Some of the BROADER IMPLICATIONS of SCIENCE

By ***P. W. Bridgman***

The following is the text of the Second John Franklin Carlson Lecture, delivered at Iowa State College on May 1, 1957. Prof. Bridgman, who retired from active teaching at Harvard University in 1954 after being associated with Harvard for half a century, is known for his pioneering research in high pressures and for his contributions to thermodynamical theory and the philosophy of science. His work has brought him many honors, including the Nobel Prize in Physics in 1946.

THE impact of science on life is twofold. There is in the first place the technological impact. Here the factual discoveries of science are converted into practice; we discover how to make new sorts of things and how to do new sorts of things. Some of these new things have an impact on daily living so revolutionary that society and the world are transformed—such transformation has occurred often in the past and is still continuing. Among examples may be mentioned improvements in communication and transportation, improvements in health and medicine, and improvements in the production of power. However, the technological impact need not necessarily lead to improvement, for there is no guarantee that society will put the new inventions to beneficent uses, as is all too evident when we consider the military situation. In general, advancing technology gives us increased power over our environment, including our fellows, and it is up to us whether the use shall be beneficent or harmful. Whether beneficent or otherwise, it is characteristic of most technological advance that it follows rather closely in time the scientific discovery which made it possible; it is particularly characteristic of the present that the temporal lag between discovery and application is becoming shorter and shorter. This is natural in view of the increasing number of people who are employed in converting discovery into application, and the increasingly keen economic competition to discover the possibilities of such conversion before our competitor.

The second impact of science is ideological. People's ideas do change in a fundamental way as a result of scientific discovery. There is an important qualitative difference between the technological and the ideological impact in that the ideological impact is usually so delayed that the connection with the basic scientific discovery is not always obvious to casual inspection, the scientific event producing the change usually having occurred in a previous generation. Nevertheless, the connection is obvious enough to a student of history, and examples are plentiful. One example is the change of attitude in the last century of all thinking people toward the law of cause and effect—the conviction that the physical world is orderly, and furthermore that it is so constructed that it will yield its secrets to intelligent attack has come to be held by most educated people. This was not always the attitude of intelligent people, but instead an animistic attitude was commonly held, according to which the various natural phenomena took place according to the caprices of whichever particular spirit might be in control of the particular phenomenon. This change of attitude can be traced back to the scientific revolution spearpointed in particular by Galileo and Newton. Newton's achievement in bringing the phenomena of celestial mechanics under a single coherent point of view that could be expressed through mathematical equations produced a revolution in thinking which we now find difficult to appreciate. Or a second example, nearer in time, is the change in our attitude toward man's place in the universe, resulting from Darwin's theory of evolution. In fact, this is so near in time that the implications are not even yet universally accepted, as was emphasized by the Scopes trial and by the survival to this day of fundamentalist doctrine in some of the lesser religious sects.

The tempo of scientific discovery resulting in technological advance has obviously been accelerating, but no less has the tempo been accelerating of the sort of discovery that results in ideological change. Since the turn of the century, science has been discovering new things pregnant with ideological change so rapidly that not even all scientists are aware of the implications, and the

nonscientist is confronted with a mass of new material for thought which he has hardly begun to digest, if indeed he is aware of its existence. A new invention is distinctly in order of some intellectual enzyme that would accelerate the digestion of new ideas. There is no doubt that many people realize the need and are trying to find such an enzyme, but success up to the present has not been conspicuous.

The fundamental ideological problem which confronts us all, scientist and nonscientist alike, is the problem of finding intellectually satisfactory methods of dealing with the world around us. This problem we have always had with us. The traditional methods of attack on this problem in the past have not involved the scientist to any considerable extent, but have rather been the concern of the philosopher. How does it come about that the picture is now changing and that the scientist is becoming increasingly involved? I think this change has a twofold reason. In the first place, the nature of the world with which we are trying to make satisfying intellectual contact is rapidly changing because of the factual discoveries of science; and, in the second place, our conception of what constitutes an intellectually satisfying method is also changing because of the experience of the scientist that traditional intellectual methods are no longer satisfactory and do not function as had been implicitly supposed. I think the second reason is the more important. It was a rude shock to the scientist, from which he has not yet recovered, to find that traditional intellectual attitudes were no longer adequate in the new experimental situations. Now this discovery of intellectual inadequacy was not brand new, but glimpses of the state of affairs had been dimly described by a few philosophers and nonscientists for some time. The fact that the scientist has taken more to heart than his nonscientific colleague the implications of recent factual discoveries is not particularly to the credit of the scientist as opposed to the nonscientist. It comes about in large part because the situations with which the scientist deals are incomparably simpler than the ordinary economic, political, social, or religious situations of daily life, the complexity of which we even yet hardly appreciate. While the factual situations of daily life, in which we are so largely concerned with our fellow men, are admittedly less simple than the factual situations involving material things with which most of science is concerned, the scientist still further emphasizes the difference by the invention of a method, the method of experiment, especially designed to simplify the situations with which he has to deal.

Whatever the reason, and irrespective of any blame or credit, I take it to be a fact of observation that things are occurring in science which are going to involve dramatic changes in the ideological outlook of every one of us, scientist or not, and I would like to examine with you what some of these are.

It might be thought that I should begin by specifying what I mean by science and by the scientific method which is forcing these ideological changes. It is, however, notorious that a satisfactory definition is one of the most difficult things to achieve, so that one sidesteps the demand for a definition if he can. I think that we can side-step here the need for a precise definition. All of us can enumerate specific sciences, and the definition implied in such an enumeration is good enough for our needs. It is true that one may get into controversial ground, and there is no consensus as to whether such an activity as the study of history is properly to be called scientific or not. I do not have to settle questions of this sort, but shall merely remark that the sciences which I have in the back of my head would usually be described as the physical sciences, of which I regard physics as the prime exemplar. With regard to scientific method, I am one of those who do not think there is a scientific method as such, but that what primarily distinguishes science from other intellectual activities is the nature of the subject matter. The fundamental intellectual problem of the scientist is to find an intellectually satisfying method of dealing with certain aspects of the world around him, but this is no less the object of other primarily intellectual disciplines—a philosophically minded lawyer, for example, is engaged in trying to find an intellectually satisfying method of dealing with the sphere of human legalistic activity no less than is the physicist in trying to deal with the world of his laboratory. That this is so is fortunate, and gives our considerations here a wider interest, for there is something common to all human intellectual activity which enables experience in one field to be carried over into others. With regard to the subject matter of science, one of the very broad characteristics which distinguishes it from many other human activities such as aesthetics and ethics, is that the scientist can ask whether his statements are "correct" or not, and that there are procedures for finding whether a statement is correct or not. On the other hand, it does not make sense to ask whether a statement of aesthetics, such as "the sunset yesterday was beautiful", is a correct statement or not.

LET us now ask what new insights the scientist, and in particular the physicist, has been acquiring which are fraught with ideological change, not only for the scientist, but for the intelligent man in general. In my answer I can only attempt to present rather dogmatically what seem to me to be the most important features of the picture, and shall be compelled, because of lack of time, to omit any detailed argument in justification. Perhaps the new insights which we have had longest go back to our experience with special relativity theory in the early years of the century. Relativity theory forced a change of attitude which was perhaps too broad to characterize by any one new insight. A number of different new specific insights can be distinguished, such as the relativity of measurement, including in particular the relativity of simultaneity, and the necessity for a re-examination of fundamentals when new factual discoveries have been made. I would like to consider here a single, much broader insight, suggested by the particular insights of relativity theory but

not immediately equivalent to them. This is the insight of the importance of the role played by the verbal element in all our handling of the world around us. The lesson of relativity theory was, among others, the lesson of the importance of attaining precision in our meanings and the verbal expression of them. Meanings should be precise enough to enable us to reproduce the full experimental situation, and when the situation becomes complex, as it does when we enter the new field of high velocities, the demands on precision become exacting enough to demand what is essentially a new technique for giving meanings. What this technique is I shall not try to elaborate here—briefly it is a technique which I have called "operational", and I have examined what is involved at considerable length in other places. The details of the technique are not important for us here. What is important is that experience with relativity theory has made us self-conscious to the extent of forcing us to ask "what is the meaning?" in many situations which we would formerly have taken for granted. Furthermore, it has forced us to set up *some* criterion of meaning, whether operational or not is not important, according to which we judge the meaningfulness of our statements or terms. The mere verbal trick of asking "what is the meaning?" in some situations may entirely change our attitude toward the whole problem. For example, if we are asked "Do you believe in the existence of an external world?", we can see that the word "solipsism" is almost on the lips of our interrogator, and that if we are not careful we are going to be accused of it. But if we reply "What do you mean by external world?", the discussion is at once shifted to a level on which the term "solipsism" is not applicable.

At the social level, on which most of our daily lives as well as our science is lived, meanings are almost entirely a verbal matter. By concentrating attention on meanings we thus become conscious of the complexity of the verbal structure which we have erected for ourselves, and become more vividly aware of the extent to which our entire outlook is colored by the verbal machinery which we have unthinkingly inherited. Here the structure of the grammar of our language plays a role which is not usually appreciated. This is true of the nonscientist as well as the scientist. For example, the Indo-European languages have a preference for transitive as compared with intransitive verbs. This leads to the invention of nouns to serve as the objects of verbs —we are not content to say merely "I do" but must say rather "I do something". The result is that it is uncongenial for us to speak of the process of doing but must instead reify the activity. This colors all our philosophy from the time of Plato to the present—we concentrate our attention on the objects of our experience and not on our doings. This colors even our physics. The energy concept, for example, is usually thought to be perhaps the most fundamental concept of physics, but even here we have reification at work. All that we experience is one body acting on another, but our linguistic habits make it very easy for us to invent a something, energy, which passes from one body to the other when this interactivity occurs, and in fact the compulsion of our linguistic habits is so strong that we feel that we have achieved an "explanation" in talking in this way about what happens. That the situation is actually much too complex to be covered by such a simple reification was emphatically brought to light when relativity theory was forced to devise a way of talking which would be applicable to bodies moving with respect to each other with high velocities. It was found that no simple reification would suffice, but that the situation in its entirety demanded a sixteen-component tensor, with involvements with the nine stress components, the three components of momentum, and the three components of energy flux. In general, the moral is that actual situations are often too complicated to be adequately handled by the simple verbal machinery which we intuitively know how to use, and that the best we can do is to subject our verbal practice to the constant control of checks and balances, recognizing that we can pursue a specific verbal attack only a limited distance, and that we must presently replace it with another.

A realization of this is even more important on the level of daily life than on the scientific level. In daily life we continually encounter situations and use concepts which must not be taken too literally, which is merely another way of saying that they must not be pushed too far. The argumentative bore is essentially a man who takes his verbal machinery too seriously, and does not have the common sense to know when he should stop pushing his logic. A sense of humor is helpful in saving such situations—man should not take himself, or the human race either, for that matter, too seriously. The same sort of thing often occurs on a much broader social scale than that of the individual, and there may be mass movements in which the majority of society has for the time being lost its common sense ability to stop verbalizing when things are obviously going too far. To give a single somewhat trivial example, it seems to me that the current fashion in handling very small children is a case in point; to refuse to spank a willfully obnoxious youngster because of the harm it may do his "personality" seems to me to be pushing the verbal implications in personality too far. At a recent important sociological conference I heard a discussion by a psychoanalyst of the justification for punishing criminals which impressed me as much of the same sort. The argument was that punishment was seldom if ever justified, and that the criminal should rather be regarded as a victim of bad luck. This seemed to me to be pushing the concept of "responsibility" to a verbal extreme.

No linguistic structure is capable of reproducing the full complexity of experience. We have said that the only feasible way of dealing with this is to push a particular verbal line of attack as far as it can go, and then switch to another verbal level, which we again abandon when we have to. Many people are unwilling to do this, but insist on a single self-consistent verbal scheme into which they try to force all experience. In

doing this they create a purely verbal world in which they can live a pretty nearly autonomous existence, fortified by the ability of many of their fellows to live in the same verbal world. It is a bit of an art to know how to switch from one verbal level to another. The conviction of the importance of knowing when to switch is one of the lessons which we may take from the experience of the scientist with relativity theory.

Logic is an activity in which we are now seeing that the verbal involvement is closer than had been realized. There are some languages, notably some of the North American Indian languages, in which it is, to say the least, exceedingly difficult to formulate a general proposition, so that any logical processes which these Indians use cannot well be expressed in the form of the conventional syllogism. In general, it begins to appear that conventional syllogistic reasoning, which has been claimed to be a necessary consequence of the "laws of thought" may rather be a characteristic of the Indo-European group of languages.

It would be a mistake to jump to the conclusion that verbal activity as such is to be condemned. It is felt by many that the epithet "verbal" is an epithet of reproach. It is indeed true that it is often used with this connotation, and many times this is justified, particularly when there is no awareness of the verbal element. But in many situations it need not be an epithet of reproach, for in fact there is much wisdom in our verbal instincts, which have been formed over the generations in the hard school of trying to adapt ourselves to our environment. There are even situations in physics in which the verbal trail has led to scientific discovery. The situation with regard to energy, already mentioned, is of this kind, in which our verbal demands have led inevitably to the recognition that "energy" is not a thing but a tensor with sixteen components. There are other similar situations with regard to the creation and flow of entropy.

So much for the very broad insights into some of the implications of the verbal character of our activity which can be traced back to the stimulus of relativity theory. Now let us consider some of the insights afforded by quantum theory, which are on the whole, I believe, more revolutionary than those afforded by relativity theory. The domain covered by quantum theory is often described as the microscopic domain, and it is true that most of the pronouncements of quantum theory have to do with atoms and electrons and individual light quanta. In dealing with these small entities it was discovered that many of our ordinary ways of thinking are not applicable without modification. This is not the place to go into technical details and I can only suggest what the nature of the situation is. For instance, the ordinary concept of identity fails when applied to the electron, so that it does not make sense to ask whether the electron which we now find in a box is the *same* electron as the one we found there a moment ago. The ordinary concepts of time and space also fail for the electron—we cannot ask what is the position of an electron now and ask what is its velocity or energy at the same time. The concept of cause and effect also fails for the single electron, for there is no way of predicting from present measurements what our future measurements will give us. All these concepts—identity, space and time, cause and effect—are concepts which grew up and were validated within the familiar domain of experience. We now find that they fail when pushed into new domains of experience, previously not entered. The moral of this should be carried over to situations broader than those of atomic physics. We should see that the intellectual tools with which we try to get into contact with our surroundings were developed in a restricted range, and that they carry no internal guarantee that they will be valid outside that range. In fact, if we really take to heart the lesson, I think we will come to feel that the overwhelming presumption is that when we leave the range of restricted previous experience, we will find both new factual situations of which we previously had no inkling and will also find that the intellectual tools with which we handled our former experience are no longer adequate. It seems to me that in the social and political arena the range of our experience is now broadening in just such a way as to raise the presumption that traditional habits of thought will no longer be adequate, but that new points of view and new philosophies will be needed. The whole world is becoming interconnected and one, in a way which makes obsolete old provincial philosophies. No longer is a local political or religious philosophy a matter of indifference to the rest of the world, but we are all vitally concerned. To bring the matter pretty close to home, it seems to me that our whole philosophy of democracy should be re-examined. Democracy has been slowly evolving by imperceptible gradations into something very different from that from which we started, but there is no popular appreciation of this and certainly no self-conscious re-examination of the presuppositions that were historically determinative, to see whether they are still valid today. It seems to me that a new ethics is demanded to meet the changing situation. We have evolved into a society in which mass opinion, which is unavoidably not the best educated opinion, controls in a way which would have shocked the founding fathers, who conceived that the purpose of the machinery of democracy was to provide the means by which the most enlightened sentiments in the community should direct the course of events. The popular majority now controls. Control means potential superior force. This superior force is potentially exerted in every majority decision, although the actual exercise of naked force is seldom encountered. The new ethics which seems to me demanded is an ethics controlling the exercise of force by the majority. Since the majority is only the individuals who compose it, the question reduces to the question of the ethics which should control the individual in his exercise of force in his capacity as a member of a majority. Now every individual who is decently sensitive to his fellow men recognizes and respects an ethics in his individual exercise of force on his indi-

vidual fellow man. There are certain things which a decently socially responsible man cannot bring himself to do, even if it is to his own advantage, so long as the contact is between individual and individual so that the full mutuality of the relationship is obvious. But once let that man become a member of a majority, in which the immediacy of the individual contact is obscured, and he will consent to the use of force to his own advantage in a way which would be unthinkable to him as an individual. I would like to see more of individual ethics carried over into group ethics. I do not believe that any extant ethical system places the emphasis on this aspect of the relation of man to man that is demanded by our evolving society.

We have spoken of the new domain which has afforded the new insights of quantum theory as the "microscopic" domain because we are here so much concerned with atoms and electrons and other traditionally microscopic things. But if we examine what the "microscopic" things really are, we see that we are still on the scale of daily life, after all. It is only that we have found how to enrich the everyday world by finding how to do new sorts of things in it. We have invented microscopes, or Geiger counters, or cloud chambers, which are all instruments on the scale of everyday life, and the electrons or atoms which we say are revealed to us through these instruments receive their meaning through the measurements made with these instruments perceived by the same old senses operating on the scale of everyday life. The Maxwell demon, who could perceive and deal with the individual molecules of a gas, is a conceptual invention not corresponding to anything that happens to us. The nature of this situation is well recognized by many physicists concerned with quantum theory, although not by all, and it is frequently said that the new concepts of quantum theory must find their meanings on the scale of everyday life. This leads to what I believe to be one of the most important of the insights afforded by quantum theory, the insight, namely, that it is probable that the roots of the conceptual difficulties which quantum theory is bringing to light were always present in our everyday conceptual structure. If so, they might have been discovered earlier by sufficiently acute analysis. The probability of the correctness of this view is increased by the fact that relativity theory has already encountered a similar situation. For example, we might have been prepared for the relativity of simultaneity by arm chair reflection that the operations for measuring simultaneity involve the relative motion of two observers. If we accept the insight that the roots of our present difficulties were always with us, it becomes a fertile field for investigation to discover by more careful analysis just what these roots were. Still more does it suggest itself that there are still other features in our everyday conceptual structure which have never been uncovered. This affords a potent stimulus to make our analysis as searching as we can. I am convinced that there is a great deal to be done here. I believe that some of the most elementary operations have never been sufficiently examined, and that there are new things waiting to be found. For example, I have recently come across unsuspected assumptions back of the supposedly completely understood operation of counting.

In analyzing in detail how the traditional conceptual tools fail in the quantum domain another insight has been acquired which has implications far beyond the original range. Bohr and Heisenberg have shown by many examples how the interrelated uncertainties in measurement which are formulated in the Heisenberg principle result from the interaction between the object and the instrument of measurement. Now as long ago as it was known that light exerts a pressure we had the means of knowing that the act of observation reacts on the object being measured. The new feature uncovered by quantum theory is that, on the atomic scale, this interaction is uncontrollable and unpredictable. This means that in principle the object of knowledge and the instrument of knowledge must be thought of together as one indivisible whole. It is not easy for us to think in this way, but when we do, we find that many things appear in a new light and the atmosphere of paradox often disappears. For instance, the fact that the electron does not have identity appears less paradoxical when we reflect that an electron is not a thing in and for itself, but is an aspect of what happens in a larger situation, the larger situation including all the instrumentation usually thought of as merely revealing something about the electron in and for itself. We can set up our apparatus so that the measurement we make is of what we call the "position" of the electron, or we can set it up so as to measure the "velocity" of the electron. Heisenberg's principle states that the electron cannot simultaneously "have" position and velocity. This does not now appear so paradoxical if we express this by saying that we can have an electron as an aspect of a position apparatus or as an aspect of a velocity apparatus, whichever we choose, but not both. From this point of view we should not speak of an electron at all, but rather say: the position apparatus "electrons", or the velocity apparatus "electrons".

ANOTHER topic which appears in a different light is that of probability. It is surprising, and surely significant, that in spite of prolonged discussion by many men of the highest technical competence, the subject of probability is still controversial. Quantum theory, with its interpretation of the psi function of the fundamental Schrödinger equations in terms of probability, has only accentuated the disagreement and emphasized the desirability of reaching some sort of agreement. One of the chief topics of controversy is the "reality" status of probability in the world of concrete objects and events. In what sense do concrete individual happenings "have" a probability? The point of view that wants to make an individual throw of a die, for example, have an objective probability is the point of view that wants to consider the throw of the die as an event in and for itself, completely divorced from the events that are associated with it and from the operations

which give probability meaning. If we consider the whole picture, however, throw of the die and the background in which we calculate its probability, we see that there is a subjective element that we cannot get rid of, and that probability is a more complicated thing than at first appears. Although the necessity for keeping in mind the whole background is, I believe, especially pressing in the situations presented by probability, I believe that it is always present to some extent in every situation in which we try to apply mathematics to concrete situations. The difficulties presented by probability are not different in kind from those we encounter in many other places—only they are more obvious and greater.

The insight that it may be dangerous to pick a situation to pieces and analyze it into parts is not an insight for which we had to wait for quantum theory, but the vision had already been seen in other fields. "Holism" is a word that springs to mind in this connection. Now the desirability of a "holistic" point of view in many situations may be readily conceded—the difficulty is how to achieve it. It seems to me that we are here brought face to face with mutually inconsistent demands and that a completely satisfactory solution is not attainable. For it seems to me that perhaps the first prerequisite to all human thinking is the ability to consider one thing at a time and to isolate the various features of experience from their surroundings. The infant makes progress in adapting itself to its environment only when it is able to recognize objects and events as self-contained things which recur, and which may be experienced over and over again in different surroundings. Language itself is composed of words, which are merely symbols for relatively fixed aspects of our experience, taken in isolation and abstracted from their surroundings. On a more sophisticated plane, modern science is built on experiment, which exploits the simplification that results when individual features can be picked out from a complex environment, isolated for study, and individually controlled. "Isolation" appears essential for thinking, yet when we push the analysis far enough we see that isolation is in principle impossible, and that no event ever exactly recurs and no word ever means exactly the same twice. The situation can be dealt with only approximately, and by operating first on one level and then on another. In the last analysis we are forced to practice an art, not a science.

It is often said that quantum theory has shown that the observer is not to be forgotten in any analysis, but that he has a role to play of usually unappreciated importance. Now it does indeed seem to me that there is concealed here a new insight, but I believe it is an insight only suggested by the quantum situation and not precisely indicated. The technical observer of quantum theory is little more than the instrument of measurement—in the reaction of this instrument with the object of measurement is to be found the explanation of many of the paradoxes. I think this suggests something further—quantum theory deals with the object of knowledge and the instrument of knowledge; these it has taught us must be treated as an indissoluble whole. But beyond this we have the knowledge itself, which quantum theory treats as an end product, without attempt at analysis. But what is this "knowledge" and what are its implications? The question is not new but has been the concern of philosophers for two thousand years, who have discussed it under the title "epistemology". To a somewhat sceptical outsider it does not appear that all the philosophical concern with epistemology has got us very far. I think one can at the present time discern the dawning of a new insight that is so devastatingly simple that the implications are not even yet fully grasped. This insight comes from the simple observation that knowledge never occurs except in conjunction with a human nervous system which has itself been subjected to elaborate preconditioning. A number of recent scientific developments are playing together in favoring this insight. Perhaps the most important is the recent development of complicated calculating machinery, which so successfully performs operations previously performable only by human beings as to seriously suggest the question as to whether such machines may properly be said to "think". There has been much discussion in the technical literature—there seem to be two main attitudes toward this question. One group sees no reason "in principle" why human thinking should not be duplicated by a sufficiently complex structure which could be constructed by us in a physical or chemical laboratory, although it is to be recognized that the complexities may be so great that at present they can be reproduced only with the cooperation of a biological living system. The other group, which appears to me to be more obviously swayed by emotional considerations, takes the position that thought is something *sui generis,* and that we will never be able to make a machine that will "think". To maintain this position, emphasis is laid on those characteristics of thinking, such as the ability to set its own problems or to think about thinking, which have not yet been incorporated into any computing machine. The discussion continues, and it is not yet clear whether or not some new feature not yet visualizable as attainable in computing machinery will be necessary in order to reproduce successfully all that is usually implied in "thinking".

A number of recently developed lines of inquiry are all converging on giving a better understanding of what is involved in trying to reproduce some of the functioning of the nervous system and the still more general problem of understanding the nature of the nervous system itself. One such line of inquiry is information theory, which is proving to have application far beyond the range of communication engineering, for which it was designed, even reaching so far as to throw new light on complex biological problems. Closely related to information theory is the subject of servomechanisms, that is, those mechanisms which automatically alter their functioning in response to changes in their environment. This is the subject for which Norbert Wiener coined the word "cybernetics", and to which he made important contributions. On the physiological side,

knowledge of the manner of functioning of the brain is accumulating at a rapidly accelerating pace, stimulated by the development of new electrical techniques. This subject is, however, admittedly still in its infancy. It is not known, for example, what in the functioning of the brain corresponds to what we call consciousness. An appreciation is growing of the complexities of the processes back of "perception". Of course the psychologists have realized this for a long time, and have been able to demonstrate it by the systematic study of various sorts of illusions. Recently a new vividness has been given to the realization of the complexity of this situation by the ingenious "demonstrations" of the late Adelbert Ames, Jr., and his colleagues. The perception of space, which for us is so immediate and compulsive, is seen as something of great complexity, involving both the present structure and the past preconditioning of the nervous system. One cannot see the "demonstrations" without being impelled to ask whether the mold of space and time, into which our perceptions pour the world of our experience, is a "good" mold or not. In view of the facts in the quantum domain of the very small, and the new cosmological discoveries on the scale of the very large, including the possibility of the continuous creation of matter, one cannot help feeling that the mold of space and time is not a very good mold for the entire range of phenomena. Whether it is possible to create a better mold is not at present evident. It is at least evident that ingrained habits of thought are going to demand a supremely creative act of imagination if we are ever going to break out of the rut.

BRAIN physiology is giving the insight that the complexity of the brain is so enormous as to provide by a fantastically wide margin for the possibility of all the conscious experiences which a man can have in a lifetime. Scientific economy demands, therefore, that in our endeavor to understand the nature of thinking we exhaust the possibilities in the complexity of our nervous organization as we now know it before we introduce any at present unknown or extra-natural considerations. There is at present no indication whatever that a complete reduction to natural factors will not ultimately be possible. While brain physiology is suggesting the adequacy of the nervous structure of the brain to provide for all our thinking, it is at the same time emphasizing the complete impotence of the brain to reproduce the full complexity of the external world of which it is a part. The reason is simply that the external world is so much bigger than the brain that full correspondence between the state of the brain and the state of the world is utterly impossible. From this point of view it is little short of a miracle that the brain is able to set up a correspondence with the external world good enough to satisfy the demands of mere survival. Specialized modes of functioning would seem to be demanded which slowly evolved with the evolution of organic life on this earth. At the same time, there is no reason to think that such methods of functioning would be adapted to meet the full range of requirements beyond the necessities of survival. One of the specialized modes of function which the brain has evolved and of which we have already spoken, is to "isolate" features out of the whole matrix of experience. "Isolation" gives us our objects and our words, without which thinking seems inconceivable. We are, nevertheless, encountering new realms of experience in which we can see that this ubiquitous device may no longer be adequate.

It did not need the recent developments of brain physiology to emphasize the complexity of the nervous processes in the brain. One of the most important of the insights of Freud was the realization that processes are going on in the brain of which we are usually completely unaware, but which may nevertheless on occasion play a dominating role, even at the level of conscious activity. From this point of view it has always seemed to me that philosophers like Hume and Mach, who have insisted on the reducibility of all experience to sense impressions, have grossly oversimplified. Even under the thesis that only natural factors are involved in the behavior of organisms, surely no one would undertake to reproduce the behavior of a man or of any other organism, no matter how simple, given only the complete history of all the stimulus which it had received through its sense organs. In addition, the complete biological inheritance would be required, which determines, among other things, whether the egg turns into a man or an amoeba, and which can by no means be described in terms of stimuli to the organism from outside, whether conscious or not.

There is a recent development in mathematics which emphasizes the difficulty of adequately understanding the nature of knowledge. In much of the discussion of whether a machine could be constructed which might properly be said to "think", particular emphasis is usually laid on the difficulty of making a machine that will do such things as reconstruct itself, as do biological systems, or "learn" in the sense of being able to modify its own built-in codes of action. Now these are special cases of the machine dealing with itself. These special problems can probably be solved to at least some degree of approximation—the point I want to make is that whenever a system is required to deal with itself it is felt that special difficulties are involved which will demand special methods of solution. A recent development in mathematical logic is suggestive in this connection. Gödel was able to show that a logical system of the complexity of arithmetic can never be proven to be free from concealed self-contradiction so long as one is restricted to theorems provable within the system of arithmetic. This discovery was perhaps as shocking to the preconceived notions of many mathematicians as was relativity theory or quantum theory to the physicist. The conceptual implications for the mathematician are still being discussed. For us, we concentrate on one simple aspect of this situation, namely that here we have a system, arithmetic, dealing with itself, and encountering limitations which had not been suspected until they were brought to light by detailed analysis. It does not need much effort of the imagination to see

here something of more general import, and to expect that whenever we find a system dealing with itself we may find special and perhaps even insurmountable limitations. The application to our present problem is immediate, for when *we* try to understand the nature of knowledge, we have a nervous system attempting to deal with an aspect of its own functioning. That is, we have a system dealing with itself. Expressed differently, we as individuals, and the human race as a race, cannot get away from ourselves, in spite of our fond imagining that we can and in spite of the fact that the structure of much of our thought ignores recognition of our inability so to do. The presumption that there must be unsuspected inherent limitations because of this is almost irresistible.

THE broad outcome of these considerations stemming from brain physiology, cybernetics, and information theory, and indeed also stemming from the more particular insights of physical science afforded by relativity theory and quantum theory, may be simply formulated in the statement that we do not yet understand the nature of our thinking or of our intellectual tools. It seems to me that the one overwhelmingly important intellectual problem before us is to acquire more adequate understanding of the nature of thinking. Who can doubt that when we have acquired it, the complex problems of daily life, to which unreflective familiarity has lent such a deceptively simple appearance, will appear in a light sufficiently illuminating so that we may hope to get some degree of rationality into our handling of them?

In the meantime, on a less grandiose scale, I think that science gives insights into the nonscientific situations of the humanities and daily life sufficient to justify us in attempting to make a more rational attack on some of these problems without waiting for a complete final solution. Consider, for example, a field which it is usually said science is unable to enter, the field of values. It must be admitted that simple observation of any of the special sciences shows that science has no method of determining what we *should* do in various situations; its function is rather descriptive, explanatory, and predictive. Although science has to accept values as "given", as the pre-set conditions of a problem to which it has addressed itself, science can legitimately strive for more precise description of that human behavior which concerns itself with values, and in so doing may uncover aspects of the situation not previously fully appreciated. Or science can set itself the problem of explaining how it came about that particular sorts of behavior are accepted as having value. Finally, science can set itself the problem of predicting with more assurance than would casually be possible what will be the consequences, to society and the individual, of acting in accordance with any particular set of values. Now all these scientific activities carry the potentiality for most important reactions back to the system of values itself. For the value which a man ascribes to a particular line of conduct can hardly help being affected if he sees it in an unfavorable historical perspective, or if he realizes that consistent action by other people according to that value would result in social effects which he had not anticipated and which he does not desire. In fact, it seems to me that we have here the ultimate and the only rational tool by which we may hope to purify our values. It does no real good to moralize or to tell a man what is his duty. If a man responds to the appeal to do his duty, it is only because of the veiled threat of social coercion—"he who consents against his will is of the same opinion still." But a man will change his values when he sees that there are consequences which he had not realized. The task of the individual in forming his value system is to acquire the greatest possible self-consciousness of all the consequences implicit in his value system. Society, in educating the values of the individual, can rightly do no more than to devise methods for making the individual fully aware of all the consequences of acting according to this or that code of values. Further, a task of society is to devise such a method of mutual living that the individuals may realize their own values with the minimum amount of mutual interference. It will doubtless happen that the self-consciously educated values of some individuals will be so inconsistent with the value of the median that the only possible way of dealing with such individuals is by forcible repression, something which is practical provided there are only a few such individuals.

It is to the advantage of society that every individual acquire the greatest possible degree of self-consciousness of the consequences of his own value system, because in this way there is the greatest stability against the possibility of unprepared-for change. The great gamble to which society is committed is that the average human being is so constituted that his value system will be compatible with the harmonious living together of all. If this is not true, we had better find it out as soon as possible, and in the light of it revise our whole social philosophy. In this re-assessing of values, from the point of view of both the individual and society, the insights which we are acquiring from our scientific experience may well play a determinative role.

In conclusion and summary, the scientific enterprise is not different in kind from any other human enterprise in which the method of intelligence is competent to play a leading role. The situations which are the immediate concern of science are, however, of much greater simplicity than the situations of daily life. Because of this greater simplicity science has been the first to acquire the new insights which are demanded to cope with the ever-growing complexity of our environment. These same insights are applicable in the much wider setting afforded by society. When, by the application of these insights, we have become masters of our intellectual tools and understand the nature and the limitations of thinking, we may expect to surmount the frustrations which now so often beset us. The way is long and difficult, however, and will demand a radical break with traditional habits of thought.