Zygon | Journal of RELIGION AND SCIENCE vol. 7, no. 4

# THE SCIENTIFIC AND TECHNOLOGICAL REVOLUTIONS AND THEIR IMPLICATIONS FOR SOCIETY

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It is becoming almost a boring truism that the interaction of science and society provides one of the most baffling problems of the present age. Examples abound; their mere enumeration could almost fill a book. We hear that the ever-increasing acceleration of scientific research is leading rapidly to applications that invade every aspect of human life in advanced societies and this to an extent undreamed of even a few generations ago; the mass media bombard us daily with references to what science has in store for the future of man, with special emphasis on the horrible. We are awed by the increasing scientific sophistication of weapons of war. The computerization of industrial and governmental activities, laid by most at the door of scientific research, is said to threaten the privacy of the individual. The latest crisis, concerning the deterioration of the environment, is envisioned by many as a direct result of man's insistence on the use of his scientific ideas to interfere with the ordinary course of nature. It is widely felt that the decline in the influence of religion as a basis for ethical behavior of human beings is directly due to the increased secularization of social ideas, stimulated by the feeling that science and technology provide the only rational guide to life and that all else is irrelevant superstition.

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The voices that are continually reminding us of the nature and consequences of the interaction of science and society are numerous, often impressive, but also cacophonous. We do our best to listen to the words of wisdom from the Mumfords, the Galbraiths, the Polanyis, the McLuhans, the Poppers, the Bronowskis, the Reichs, and to many it all seems very confusing. It is doubly so to me, since as a scientist in the special field of physics I have devoted my professional career to trying to find out how things go in certain portions of our experience with minimal interest in the so-called consequences and to endeavoring to impart to youth some notion of what science is all about. At the same time I have been unable to avoid the realization that there is something bothersome, not to say actually wrong, about the relation between science and society. I present my comments with all due modesty, realizing that as a scientist I possess a built-in bias, and that in a field so vast my grasp is bound to be fragmentary.

## I. THE SETTING OF THE PROBLEM AND THE NATURE OF SCIENCE

Where shall we begin our study? A good opening is provided by the complexity of modern life in so-called developed countries, a never-ending theme in social discussions on any level. What does it mean? One obvious symbol of it is the increased involvement of everyone with material objects. One look at a modern kitchen with its more or less complicated labor-saving devices, such as mechanical refrigerators, automatic electric stoves, dishwashers, waste disposals, and mixers, should bring home to the housewife the changes merely due to material gadgets that seventy-five years has brought about in much of domestic economy. But we see this on all sides: motor cars, airplanes, and high-speed highways. No living room is complete without its radio and television. Many people feel they must carry these communication devices with them wherever they go.

Think also of our involvement with paper—a simple enough material object it would seem—but as it enters our lives it is almost overwhelming in its extent and variety. Not without reason has it been said that we live in an age of paper.

Health in modern society is also a complicated matter with the countless drugs that are being developed and tried out in every conceivable way. Some think we are being about literally "pilled" to death. The modern physician has physical instruments at his disposal unheard of a century ago.

A whole book could be devoted to this involvement with material things. But this preoccupation is not the only type of complexity. Human beings are increasingly involved with other people. This is illustrated not only by our obviously greater dependence on institutions like banks and insurance companies, and on government officials through taxation, social security, medicine, etc., but also by every aspect of the ordinary routine of life. Thus we no longer entertain ourselves. We are entertained by others who make a business of it on radio and television. Instead of being something to look forward to, entertainment is a saturation process, a kind of anodyne without stimulus or meaning.

The mental involvement in trying to keep up with what is going on all over the world is another factor adding to life's complexity. The "bad" news comes over the radio and television many times daily with a claim on attention which is psychologically very demanding. There is something irresistibly compulsive about the voices of doom which besiege our ears with monotonous regularity. Each week brings a new crisis to add to the list of those previously certified as sure to lead to the destruction of our civilization. The vapid commercials on TV and radio programs scarcely provide any echo of sanity in a disordered world; the best that can be said of them is epitomized in the phrase "comic relief."

As an old man contemplates this situation he is apt to look back with nostalgia on the "simplicity" of life in his youth. Much of the apparent change is very likely an illusion due to a change in perspective or even more probably connected with sheer ignorance. But this very word "ignorance" is relevant to the whole situation: today we are not permitted to ignore what goes on anywhere and everywhere. If we "live" at all, we are in the midst of a constant hurly-burly which we cannot escape.

*Modern Society and the Scientific and Technological Revolution.* The complexity of modern life in society about which we have been speaking is commonly attributed to the modern scientific and technological revolution. In simpler language this means it is due to basic changes in the ways of looking at things (science) and basic changes in the ways of doing things (technology).

Immediately an important problem in terminology crops up. Is "revolution" the appropriate way to refer to the above changes? It implies a complete overturn in ways of thinking and doing. A political revolution is a complete change in form of government. In order to avoid embarrassing misconceptions, the word "revolution" should be used with great care in the context of science and technology. Undoubtedly the invention of a machine like the lever was a revolution in technology; the invention of the concept of gravitation may fairly be considered to mark a revolution in physical science; but to apply the term to the modern twentieth-century advances in science and technology involves a misconception as to what actually happened with the introduction of relativity and quantum theory in physics or electronics into technology. The better word to describe what has happened here is "evolution." What people really mean by the "revolution" in twentieth-century science and technology is the relatively rapid development of more successful ways of thinking and doing, a speeded-up process of evolution of ideas and methods definitely suggested by what had gone before.

Whatever the terminology there is no doubt that the rapid pace of progress in science and technology in the twentieth century is having a profound influence on the nature of society. Some features of this impact we now proceed to examine. But before we embark, it is essential that we should make clear what we mean by science and technology. We begin with science.

*The Nature of Science.* It would seem to be far from simple to epitomize in a few words the nature of an activity as multifarious as science. In fact there are many who say it cannot be done, and that one can never hope to understand what science is without spending a lifetime studying it—or at any rate observing closely for a rather long time the behavior of a person calling himself a scientist. But here we do not have a lifetime at our disposal and must make do with a few relatively simple English words. We shall say that science is a method for the description, creation, and understanding of human experience. It may be objected that this epitomizes all human efforts at coping with experience and this is true; to make it applicable to science, as distinguished from art, for example, we must specify the meaning to be attributed to the terms "description," "creation," and "understanding." But first we ought to say something about human experience. By this we shall mean everything that happens to each one of us during every waking moment and perhaps even while we sleep, together with the reflections made upon these happenings by the top end of the nervous system, commonly called the brain. We ought also to put emphasis on the fact that science as thus empitomized is *a* method, but certainly not the only method of grappling with experience, of trying to come to grips with it, so as to assign some meaning to it. Obviously the humanities provide a method for coping with experience, though for them the significance of the key words "description," "creation," and "understanding" is somewhat different from the meaning used by the scientist, though by no means as antagonistically different as is commonly supposed.

What then do we mean by our three key words in science? By description we mean the search for order, regularity, or pattern in experience and talking about it in the simplest way we can find. To the casual observer the flux of experience can appear a rather confused affair, possessing neither rhyme nor reason. The scientist feels that it is his job to find elements of pattern in it, or even if necessary impose such order. This might be by finding repetitive phenomena such as the succession of day and night, the passage of the stars across the sky, the cycle of the seasons, the phenomena of vibrating things, to mention a few examples. Pattern also may mean the existence of definite relations between apparently different phenomena, such as motion and sound, for example, or motion and heat, or electricity and magnetism. It has been the aim of scientists to establish as many such relations as possible and so far as possible make them quantitative in character, so that one can say how *much* of one phenomenon is associated with how much of another. When such a quantitative relation is found to be a good description of phenomena over a wide range of variation it is said to constitute a scientific law. Examples from physics would include the law connecting the velocity of sound through a fluid with the temperature of the fluid, or the law (of Ampère) connecting the magnitude of the current through a wire with the strength of the magnetic field it produces in its surroundings. An illustration from psychology would be the law connecting stimulus with sensory response in vision and audition. An example from biology would be the Mendelian laws of heredity. And so in all branches of science one finds the scientific law as the center of the descriptive process: a law in science is a precise shorthand expression, preferably in mathematical form (for mathematics is the natural language of science) for a routine or regularity in experience.

But science is not merely the description of experience. A very important part of it is the creation of experience. Instead of being content to get his experience passively the scientist decides to pursue a more active course by arranging elements of this experience artificially to see what then happens. In other words, he makes experiments. By this means he literally creates new experience which was not previously known. In this way he is also said to obtain new knowledge, but the emphasis on the creation of experience is the more significant, though the two aspects are, of course, inextricably joined.

The final and most important element in science as a method is the endeavor to understand experience. Simply put, this is the attempt to answer the question not merely *how* things happen in the world of our experience (the essence of description), but *why* they happen as they do. The scientist wants to know why the velocity of sound in air is directly proportional to the square root of the absolute temperature, or why the growth of an organism follows the compound interest law and then stops, to settle down to an equilibrium state. To answer questions of this kind the scientist invents what is called a theory, which is a kind of picture, created by the mind, of things as they are in an imaginary world. The hope is that from the assumed properties of this imaginary world the regularities of the world of our experience can be deduced by logical processes of thought. So we have as an example the molecular theory of gases, which supposes a gas to be made up of tiny particles called molecules which move with varying but on the average large velocities compared with the speeds of motion of ordinary objects in our experience, and by their collisions with the walls of containing vessels produce the observed large-scale behavior of the gases of one's experience. From such a theory one can deduce mathematically the law of sound mentioned above. Similarly the theory of the living cell is invented in biology to explain the structure and growth of organisms. In each case the fundamental kernel of a theory is *hypothesis,* the educated guess or assumption of things as they might be. This is the stuff of which theories are made and the artistic expression of the imaginative ingenuity of the scientist. So we find the science of physics full of theories ranging all the way from the down-to-earth theory of mechanics, so useful to the engineer, to the more highly abstract theory of relativity and quantum theory. But physics does not have a monopoly of theories. All science is full of them, from the sophisticated theories of audition and vision in biology and psychology to the grand theory of evolution of species in the world of living organisms. The theory is man's answer to his insatiable question: *Why?*

We have thus categorized as simply as possible the nature of science as a method for coping with and attaching a meaning to man's multifarious and complicated experience. Though no honest scientist would claim that science is the *only* method for the successful handling of experience, he would emphasize that no aspect of this experience lies outside the realm of possible scientific investigation. It is true that there are certain phenomena, for example, those connected with what is called extrasensory perception (ESP) which at the moment do not appear to fit too readily into the framework of scientific investigation. However, it seems certain that the whole subject will ultimately become a branch of psychophysics, and it is folly to dismiss it as hopelessly unscientific. Subtle effects of the environment on living organisms, up to now scarcely explored, will undoubtedly lead to the development of new and important branches of science.

Much emphasis has been laid in recent years on the alleged dichotomy between science and the humanities as ways of looking at experience. This is unfortunate. Close examination reveals that though there are, of course, differences in detail in the meaning attributed to description, creation, and understanding between the two disciplines, there are also profound similarities which tend to provide a common ground and should make humanists and scientists more sympathetic to each other's points of view. I have elaborated on these considerations in my book, *The Role of Science in Civilization* (1963). Admittedly, there are practical difficulties in the way of a closer rapprochement between the two camps. One of these is the growing tendency for science to become more metricized and quantitative in its description and to develop in its increasing specialization rather formidable jargons, often mathematical in character. To bridge the gap we obviously need interpreters who can translate from the language of science into that of ordinary speech. This is perfectly possible, but more of it urgently needs to be done.

*Advances in Contemporary Science—Generalization of the Concept of Energy.* As has already been emphasized, the term "scientific revolution" is usually taken to signify the spectacular developments in modern physics called quantum theory and relativity, and in modern biology classified under the names genetics and molecular biology. There is no question about the fascination these developments have had for scientists, and some of this has filtered down to the lay public through more or less successful popularizations in such media as the *Scientific American, New Scientist, Science, American Scientist,* and other periodicals of similar character, as well as in many popular books. It is scarcely necessary or desirable to provide an encapsulated version of these contemporary theories in this article. The eager reader has an enormous resource in this matter available to him in any public library. What is more reasonable and relevant to the problem of the impact of science on society is to say something about the generalization of the concept of energy and its penetration into every branch of modern science, and indeed into every aspect of human life.

Science succeeds largely in the light of the appropriateness of its fundamental concepts, which are indeed the cornerstones of scientific theories. These are the ideas which are, so to speak, the nuclei of the hypotheses and assumptions at the basis of every theory. Of all the concepts of science, that of energy has proved to be the most successful.

Though the roots of the energy concept are found in antiquity, it is a striking fact that the all-embracing character and synthesizing quality of the concept were only beginning to be realized less than 150 years ago. It took the human race a long time to appreciate the advantage of inventing the idea of an entity which, while *constant* in measure throughout the world of our experience, could by its transfer from one place to another and its transformation from one form to another permit a more effective understanding of all natural phenomena. Popular terminology concerning the concept of energy is confusing and misleading. The technologist continually emphasizes the need for more "power" to run our industrialized society. What he means is the need for the increased large-scale transformation of energy from one form to another and its more efficient transmission from one place to another. Even the talk about the need for greater energy "supply" to facilitate the economic growth of underdeveloped countries is a misnomer. This suggests we create energy, which is not possible since the total amount in the world of our experience is constant, and again all we can do is transform or transfer parts of the whole.

The key idea involved in energy is the notion of constancy in the midst of change. When the ancients hit upon the invention of that marvelous contrivance, the machine (for example, the lever, which enables the application of a small force to lead to the exertion of a large force), they ultimately realized that the gain produced was accompanied by a loss, namely, in the speed with which the increased force could do its job. In other words, in the action of a machine something stays constant. We now express the action of a machine as the transfer of a given, constant amount of energy in the form of mechanical work from the input to the output end of the machine.

When the steam engine was introduced into technology as a replacement of human labor, emphasis was first placed on the role of expanding steam in the performance of mechanical work. It was realized, of course, that one has to supply heat in order to get the steam, but the role of the heat in the action of the engine was not at first appreciated. Later, it was seen that one can understand the action of the engine more effectively by supposing that in every cycle of the engine's performance a certain definite amount of energy in the form of heat is transformed into energy in the form of mechanical work which permits the engine to move things, etc. This view did not gain currency among scientists and technologists until around 1840, with the labors of the German physician Julius Robert Mayer (really one of the greatest physicists of the nineteenth century) and the English amateur physicist, James Prescott Joule, who by his extraordinary experimental ability first measured precisely the mechanical equivalent of heat, the quantity which Mayer was the first to calculate theoretically.

The second half of the nineteenth century witnessed the clarification of the concept of energy and its extension into every branch of physical science. Thus, for example, the production of sound came to be looked upon as the transfer of the mechanical energy of a disturbance such as the impact of a hammer on a solid to the surrounding medium and its transmission by means of what is called a wave. Similarly the light from a flame or star is, on this view, energy in electromagnetic form, ultimately equivalent to, but merely of much higher frequency than the electrical energy produced in a dynamo. On the other hand, the electrical energy produced by the dynamo can be transmitted over wires to distant places where it in turn can be transformed into mechanical energy (motors), or heat, or light, or any other physical manifestation you care to name.

The concept of energy has permeated all branches of physics and chemistry. Even quantum theory in its essence may be looked upon merely as the "atomization" of energy, together with all its amazing consequences. Relativity leads to the result that the velocity of light in free space ($3 \times 10^8$ meters per second) is the maximum velocity with which energy can be transferred from one place to another in the universe of our experience. The twentieth century has seen the penetration of the energy concept into the biological sciences. The basal metabolism of the living organism is now expressed in terms of energy transformation, something foretold by Mayer 125 years ago but not appreciated in his time. The psychophysicist measures sensory perception in terms of the electromagnetic energy necessary to excite the eye and the acoustic energy necessary to stimulate the ear. Whether we are concerned with the light waves from the sun and the stars or the radio waves from our broadcasting stations, the waves of the ocean or the seismic waves that rock our poor old earth, the heart of the description of what goes on is energy. The same is true of all the activities of living organisms.

One of the features of the energy concept attractive to a scientist is that the energy transformation in any phenomenon can be measured, in many cases with enormous precision. He may, of course, be misled, but somehow this conveys a feeling of greater understanding, of more immediate grasp. The fundamental practical unit of energy in the metric system is the joule or watt second, but since this is not so generally familiar to the public, let us use the kilowatt hour, which ought to mean something to anyone who has an electric bill to pay each month for the pleasure of utilizing electrical energy in his home. What he pays the electrical company for is the transformation of heat energy into mechanical energy in the giant turbines and then into electrical energy in the coupled dynamo generator. Assume that the power company charges five cents per kilowatt hour, an average sort of rate. If your bill per month is $10.00 (a typical small household bill), this means that in one month you have transformed two hundred kilowatt hours of energy in the various appliances for which you use electricity. This amount of energy would be enough to keep three one-hundred-watt electric light bulbs lighted continuously for the whole month, night and day. Let us hope, however, you do not indulge in such uneconomical and unnecessary transformation! Notice we do not use the common term "consumption." For this is wrong; you do not consume the energy supplied you by the power plant. You merely have the privilege of transforming it into some other form, for example, light or mechanical work. Most of this energy is ultimately transformed into heat—the vast energy sink in the universe of our experience.

Amounts of energy encountered in human experience range from the very large to the very small. Our sun pours out light energy (strictly electromagnetic radiation energy) at the rate of about $7 \times 10^{21}$ kilowatt hours per minute. It is a very prodigal transformer of energy, utilizing nuclear transformation processes similar to that involved in the hydrogen bomb. On the other hand the human eye can detect light whose energy content is only about $3 \times 10^{-25}$ kilowatt hour. It turns out that the normal ear is about equally sensitive.

It is clear that in the concept of energy and its generalization the scientist has at his disposal a powerful weapon for the unification of science, and it is precisely in this unity of science that we begin to grasp the possible ultimate implications of science for human life and society. It will be the task of the suceeding parts in this article to explore these implications. But we must first say something about technology and its relation to science.

## II. THE NATURE AND EVOLUTION OF TECHNOLOGY AND ITS RELATION TO SCIENCE

Science has been defined in Part I as a method for the description, creation, and understanding of human experience. Technology, on the other hand, is human activity directed toward the satisfaction of real or imagined human needs by appropriate manipulation and more effective use of the environment. Unlike science, technology is as old as man himself. The provision of food and shelter was a necessity of life and constituted, in earliest times as it does today, perhaps the most fundamental part of technology. Man's desire to improve the ways of raising and processing food and to make more sturdy and attractive shelters illustrates what is meant by the development or evolution of technology.

Attention is directed to the use of the words "real or imagined" in the description of the needs of man to be satisfied by technology. Everyone recognizes that there are certain human needs which must be met if life is to exist at all. These certainly are real enough needs. But man has never limited his technology to these: he has continually invented new needs, such as, for example, the need for better weapons for use both against animals for food and his so-called enemies in society, and has then been stimulated to look for improved technology to satisfy these needs. This is a very important consideration in the problem of the relation of technology to society, and we shall return to it in Part III.

Since man had to provide means for his sheer existence before he had the leisure to translate his wonder about the world around him into any elaborate form, we are justified in concluding that technology far antedated science. We must indeed be cautious here, for the record of what our primitive ancestors really *thought* about their experience is very incomplete. What the archeologists discover about prehistoric man are mainly artifacts, and it is very difficult to know whether their form and presumptive use reflect any thought that could be associated with what we have somewhat arbitrarily decided to call science. We are certainly not at all sure of a genesis of science until a written record emerges, that is, until adequate language was invented and began to be used to describe things in written form. Of course, as civilization progressed and science developed, its relation with technology early became close and has grown ever closer through the centuries. It will be part of our task to trace the growth of this relation and its importance for the influence both activities have had on man in society. But first we must review briefly the evolution of technology itself.

*The Evolution of Technology.* This is a long story, and many books have been written about it. It involves, of course, every aspect of man's everyday existence: production and preparation of food, disposal of waste, building and furnishing of shelters, manufacture of tools for all sorts of purposes, household appliances, means of transportation, fuels and devices for keeping warm in winter, production of medicines, water supply, materials for providing illumination at night. To which we must reluctantly add weapons of war, for a large part of man's technology has been the search for and perfection of means for throwing the most damaging objects he could find at other living things.

A brief review is all that is possible here, but this appears essential in the light of the later discussion of the role of science in technology and the impact of both on society.

All the activities mentioned above imply the necessity of what is commonly termed labor. In other words, somebody or something has to scurry around and exert himself or itself to produce the desired manipulation of the environment. In the earliest times this labor was provided by domesticated animals or human beings, the latter often in the category of slaves. While labor in this form was cheap and plentiful, there was not much incentive for the clever ones who were in a position to crack the whip over the workers to look for other ways of getting the job done. However, we know technology did advance, so sometime, somewhere, somebody decided that the wind might be made to propel a boat by using a sail instead of by men using oars. Somewhere along the line somebody thought of the possibility of using falling water to turn a wheel, which in turn would grind corn, in place of the clumsy use of animals or men.

From the standpoint of the concept of energy as discussed in Part I, the above technological inventions are now simply interpreted as examples of the transfer of energy from an apparently readily available inanimate form (i.e., the energy of motion of the wind or flowing water) to the energy of motion of something of use to human beings (e.g., the motion of a boat or of a millstone). So we may properly look at the whole development of technology as the result of the search for methods of energy transfer and transformation sufficient to do certain essential jobs while taking the sting out of human labor and decreasing the dependence on that of animals. The invention of the machine went part way in this direction. The lever, the inclined plane, the pulley in its many forms, the wheel and axle, etc., made all human or animal exertion applied to the machine easier but did not by any means decrease the total amount of work involved in a given task: if the exertion (force) was diminished, the time taken to do the job was increased. So the machine was not the whole answer to technological development. Some bright person had to think of a way to get around the labor of a living thing altogether. This was accomplished by the invention of an engine, which in modern terminology is a device that transforms energy from one form (which happens to be readily available) to energy in a form desirable for the performance of a specific task. The first such type of engine to be developed was the heat engine employing steam. In essence what this does is to transform the chemical energy in fossil fuel (e.g., coal) to energy in the form of heat and then further transform this heat energy into mechanical energy of motion, which is then transferable by means of appropriate machinery to objects whose motion is desired in order to carry out assigned technological tasks (e.g., pump water or make a vehicle move).

Interestingly enough, the first heat engine was apparently the reaction turbine of Hero of Alexandria (ca. A.D. 50). This embodied the basic idea of jet propulsion and contained within itself the germ of the modern turbine, the most efficient way of using steam as the heat vehicle in a modern engine. It is not clear that any important technological application was made of Hero's device in antiquity. Nor was it resurrected when interest in the practical potentialities of the steam engine began to be realized in the latter part of the nineteenth century in Western Europe. The emphasis here was on the so-called reciprocating engine, a somewhat clumsy affair but one which dominated the steam-engine field until the end of the fourteenth century, when the steam turbine, a much more efficient heat engine, began to supersede it. In any case, it is fair to say that practically all advances in technology up to the end of the nineteenth century were either directly or indirectly tied to the gradual improvements of the heat engine, and primarily the heat engine employing steam as the working substance. Only in the twentieth century has the internal-combustion engine become the principal heat engine for the propulsion of vehicles. In any case, without the heat engine based on the ability to transform thermal energy into mechanical, electrical, and indeed any other form of energy desired for the satisfaction of human needs, there would be no modern technology. Our whole modern so-called electrical civilization is based on the power plant, at whose heart lies the giant steam turbine-driven dynamo generator.

*The Relation of Science and Technology.* We have said that technology antedated science. But it seems almost self-evident that once man has begun to ponder on why his tools and machines work the way they do as well as to observe more closely natural phenomena in the endeavor to understand them, he will inevitably use the knowledge gained to improve his technology and devise new kinds which never would have been invented had it not been for scientific investigation. We now give illustrations of both aspects of this interaction between science and technology.

The first heat engines were very clumsy and poorly constructed affairs. Mainly used in the eighteenth century for pumping water out of mines, they needed much manual attention and used an awful lot of fuel; in other words, in modern terminology their efficiency was very low. As engineering design improved and engines were made self-acting, their performance improved, and they became flexible enough to find use in various types of manufacturing and vehicle locomotion. But it was observed that the efficiency, roughly defined in terms of the mechanical work output per unit mass of fuel consumed, showed little corresponding improvement. It was widely believed that closer tolerances in moving parts, coupled with better lubrication, would increase efficiency, but this proved not to be the case. Here was a problem which technology was unable to solve. The solution was provided by science in the form of a very perceptive French savant named Sadi Carnot, who in 1824 wrote a treatise, "On the Motive Power of Fire," embodying his thoughts and investigations. Here he noted the scientific significance of the fact that in any single stroke of a steam engine only a part of the heat which goes into the cylinder with the steam actually enables the engine to do work. There is always some of it which passes out to the surroundings through the exhaust and is of no use to the engine. He defined the efficiency of the engine as the ratio of the difference between the quantity of heat taken in and the quantity of heat given out in the exhaust to the quantity of heat taken in. If no heat at all came out of the exhaust, that is, if all the heat put in led to the performance of work, its efficiency would then be unity, or 100 percent. Actually steam-engine efficiencies, even for "good" engines, in Carnot's time were only a few percent. Carnot proved, on the basis of certain assumptions which later served as a basis of the scientific theory known as thermodynamics, that the efficiency of a heat engine does not fundamentally depend on its mode of construction or even on the heat-conveying substance, whether steam, mercury, or anything else. The efficiency of even the most ideal heat engine depends on the difference between the temperature at which the heat enters the engine and the temperature at which the heat leaves via the exhaust. In fact, if we use the so-called absolute scale of temperature (Celsius degrees plus 273°), the efficiency is the difference between the input absolute temperature and the exhaust absolute temperature divided by the input absolute temperature.

This work of Carnot and the thermodynamicists who followed him showed the technologists what they had to do to improve the efficiency of heat engines. This was a direct contribution of science to the advancement of technology. This is only one of many striking examples. We shall have occasion to note some others later in this article.

But now we wish to emphasize that the scientist has been able not only to exert an influence on already existing technology, but also to create wholly new departments of technology. Probably the most striking example from the standpoint of twentieth-century civilization is the founding of the electrical industry on the basis provided by the early nineteenth-century scientists who studied the relations between electricity and magnetism solely from curiosity about these rather mysterious natural phenomena. In 1819 the Dane H. C. Oersted showed that a wire carrying an electric current acts like a magnet or, in modern terminology, creates a magnetic field. His fundamental discovery was elaborated on by the Frenchman A. M. Ampère in the early 1820s. In 1831 M. Faraday in London and J. Henry in the United States almost simultaneously showed that it is possible to produce an electric current by changing the magnetic field passing through a coil of wire. It is on these purely scientific discoveries that our whole modern electrical civilization rests. For the work of Faraday and Henry paved the way for the construction of dynamo generators for the transformation of thermal energy via mechanical energy into electrical energy, which can be transmitted over vast distances and used for multifarious purposes. And it was the work of Oersted and Ampère which showed the possibility of transforming electrical energy back into mechanical energy with the use of the electric motor.

The interactions between science and technology thus initiated became even closer as the nineteenth century progressed and has of course reached its height in our contemporary scene. This leads us to a consideration of some of the recent aspects of this interaction and the problems it poses for modern technology.

*Problems of Twentieth-Century Technology.* One result of the interaction of science with technology is the increase in speed with which new scientific knowledge is translated into technological application. We have mentioned the famous Faraday-Henry discovery of electromagnetic induction in 1831. It was a half century later when Thomas A. Edison opened the Pearl Street electric power station in

New York for the distribution of electrical energy to some of the residents of that city. The standard example of the change which has come about in our time is nuclear energy. Nuclear fission was first accomplished in a scientific experiment in 1938. As everyone knows, the first so-called atomic bomb was exploded in 1945. Of course, it may be said that this speedy practical development was carried out in the context of what was considered to be a war of national survival. But the examples provided by the civilian economy are almost as dramatic: the rise of the electronics industry in the early part of the twentieth century after the isolation of the electron around 1900, and, to take a more recent case, the development of the transistor after purely scientific research on so-called semiconductors.

How can we explain this rapid increase in the rate of technological application of scientific research? For one thing, in the twentieth century, technology has largely ceased to be the creation of the solitary inventor, guided to be sure by some scientific background but depending to a great extent on his own "hunches." Thomas A. Edison, is, of course, the prime example of the success of the lone inventor. His day appears to be over, and he has been replaced by research teams working in industrial laboratories. In fact the large-scale success of modern technology in many fields may be said to date from the organization of such laboratories, beginning with that of the General Electric Company in 1900. At the present time no industry of any size is without such a laboratory or series of laboratories, all employing scientists as well as engineers. Their task is to carry out fundamental scientific research along lines connected with the practical interests of the industry to ascertain what inventions of practical importance might be based on the results of the research, and to develop prototypes of materials of technological value as a result of these inventions. The scientists employed in an industrial laboratory will, of course, in general pay close attention to the scientific research being carried out in universities, publication of which in general takes place in scientific periodicals available to all.

It is commonly supposed that scientists in universities confine themselves to basic scientific research, that is, the kind of investigation discussed in Part I of this article, or what may be called knowledge of our experience for its own sake; scientists in industrial laboratories work on applied research, that is, the application of science to the development of gadgets to satisfy human needs. Actually, this is too simple a picture. Some very basic scientific research is done in the larger industrial laboratories, and in fact some epoch-making scientific discoveries have been made there in our time. On the other hand, some university scientists with a flair for the practical have made useful inventions. It has now become unsafe to generalize too freely in this context. However, since in our economic system an industrial laboratory exists to provide the means whereby the company that maintains it may produce saleable goods and make money, there is certainly a tendency in most industrial laboratories to stress the practical application of scientific ideas, and inevitably much research there tends to be organized. Nevertheless, since it is impossible with certainty to "program" success in any form of scientific research any more than in any other form of human activity, the more enlightened industries encourage free research, as fully as resources permit, on the part of the more competent staff members. There is involved here, of course, one of the basic problems of modern technology, namely, how to make the best possible use of scientists and scientific knowledge.

Every technological innovation involves the need for further energy transformation for its practical and extended use by human beings. One needs only to mention the motor car to understand what this means in terms of fuel to supply, by means of the transformation of chemical energy into thermal energy and then into mechanical energy in the internal combustion engine (the car's motor), the wherewithal to propel the vehicle. Other examples are legion, from the mills for the fabrication of steel to the electrical appliances in the home. So the energy supply (strictly the need for more and more energy transformation, since we do not *create* energy) has become a crucial problem in every technologically oriented society. In twentieth-century economy this has meant the enormously increased search for fossil fuels, their extraction from the earth, and their appropriate processing for combustion. The principal fossil fuels are coal, oil, and natural gas. The use of all three has led to further elaborate technology in their extraction and processing. All these stores, are, of course, the result of absorption by the earth of solar energy over eons of time. So far as mankind is concerned, they must be considered as capital resources which, once transformed into other energy forms, cannot be replaced within the probable time span of human civilization. This somber thought has not kept us from going on our merry way with faster and faster rates of energy transformation. It is no exaggeration to say that we now rate the quality of our civilization as measured in kilowatts, or perhaps we had better say terawatts (where "tera" is the presently employed prefix meaning a million million [$10^{12}$]). To what extent this is a "good" thing will be a subject for discussion in Part III. Here we are concerned with the objective facts of technology.

The realization that fossil fuels will not be readily available to man forever has prompted the search for other materials which can be economically used for energy transformation. Some of these are easily recognizable. For example, the radiation of light from the sun, which has indeed kept the earth "alive" since it was formed, is so obvious a source that one wonders why more has not been done with it. Wind and water power seem available for the asking. Finally, energy from the atomic nucleus, ordinarily referred to as atomic energy but more accurately as nuclear energy, has now proved a practical possibility. A word or two should be said about these sources of energy transformation. In a certain sense solar energy is already utilized on a large scale in the growing of crops, through the agency of photosynthesis. It has been used on a small scale for the heating of houses and for cooking in certain parts of the world. Its really large-scale use probably awaits the day when fossil fuels finally become uneconomical due to their increasing scarcity.

Wind and water power are, of course, strictly speaking other examples of solar energy. Both, however, though apparently provided gratis for the use of man, are unequally distributed both in space and time. The wind does not blow everywhere all the time. Large waterfalls are distributed very sparsely over the earth's surface, and the damming of rivers and lakes involves very large capital investment costs. Nevertheless, more should be done to exploit the use of these energy transformation sources if only because they involve negligible environmental pollution as compared with the combustion of fossil fuels.

Numerous so-called nuclear reactors are now in use in the United States and Western Europe, particularly Britain. At the present time they supply only a small fraction of the power requirements in their respective countries, but undoubtedly their employment will increase, in spite of some public fears with regard to their safety when located in or near large population centers. Such fears are greatly exaggerated. It must be emphasized that the use of so-called fissionable material in these reactors is a drain on capital energy reserves in the earth somewhat similar to the use of coal and oil. However, the nuclear energy transformations are so enormously more efficient than that involved in the combustion of fossil fuels that the supply of material will probably far outlast the economically available supply of coal and oil. Everyone has heard of the even more efficient fusion process employing the energy released in the formation of helium from hydrogen. A very large amount of research has gone into the engineering aspects of this process, but so far it has not proved technologically viable. The prospects for an early solution of this problem are not bright, though if previous experience is any guide success will come. When it does, the energy supply problem for technology would be solved forever, since this source would be inexhaustible in terms of any reasonable assumption with regard to the presumptive future of human life on this planet.

Though the energy supply poses a crucial problem for modern technology, it is by no means the only significant one. Fully as important is that of the *control* of the vast complex of energy transformations at the basis of our technological civilization. The simplest example will illustrate this point. Though a heat engine will not accomplish anything without fuel, its accomplishment will be useless unless the rate of transformation of energy from this fuel is controlled in the light of what the engine is intended to do, that is, to supply mechanical energy to a load (e.g., turn the armature of an electric generator, propel a vehicle, pump water, etc.). When the load demands more energy, something must tell the engine to transform energy at a greater rate; otherwise the engine will stall. When the load decreases measurably, the same agency must inform the engine that it should decrease its rate of transformation; otherwise the engine will race. The agency that accomplishes this end is called a governor. It is the helmsman of the energy-transforming device. All such transforming devices must possess control agencies of this kind. Recognition of the importance of the control of energy transformations has led to the development of a very important branch of technologically oriented science called cybernetics (from the Greek meaning helmsman). The important task of this science is to devise sophisticated ways in which minute quantities of energy can be employed in controlling the rate of transformation of very large amounts. Our living-room thermostat is a beautiful example of a mechanism which does just this. Through the use of a very small amount of heat energy in the room it conveys information to the heater in the basement either to provide more heat or to provide less.

Cybernetics pervades all aspects of human activity. When we drive our cars, we are cyberneticians, since through the very small amounts of energy transformation and transfer involved in the motions of our eyes, our hands, and our feet, we control the relatively large amounts of energy represented in the propulsion of the vehicle.

It takes but little thought to realize that the key idea in cybernetics is the transmission of information, that is, a collection of signs interpretable as a message. So there has grown up a branch of knowledge called information theory, which is again a technologically-oriented science, very strongly tainted with mathematics. Here technology realizes the enormous importance of human communication, which is obviously a cybernetic device without which life in society would be impossible. So language in all its aspects becomes a vital factor in the advance of technology, and its properties are now being studied in detail not only by linguists and philologists but by scientists in speech communication.

Modern technology has come to depend on high-speed mathematical calculation and data processing. Hence we have entered the age of elaborate digital computers which can count at speeds far exceeding any human capacity. The versatility of the computer is fantastic. It not only can perform in a few seconds complicated mathematical calculations which, even with the use of a desk calculator, would take the normal human being days and even weeks, but when properly programmed can control large-scale industrial processes. Its use in business accounting is well known.

With the use of the computer we approach the age of automation in which much of the labor formerly done by human beings is being replaced by automatic devices controlled by computers. If we wish to use the word "revolution" at all, then the real revolution in technology in the twentieth century is the innovations brought about by the computer and automation. The implications of this for society and the future of man will be examined in Part III.

## III. IMPLICATIONS OF SCIENCE AND TECHNOLOGY FOR THE FUTURE OF MAN

It is a bold venture indeed to embark on a topic of this complexity, and I hope to do justice to it in a few pages. Even to talk sense on a single one of its various aspects is not easy. It amounts to uttering prophecy not only about what the science of the future will be like, but also about what man will be like. And it really goes beyond this, because it demands that something be said about the future interaction between the two.

Though, as we have previously stressed, it is growing increasingly difficult to distinguish contemporary science from technology, at least insofar as its relation to society is concerned, we shall endeavor for the time being to maintain the distinction. Our plan, then, is to examine first the long-term implications of science as related to man. Then we shall discuss the short-term implications.

*Science—the Long-Term Implications.* Before discussing this topic in detail, we ought to note its relation to an important historical theory, namely that known as historicism. This viewpoint insists that one can use past history as a means of predicting the future course of history, in effect predicting the future of man. There has been much controversy over this thesis. Karl Popper, the eminent British scholar in the philosophy of science, felt he could demolish the whole viewpoint by a simple logical syllogism. His major premise was that the future of man depends on the evolution of knowledge, specifically scientific knowledge. His minor premise was that one cannot predict the future development of scientific knowledge. The conclusion that follows is that it is not possible to predict the future course of history. It will be noted that the problem of the implications of science for the future of man enters vitally into both premises of this syllogistic argument. Here we must ask ourselves two questions. The first is: Does the future of man really depend on the future development of science? The second is: Must we confess our ignorance of the future course of science?

Let us consider the second question first. Most scientists agree that science is an open-ended activity, and that we have by no means reached the stage where we have attained to *all* the basic principles at the root of scientific description of our experience. In fact, most scientists agree that there is no sense in talking about a limit to human experience. There is, on this view, no end to it. As we have seen, it is indeed one function of science to *create* new experience, and this is happening all the time. There are, of course, a few scientists who believe that the principles of the now existing successful scientific theories are adequate for the understanding of all future experience. But it is hard to see how this view can be maintained in the face of the fact that we are largely unable to predict in detail what that future experience is going to be.

It would then appear that in feeling forced to accept Popper's second premise we are placing a very considerable obstacle in the way of a meaningful discussion of the implications of science for the future of man. We shall return to this point in a moment.

But let us now look at the first premise and the question connected with it. Can we plausibly assume that the future course of man's existence on earth depends on science? History, indeed, makes it plain that the development of science *has* materially influenced the course of civilization, especially since the seventeenth century and with what may be considered an accelerated pace in the twentieth, if we think of science-oriented technology. Can we be sure that this profound influence will continue into the future?

It must be confessed that there exist differences of opinion on this point at the present time. During the past decade, and more intensively in the past five years, there has been growing up a feeling among the general public that science as an element in human progress is overrated, and that its good contributions are outweighed by the evil results that have followed its applications. Much of this growing aversion is directed, to be sure, at the advanced technology which has resulted from scientific research, but the blame is pretty generally laid on science. Examples abound. We mention here so-called scientific warfare with sophisticated weapons which can readily be made to seem horrible to the impressionable person; the pollution of the environment; the supply of relatively enormous sums of public money for the support of esoteric scientific research, which the lay public cannot understand, for example, nuclear and high-energy physics, while the social problems of the cities are neglected; the devotion of even larger sums to cosmic exploration, which many regard as a form of athletic competition with rival nations, etc. If you add to this a very real feeling on the part of many, especially young students, that too many scientists are selfish, arrogant folk who believe that only through science can one hope to understand anything about human experience, it is not difficult to understand that in our time science has been to some extent forced into a defensive position, which would have been hard to foresee when the discipline was "riding high" in the years after the end of World War II.

If the viewpoints just mentioned represent a really deep-seated aversion to science in all its branches and if, because of popular pressure, the public financial support of scientific research drops back to its relative status of seventy-five years ago, it seems clear that the number of young people who can be educated in scientific research will necessarily be drastically reduced, and the whole scope of science as an element in our culture will be correspondingly attenuated. The process of erosion could be accelerated if the reported hostility of the young reaches epidemic proportions. There can be no science without scientists, and clearly no ultimate influence of science on society if, say, in a hundred years from now, the few scientists left are forced into hiding, with no successors in sight. It is believed by some that the future of organized religion as an effective force in the behavior of man in society is bleak and growing bleaker. Is there any real reason to suppose that science as a cultural activity should avoid a similar fate?

I find it difficult to believe that the possibilities set forth in the preceding paragraphs are a completely realistic assessment of the situation. Science has evolved essentially from human curiosity, and it is hard to stifle this curiosity without destroying the people that have it, or at the least without treating it as a kind of insanity demanding incarceration. If history teaches us anything, it is that most people demonstrate some curiosity about the world of their experience, and a few have this characteristic developed to an intense degree. It is, of course, possible that in the course of the next million years man will have retrogressed to the level of what we now call the lower animals, and his rational faculties will be replaced by instinct alone. Such speculations, however, are not helpful for our present discussion, and we shall ignore them.

It may be said, however, that even if human curiosity cannot be stifled, it can be discouraged by the lack of support. Some pessimists point to the fact that modern scientific research demands expensive equipment, and that ultimately society has to provide this for the scientist. This view fails to take into account that some of the greatest scientific discoveries of the past were made by men whose support by society was minimal. We think, for example, of Julius Robert Mayer, the physician in the little town of Heilbronn in southern Germany, who as an amateur scientist was one of the founders of thermodynamics. To cite another example, Michael Faraday discovered electromagnetic induction on what would now be called a shoestring. Other cases of this sort are legion. There seems no reason to believe that this sort of thing cannot happen again. In fact, it *is* happening at the present time.

It is indeed altogether possible that some of the more expensive types of scientific research, such as are exemplified in the construction of multimillion-dollar accelerators in nuclear and high-energy physics, will lead to diminishing returns in the advancement of science; and that breakthroughs in our understanding of experience will be made with much simpler equipment. As in the past, the principal criteria for success in science in the future will not be merely hard work, but the development of imaginative ideas by thinkers who have the quality which, for want of a better name, we call insight. It is not likely that people of this kind will ever wholly die out while mankind continues its existence.

We conclude that there is little likelihood that science as a form of human culture will vanish. The number of scientists relative to the total population may indeed decrease in the future, particularly if the economic rewards are diminished. This may not, after all, be a bad thing. I suspect that large numbers of persons trained in science in the last fifty years are hardly to be considered real scientists, but are more properly to be called technicians who have embarked on their careers because they were led to believe that "science" offers superior material rewards; their devotion to the high ideals of the scientific profession may be regarded as minimal. The real scientists, whose work will continue to influence the future of man, will inevitably always be a small minority.

It seems altogether likely, therefore, that science will be with us in the indefinite future, and that it will continue to exert an impact on man in society as it has in the past. It will do this by influencing the way people think about their experience, and it will of course exert a profound influence on people's activities through science-oriented technology.

Let us then return to Popper's second thesis. Even though we cannot safely predict the future course of development of science in detail, we can feel fairly sure of the continued validity of one great scientific theory applicable to large-scale experience, namely, the theory of thermodynamics, the first of whose fundamental concepts is that of energy, already mentioned in Part I as the most important concept in the whole of science. The so-called first law of thermodynamics is one of the most basic of scientific principles. According to it, the total amount of energy in the universe of our experience is constant. All that can be done with it is to transfer it in one form from one place to another or to transform it from one form to another; illustrations of this have already been provided in Part I. This principle is, of course, a hypothesis whose validity we cannot establish by logical reasoning. But man has so far discovered no contradiction to results deduced from it in any aspect of human experience, and we therefore may feel pragmatically confident of its long-term validity as a scientific principle. This does not mean that something may not happen thousands or millions of years from now to make it unacceptable as a vehicle for understanding experience. Acceptance of the belief that this is likely to happen would force us back to the strict construction of Popper's second premise—that we simply cannot predict the future of science. In this case we are really forbidden logically to say anything at all about the long-term implications of science for the future of society. This would end our story here!

The principle of the conservation of energy is not the whole story of thermodynamics. In this interpretation of nature, which has been confirmed by every facet of human experience, nature appears to insist that not only may energy not be created or destroyed, but that in every transformation of energy from one form to another there is a decrease in our ability to repeat that transformation. In other words, though the total amount of energy in the universe stays constant, there is a steady decrease in its availability for transformation. This is the essential content of the famous second principle of thermodynamics. The measure of the unavailability of energy for transformation is called entropy, and the second principle may be stated in the form that in all natural processes the entropy of the universe increases. The implication is that eventually the entropy of the universe will reach its maximum value, and that then no more transformations of energy will be possible. This will correspond to a kind of "death" of the universe, and in fact a century ago the German physicist Rudolf Clausius called this state the heat death.

Two observations are in order here. In the first place the second principle, like the first, is a hypothesis. Its validity is guaranteed only by the experiential confirmation of its predictions. So far the experience of the human race has not provided any breakdown of the principle. It is possible that at some later age, and in remote corners of the universe which may become in time accessible, the principle may cease to hold. If we are willing to put our faith in statistics and the law of large numbers, any breakdown of the second principle seems unlikely. The time scale of its operation is, of course, enormous, and one might conclude, therefore, that its implications for the future of the human race are minimal. But there are reasons for being a bit wary of this dismissal of the principle. We might want to pay some attention to the fact that the ever-accelerating rate of energy transformation, which is at the basis of our modern industrial civilization, implies an increasing rate of entropy increase. Moreover man's unhappy zest for the destruction of everything around him, including the lives of his fellowmen, operates in the same direction.

But the second principle of thermodynamics has perhaps a more significant immediate implication to guide behavior. Just as the decay of man's works and institutions (like the death, often promoted by violence, of each one of us) are exemplifications of the increase in entropy in our universe, so the long and costly process of building up those structures and institutions (to produce what we may call an orderly civilization governing the behavior of man in society) represents a countertrend within the semipermeable boundaries of local systems against the general direction prescribed by the second principle—a decrease or consumption of entropy *on a local scale.* This suggests that our everlasting fight within the permeable boundaries of a living system to prevent the disordering consequences of the second principle of thermodynamics gives a basic definition of the ultimate value, purpose, or goal of life. Hence we ought to be encouraging in every way possible the preservation and extension of those behaviors and institutions which show the possibility of providing the most widespread and enduring order of human life. One might even erect this into an imperative (and I have done so), a thermodynamic imperative! It is the obligation of each one of us during our life on earth to fight the consequences of the second principle by preventing as much as possible the increase of entropy within the permeable bounds of the system of life of which we are a part.

*Science—the Short-Term Implications.* The considerations to which we have just given our attention may be thought too speculative and visionary to be of value with reference to our immediate problems. Most people naturally want to know what implications science has for them during their own lifetimes or at most those of their children and grandchildren. There are few who are able or willing to take a much longer look into the future. So now we turn to the likely short-term influence of science.

An important ideological influence of science on human thinking, which will become more marked in the next twenty-five years, stems directly from a growing realization of the essential unity of science. This statement may seem strange in the light of the obvious, ever-increasing specialization that characterizes modern science. But it will be noted that this process is accompanied by strengthened emphasis on interdisciplinary scientific activities. Astrophysics joins astronomy and physics, psychophysics joins physics and psychology, geophysics stresses the physics of terrestrial phenomena, etc. The rapid development of these fields reflects a renewed emphasis on the realization that nature knows no sharp boundaries between the various disciplines that purport to describe it, and that the conventional separation into the various so-called branches of science is purely arbitrary and now outmoded. This stress on the essential unity of science is bound to have a profound effect on the attitude of the lay public toward science. It also provides the scientist with more powerful tools for the solution of outstanding problems. Thus the collaboration of physical scientists and life scientists is facilitating our understanding of the nature of life itself. Closely associated with this is progress toward an understanding of the nature of thought as one of the unique aspects of human life.

This interdisciplinary activity is also promoting the social sciences as logical analogs of natural science in spite of what may be called the obvious psychological differences. There is small reason to doubt that the behavior of man in society is a perfectly possible subject for scientific inquiry, and that the application of the scientific method here will greatly increase our understanding of what at the moment are considered to be perplexing phenomena. Along with this will go an expanding awareness on the part of scientists of the essential role of the humanities in culture and, hopefully, a corresponding appreciation by humanists of the cultural value of science. It is imperative that the protagonists of the two great ways of looking at human experience should draw together if mankind's problems are to be solved in a rational fashion. There are encouraging straws in the wind in this connection. Many outstanding scientists are showing great interest in problems of philosophy and religion, and many humanists are expressing their realization that science is not just a collection of callous facts. Dangerous elements in this business should not be overlooked. Some scientists, trading on their scientific prestige as Nobel laureates, have made public statements on matters on which they are singularly uninformed. The mass media are not always alert in realizing the damage that can ensue from such ex cathedra pronouncements.

This reminds us to say something about the role of press, radio, and television in producing greater awareness of the social implications of modern science. Educational television is presenting many excellent and accurate programs on scientific concepts, and it is clear that these are leading to improved public understanding of science. On the other hand, there is a tendency on the part of the press to exaggerate the significance of new scientific discoveries reported at scientific meetings or through information supplied by the public information divisions of scientific societies. In order to provide a fetching headline, the science correspondent of the press is often tempted to feature the most speculative and least certain aspect of a scientific story. This can produce unhappy results in the lay mind, particularly if the story relates to biology and medicine. The answer to the problem is greater grasp of science on the part of newspaper science writers and improved collaboration between them and scientific societies and university science departments.

*Implications of Technology.* There is little doubt that in the public mind the greatest influence of science on man's future appears to lie in science-oriented technology. Even most scientists will concede this, although they will continue to stress that the effect of science on human modes of thinking and attitudes toward experience may well prove more significant in the long run. An unbiased view of history substantiates this conviction. However, the impact of technology is so obvious that it must be considered with care and in some detail.

Technology is an activity directed toward the satisfaction of human needs by appropriate manipulation of the environment. The enormous success of the technology of the twentieth century in achieving this end in the so-called developed countries of the world is admitted without argument. If the real basic needs of humanity are food, clothing, shelter, rapid transportation and communication, and release from the sting of hard physical labor exemplified by the wear and tear on the human muscular system, modern technology has met these needs beyond the wildest dreams of a few centuries ago. It has indeed abolished hard physical labor to such an extent that those persons in a developed country whose only means of making a living lie in their capacity for muscular exertion have been reduced to a very precarious economic situation, necessitating the introduction of programs of public welfare. Here we encounter one of the ineluctable realities of human experience, often ignored by the enthusiasts for utopia: for every advantage introduced by technology into human affairs there is a compensating disadvantage, for every plus there is a minus. This fundamental principle of compensation, of which the first law of thermodynamics is a well-known special case, has been emphasized by profound, humanistic thinkers down through the ages. Neglecting it simply leads to needless frustration. In this universe of ours one thing seems sure, and that is we do not get something for nothing.

Another characteristic of modern technology is that it not only has taken care of the primitive and universally recognized human needs but, more significantly, is creating new needs which were scarcely envisioned by our forebears. A clever idea emerges from the mind of a scientist; an enterprising technologist sees its commercial possibilities; soon some brand-new hardware is created and sold to the public by a vigorous advertising campaign as something that no one who counts should be without. A new "need" is born! Examples in our day are numberless.

Looked at dispassionately, this process may appear deplorable and even senseless to the philosopher. Why should human beings really need all these gadgets placed at their disposal and almost rammed down their throats? The short answer is that they do not! But from another point of view, such developments certainly make life more complicated, and that means more interesting to many, if not most. Moreover, in the process of creating a new need whole new industries are born, providing work for countless numbers of people under conditions far more favorable to well-being than the labor of our ancestors.

The pessimist or even the judicious optimist will observe that one of the "great" industries connected with the satisfaction of assumed human needs is, of course, the advertising business. Some may be inclined to question its contribution to human welfare, since its cost is added to the cost to the consumer of the products advertised. Its role in the process of creating needs which are not strictly necessary needs no belaboring here. This is not the place for a thorough study of its role in modern society. One might remark only that the psychological effect in many cases is probably to encourage consumer resistance to far-fetched claims. This seems to be all to the good.

The remarks made earlier about the difficulty of stifling or discouraging scientific research in a free society apply equally well to technology. As long as people are free to invent and to find persons with adequate resources to exploit such inventions, technological activity will persist and grow, and the population will be free to take advantage of the results as it sees fit. It is obvious that the state will endeavor to exert a measure of control over technological proliferation, but any rigid control means a completely planned economy, which is repugnant to the Western tradition.

The point of view that technology should be left free to develop will not be greeted cheerfully by those who now show great concern over what they term the abuses associated with technological progress. They point in particular to the deterioration of the environment as a direct consequence of unbridled manufacturing as well as the ever-increasing transformation of energy from fossil fuel into the motional energy of motor cars. No one can deny the existence of such effects, nor their growing menace to the environment, particularly in the neighborhood of large cities. It should be pointed out that environmental pollution is no new thing. From the beginning man has had rubbish to dispose of, and in fact if he had not, we would now know a lot less about the living patterns of our primitive ancestors. The problem has, of course, become more serious with the growth of population and the desire of people to enjoy the fruits of advanced technology, particularly while they live in congested areas. While the evils are real enough, there has been an obvious tendency to exaggerate them: prophets of doom have always been with us and always will be. One thing seems sure: the solution of the problem of environmental deterioration will not be found in a brake on technological advance, but rather in the development of more and better technology. In a democracy where free enterprise means what the name implies, people will not be willing to go back to the "simple" life of long ago, the "golden age" that never was, save in somebody's imagination. The cleaning up of the environment and the maintenance of it in a healthy condition will be carried out by technological means, whose efficiency will be enhanced by scientific research. There will of course be a bill for all this and it will be paid, as always, by those who enjoy the advantages of a clean environment and the comforts which technology provides. It is admitted that the problem is not a simple one. Government activity on a rather large scale will be involved in order to assure that some private affluence is employed to reduce the public squalor.

The demands of the environment will, of course, necessitate increase in the rate of energy transformation. This will encourage the search for newer and better means of utilizing energy sources available to us, a great challenge to science and technology of the future. We have already commented in Part II on possibilities in this direction. Not only must the energy supply be increased, but its present maldistribution must be corrected to provide a fairer share to the underdeveloped parts of the world. There seems to be little doubt that this problem of the energy supply and its more equitable distribution will be solved. If it is not, technology as a means of modifying the environment for the comfort of man will wither away, for energy transformation is the lifeblood of technology.

Those who inveigh against the advance of technology as an abuse of the environment are invited to remember that technology is really only a tool at the disposal of man to enable him to enlarge the number of choices available to him in his fight for survival. In the development of civilization man has always had to choose among various methods available for insuring his continued existence. Every choice has involved disadvantages as well as advantages. It is folly to expect that advanced technology will relieve us entirely of the dilemmas which have always affected the human race. It merely will change their character. We find a good example in medical technology. Advances in modern medical treatment and public health techniques have made possible the saving of countless lives whose earthly existence up to fairly recent times was commonly terminated at an early age. This appears to be a move consonant with high ethical ideals. But it has led to some unfortunate consequences. It has helped decidedly to increase world population, especially in those underdeveloped countries where the pressure on the food supply has always been critically great. At the same time it has immensely increased the burden on medical facilities everywhere to take care of the middle-aged people with not-so-strong constitutions who would not be around at all had it not been for improved immunization and other medical treatment for children. The dilemma here is obvious. Shall we blame it all on technology? Shall we settle for retrogression in medicine? It is equally obvious that we shall not. What we shall do is what is in fact being done already, and that is to invent new technology to cope with the difficulties resulting from the old. Birth control methods and more efficient ways of raising food will make an impact on population and starvation problems. More efficient medical technology plus renewed basic research in medicine will contribute to the conquest of the diseases of the middle-aged and old. But we must not expect that all this will provide a neat solution to our problems. There are no neat solutions and there will always be controversy over methods.

The contraceptive pill is a contribution of medical technology to birth control. The long-term physical side effects are at present unknown. One can only hope they will not be seriously adverse. A short-term sociological effect is causing concern to some. The relatively easy and safe avoidance of pregnancy is in the opinion of many leading to increasing sexual irregularity among the young. Leaving aside any question of a moral code, which some consider to be merely a relative matter, this laxity might well lead to a breakdown in the spirit of loyalty and obligation which is a cornerstone of family stability. So we have dilemma compounding dilemma. There is no likelihood that it will ever be otherwise. But this in no wise justifies us in abandoning technological innovation.

## Summary and Conclusion

In the three parts of this article we have sought to review the nature of science and technology. We have summarized some modern developments in both disciplines and have stressed the close relation between them in our time. Finally, we have attempted to assess some of the problems involved in the interaction of science and technology with man in society. It is folly to suppose that any one person can foresee the implications which advancing knowledge in these fields will have for the future of man. But we have attempted to set in perspective some of the problems involved in the interaction in question. One's attitude toward the future is to a great extent determined by his view of the present. The humanist who finds science and technology repugnant to him, or who at any rate is suspicious of what these things mean in the life of man, is naturally apt to take a pessimistic view of a future society so heavily involved with science and science-oriented technology. The scientist, on the other hand, who observes what these things have accomplished so far is inclined to take an optimistic view of the future. Science and technology have already solved difficult problems, and even if this solution introduces further problems, he may be pardoned for feeling that the best way to solve these is by the continued use of that method of rational thinking and inventive imagination exemplified by science and technology.