether there is animal life on Mars. But the realization of this goal will require some wholly new discovery in the technique of observation—a discovery not yet in sight.

Similarly, the control of certain diseases, the extension of man's life span to, say, 150 years, the control of the weather, and the many other things which we like to think about can come about only when and if totally new scientific discoveries are made. No one can say such discoveries will not be made—but no one can predict when they will come.

The second type of new developments which might be anticipated are those based on presently known scientific facts but requiring practical inventive development to bring them into being or to render them practical and economical. The practical utilization of nuclear energy for the generation of electric power lies in this class. The basic scientific knowledge necessary for this use is at hand. But how long it will be before a reliable and practical power plant will be designed and built is still uncertain. Surely experimental units will be operating within five years, assuming of course that the work of the AEC is not stalled by political interference. Within another five or ten years the engineering problems standing in the way of building a large-scale practical unit will have been solved.

## Changes we can count on

It is still uncertain, however, just how practical and how *cheap* atomic energy may be. I think it will be highly expensive for a long time. And I also think the serious dangers of the intense radiations from radioactive products will confine atomic furnaces to use only in remote locations. I will even go so far as to predict that in the year 2000 atomic energy will still be only in limited use for special purposes—and in any case will not in the least have reduced the market for coal or oil or water power. But the special purposes for which atomic energy will be useful may be of the very greatest importance—and the very expensive engineering developments required will eventually pay off.

If, however, present American industry does not need to fear the danger of a complete revolution based on atomic power, there are plenty of other possible technological developments which will result in very great changes. We can be perfectly sure that the art of communication will continue to advance at a dizzy pace. We have only begun to exploit the possibilities of rapid transmission of information by radio. Not only a news story or a picture or a television image can be transmitted, but in principle one could transmit the contents of an entire book or newspaper in a few seconds. Long-distance telephone cables may well go out of existence, and radio waves of wave lengths down to a few inches will come into use in hundreds of ways.

Transportation will not stand still either. We could have passenger air transport from coast to coast in five hours now if we were willing to pay the cost. Two hours or less is certainly coming—maybe at rather high cost.

Industrial processes will also change rapidly. Automatic-control techniques can even now eliminate great areas of routine tiring labor. The assembly line operated by a thousand men will give way to one operated by a hundred or ten or one. Maybe President Truman is right in predicting that by the year 2000 the national production will reach a value of a thousand billion dollars a year. In fact this figure *would* be realized if only the present rate of growth continued. Technologically speaking, this is certainly not impossible. Whether the political and economic problems which stand in the way can be solved or not is a subject on which I shall offer no predictions whatever.

I could, of course, go on indefinitely offering guesses about new possibilities. But you are as able to do this at your leisure as I am. As long as you refrain from predicting things that violate basic laws of physics or chemistry, *some* of your predictions are bound to come true, provided only you make lots of them.

## The challenge — and how we can meet it

And so what? What is the challenge? What shall we do about it?

There are, of course, those who fear the future—who fear the further progress of science and technology. There have always been such people. A school board in Ohio a hundred years ago passed a rule that its school rooms should not be used for discussion of such wicked and impossible things as steam engines and railroads. Still earlier in England, a member of Parliament heatedly denounced the dangers of our growing knowledge and teaching of geography. It will be the ruination of the common people, he said. Another denounced research in anatomy, holding that the Lord had purposely covered up our insides and we would only get into trouble by penetrating His curtain of modesty.

We laugh at people who could be so blind—at people who feared knowledge rather than welcomed it. We scorn those who 50 years ago lacked the vision to forsee how science and technology would change the world—and who feared and fought the changes as they came.

But are we entitled to laugh? Can anyone of us today foresee the world of 2000 A.D. or even the world of 1951? Or do any two of us agree as to what we see? We are all short-sighted. And we will never know which of us sees or guesses the future the best until events have proved his words. The important thing is not that we foresee the future but that we do not fear it. We know there will be change. The challenge is to welcome it—to encourage it—to make it a change for the better.

The first challenge is this: science and technology will bring changes—so we must be ready to make the most of them.

But waiting for new developments to come along and hoping to use them—or not be destroyed by them—is not enough. And this brings us to challenge number two: the challenge to encourage and stimulate new developments by means of applied research. Inventive ingenuity, using the techniques of modern science and technology, has not even begun to exploit the possibilities of applying present scientific knowledge for the benefit of men. Increased productivity in industry and agriculture, new products and techniques in every industrial area, new advances in medicine making immense forward strides in the conquest of disease—all of these will come—some slowly, some quickly. But they do not come automatically, or without effort or cost. But come they will, because forward-looking men in industry will put forth the effort required.

## Industry bears the burden

I wonder if you realize that, aside from developments in military technology and in some phases of agriculture and public health which will be supported by government funds, practically the whole burden of applying scientific techniques for the improvement of the material well-being of men and women in this country lies on the shoulders of industry. It is from the industrial laboratories that new and better products and techniques will come. Someone else is not going to do that job. If it is done, the management of industry and of business will do it.

It is a grave responsibility but an exciting challenge. It is precisely the kind of challenge that American industry under the free enterprise system has always met. In fact, it is a challenge that can be fully met *only* in a system of private free enterprise. New and creative ideas in technology—ideas which must originate in the minds of men—do not come from men who are not free to think—and to think for themselves. No dictator can force men to have ideas. No system of regimentation of thought will nourish creative thinking. And regimentation is equally fatal, whether it be imposed by a national dictator, by a police state or even by a government bureau. By the same token, of course, it must not be imposed by industrial management either! If there is any area of human activity which flourishes only in an atmosphere of freedom, it is the area of creative science and technology. You will never find a real scientist advocating a dictatorship. You may find scientists with all sorts of other silly ideas (for they are just like other men) but not *that* one!

Freedom—private initiative—that is the first prerequisite for a virile technology. But there are other things that industry must provide or acquire in order to maintain technological progress. There are, in fact, four things: management, money, men and knowledge.

## Management, money, men, knowledge

The intelligent management of research and an intelligent management policy toward research and toward the utilization of the products of research are a prime requisite.

Adequate funds for research are also necessary. But if the desirability and the necessity for industrial research are appreciated money will somehow be found.

The last two ingredients of industrial research—men and knowledge—may not be so easy. We sometimes tend to take them for granted. But unless industry can draw on a supply of men carefully selected and adequately and soundly trained in creative research, no million-dollar laboratories will be worth a cent in advancing technology. Research men are, of course, the products of the universities. The universities do the selecting and the training. It will be well for industry from time to time to take a look at our colleges and universities to make sure they are thriving—to make sure they are kept free. For without their products in trained minds, not only technology but all of industry would soon wither and die.

And finally, knowledge. What knowledge is needed and whence does it come? The knowledge I am talking about is knowledge about the physical world—the knowledge of science. I refer not only to the knowledge we now possess, which must flow continually into every industrial laboratory, but also new knowledge which is yet to come—new knowledge which is essential to a new technology. In other words, a strong technology—as I have already frequently said—depends upon a strong science.

And this brings me to the third challenge—a challenge which has not previously existed or one of which industry has been unconscious. This is the challenge to insure the future of science. Industry has always in the past taken basic science for granted. It has always assumed that somehow, somewhere, the new scientific discoveries on which the new technology of tomorrow would be built would be made. And where have they been made? With a few important exceptions they have come from the laboratories of the world's universities. And until a few years ago the most active university laboratories were in Europe.

And what of the science of the future? The responsibility clearly rests heavily on the universities of America. Can they meet this responsibility? Under the American system this depends upon the people of America. If the people, through taxes paid for the support of state universities and gifts to the private ones, continue to support the universities they will continue to thrive. But since industry, as we have seen, is a great benefactor of the products of the universities, namely, men and knowledge, industry too faces the challenge to insure their continued virility. Just how this will be done is not yet clear. It is a new situation—a new problem—and an adequate solution has not been found.

But we can be sure of one thing, that if the challenges I have presented are met—the challenges to support science, to encourage technology, and to make use of their products—then no prediction about the future material welfare of this country is rosy enough to live up to the actual facts as they are certain to develop.