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PHYSICS AND THE THALES PROBLEM *

INTRODUCTION

THALES, the first Philosopher, is reported to have asked "How, and of what, is the world made?", and many scientists have since tried to answer him. In my opinion, current scientific theory provides an adequate answer to the question, so that science has solved Thales' problem and has thereby repaid its debt to Thales and indirectly to Philosophy for inspiration.

In trying to establish this thesis I shall be using terms like 'problem', 'solve', 'essentially solved', in ways which are commonly used by scientists, and hence I will not engage in extended methodological excursions to clarify them. I do not think that I need justify my claim that scientists do accept theories and hypotheses, for, despite the contrary view of some philosophers, it is evident to anyone reading the scientific literature that they do. It might be contended that they should not. I shall briefly note that, in light of the evidence currently available for many scientific theories, it would be unreasonable for scientists not to accept them.

I will also not apologize for the view that scientists have repeatedly tried to solve Thales' problem and, hence, for the more general thesis that science, over time, has often repeatedly dealt with the same problem, despite variations in theory and orientation. Once again here I am at variance with some currently popular philosophical positions, but the data I shall discuss below allows, I think, for no other reasonable interpretation.

I. THE THALES PROBLEM

Physics deals with one problem and with many problems. In the widest sense, physics is the study of all phenomena that occur in nature, and its problem is to understand them. But, at any given stage in the development of physics, we are aware only of some fraction of the phenomena that will be known at a later

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* I would like to thank Professor Sidney Morgenbesser for countless illuminating discussions on the issues discussed in this paper.

stage. Furthermore, because of historical accident, cultural variation, and other incidental reasons, the physicists of different ages have often concentrated on particular phenomena or aspects of phenomena in their investigations, disregarding others for the time being.

There is, however, one problem that has remained close to the center of interest of physicists for almost 2500 years. The first explicit statement of the problem is attributed to Thales of Miletus, who asked ''How, and of what, is the world made?'' Less poetically, we may say that the question is that of the structure and composition of bulk matter, by which is meant the objects and substances we find around us.

Of course, other interpretations of Thales' words are possible, including one which would make the question equivalent to all of science. I believe that other interpretations are counterhistorical, but I shall touch on some of these wider questions in the last section.

Already in the asking of this question there is implicit the assumption of a simplicity underlying the complexities of bulk matter. Starting with the Ionians, physicists have proceeded under this assumption, with the result that, by the middle of the twentieth century, we have found a comprehensive explanation of the properties of bulk matter. I refer of course to the description in which matter is taken to be composed of nuclei and electrons, and these objects follow the laws of quantum mechanics.

With this theory I believe that we have essentially answered Thales' question, at least in the sense it was originally posed. The answer is that many aspects of the world around us can be understood by supposing that matter is composed of atoms. Most of the remainder are understood by analyzing the atoms into electrons and nuclei. A very small number of everyday phenomena, such as the shining of the sun, require for their understanding a further analysis of the nuclei into neutrons and protons, together with the introduction of the neutrino, a very weakly interacting particle which seems to play no role in natural phenomena other than in certain decay processes.

There are, involved in everyday phenomena, other components than bulk matter, such as light, heat, psychological qualities, etc. When I refer to the understanding of such phenomena, I will stress those aspects which depend on the structure of matter per se. To the extent that the other components are a part of physics, I would say they are also rather well understood, but it would take me too far afield to discuss the ''immaterial'' aspects of physical phenomena in detail.

The multitude of "elementary particles" which have been discovered in high-energy physics in the past thirty years appear to play a negligible role in phenomena outside the laboratory, except perhaps on a cosmic scale. I shall cite some of the evidence for this conclusion in section III. Because of this "irrelevance" of the elementary particles for most natural phenomena, it seems inappropriate to include the study of them in Thales' problem. Evidently, this is not to say that such a study is unimportant. Indeed, elementary-particle physics is one of the frontiers of human inquiry, and very subtle intellectual questions are involved in it which we are far from answering. Some of these will be alluded to in section IV. Nevertheless, I think that it is a mistake to let the unsolved problems of particle physics obscure the progress we have made in understanding matter.

Although, in the deepest sense that we know, matter is composed of particles like neutrons and protons which we do not wholly understand, none of the phenomena we generally come across seem to depend on those aspects of particle physics which are still mysterious. It is in this sense that I believe that we have solved Thales' problem, and now understand "How, and of what the world is made."

In order to document this thesis, I shall first briefly discuss some of the historical stages in our understanding of matter. In particular, I shall mention four approaches to the structure of matter. These are the views of the Greeks before Democritus, the atomic theory of Democritus, the atomic-molecular theory of the nineteenth century, and the contemporary view. By comparing these, we shall see how physics has gradually come to understand everyday phenomena in terms of objects very different from everyday objects.

Next, I shall analyze more carefully the notion that most of elementary-particle physics is irrelevant to the structure of matter. Finally, I shall finish by outlining some questions that may occupy physisicts in depth in the future, as Thales' problem has in the past.

II. Steps in the Solution of Thales' Problem

In this section, I briefly review some of the steps leading to our present understanding of matter. None of the material is novel, but I will stress certain features of it which I believe to be insufficiently appreciated. In this way, I will show some of the breaks and the continuities in the development of the solution of Thales' problem.

The earliest recorded speculations about the structure of matter, which date to 600 B.C., are based on the idea that the different forms of matter observed are composed of a single ''primal'' constituent or a few such constituents. Thales said that this primal substance was water, Heraclitus, that it was fire. At a later stage, the canonical combination of earth, air, fire, and water was introduced by Empedocles. At a distance of twenty-five centuries, these attempts may seem hopelessly naive. But it is well to note that they were among the first efforts to find a simplicity behind the complexities of natural phenomena and, as such, are the direct ancestors of our own theories of matter.

An important feature of the Ionian speculations is that the primal substance was always taken as one or more of the forms of matter apparent to the senses. To those men, it seemed very reasonable that the ultimate stuff of which the universe is made should be a familiar substance, with familiar properties. The feeling was essentially that the underlying reality should already be apparent on the surface of things. Such an attitude has indeed persisted among some of the greatest physicists through the nineteenth and twentieth centuries. Examples which come easily to mind are the desire of Maxwell for a mechanical model of the electromagnetic field and of Einstein for a deterministic substratum of quantum phenomena. It would have been comforting if the physicist's job were made easier in this way. Unfortunately, the world is not so simple, and the proper understanding of matter requires the imagination to invent entities not apparent in everyday phenomena. It is the enduring miracle of creative thought that the mind is equal to this task.

This next step was already taken by some of the Greeks, in the atomic theory of Leucippus and Democritus. In this theory, the sensorially apparent forms of matter, and their properties, are regarded as secondary, and the ultimate realities, the components of matter, are the indestructible atoms, moving about in the vacuum. Democritus himself makes this point very clearly, in his celebrated quotation: ''Color is by convention, sweetness is by convention, bitterness is by convention, in reality there is nothing but atoms and the void.''

The remarkable thing about the Greek atomic theory is not that it anticipated the atomic theory of the nineteenth century. There were, after all, no phenomena known to Democritus that required atoms for their explanation, and he does not seem to have predicted any new phenomena with his theory. What was remarkable is that he was willing to make the intellectual leap of assuming the existence of unobserved objects quite different from those found in ordinary matter, and to account for everyday objects in terms of them. It is in this sense that Democritus is a forerunner of modern physics, in which the properties of bulk matter are accounted for in terms of atoms and their component particles, which themselves behave very differently from the way bulk matter does. Of course, Democritus was not able to give such an explanation himself, since neither the relevant dynamics nor the relevant observations yet existed.

Yet so tempting was the Democritean theory that Isaac Newton more or less adopted it in his own theory of matter, as outlined in the famous Question 31 of his *Optics*. The atoms were now given inert mass and endowed with gravitation and other forces, to describe their interaction. Newton used this model to explain some of the chemical and physical properties of matter, those we would now classify under solid-state physics. There were still no quantitative results, and hence Newton's atomism was not given the attention of his dynamics.

In the nineteenth century, the atomic theory was revived by Dalton and others, who used it to explain the fact that, in chemistry, different elements always entered into compounds in amounts that were the ratios of small integers. The Daltonian atoms differ from those of Democritus mainly in that distinct elements have different kinds of atoms associated with them. As yet there is no hint of atomic structure or dynamics.

The other triumph of the atomic theory in the nineteenth century was the kinetic theory of gases. This was essentially an application of the Newtonian model mentioned above. By assuming that gases are composed of atoms that obey Newton's laws of motion it was possible to explain many properties of gases, such as the equation of state. Again, this step did not require any detailed knowledge of atomic structure at first, except the assumption that the atoms were perfectly elastic. It was possible to go somewhat further, and by examining the deviations from the ideal-gas laws, Van der Waals and Maxwell were able to determine the number of atoms per unit volume in a gas, or Avogadro's number, to about 50 per cent accuracy. With this number, it was finally possible to estimate the size of atoms, which made the atoms seem somewhat more real.

In spite of this, some of the sharpest thinkers among nineteenth-century physicists completely rejected the atomic theory. Mach, for example, went so far as to call it meaningless or useless. The main reason for this rejection seems to have been that throughout the nineteenth century the atom remained hypothetical in that there was no direct evidence for its existence. More important, it was not even clear how such evidence could be obtained in principle. In the twentieth century, through the use of techniques such as x-ray diffraction, such direct evidence was finally obtained. At the same time that this direct evidence of the existence of atoms became available, it also was discovered that atoms are not really indivisible, but rather can be analyzed into components: nuclei and electrons. Thus, somewhat paradoxically, most physicists were convinced of the existence of atoms only after the discovery that the atoms are after all not the ultimate constituents of nature.

The discovery that atoms have a structure and contain charged particles was made in the late nineteenth and early twentieth century by J. J. Thomson and Rutherford. This discovery by itself was sufficient to solve some of the remaining problems in the structure of matter, such as how bodies can be electrified and magnetized. The next step was rather unexpected. It soon became clear that the components of atoms could not be adequately described by the dynamical laws describing large-scale objects, i.e., Newton's laws of motion. This was quite shocking to the physicists, who thought that the "system of the world" had long since been discovered. Nevertheless, it did not take very long (circa 25 years) for them to invent a new description of nature, i.e., quantum mechanics, for dealing with atoms and their constituents.

Perhaps, in retrospect, the fact that some of the laws governing atoms are different from those apparently governing bulk matter should not have been so surprising as it was. As we have seen, Democritus already realized that the components of matter were different substances from matter itself. So we might have expected that the laws describing atoms might contain new features quantitatively unimportant for large objects. This may, however, be one of the arguments that can only be made from hindsight.

The Bohr-Rutherford nuclear atom, as described by quantum theory, proved sufficient to account for "all of chemistry and most of physics." This is not to say that there are no more problems left in solid-state physics or in other branches of the subject not dealing with elementary particles. The point is rather that we are almost sure that there are no new laws of physics to be discovered in these areas. I would make an exception in this statement for cosmology, or the study of the universe as a whole. Most physicists would agree that the properties of solids, liquids, gases, atoms, and even nuclei are contained in known physical laws and that the remaining problems in those fields require only that we find the correct way of applying these principles. Of course, saying this makes the problems no easier to solve.

The process of solving Thales' problem involved a double triumph of the imagination. On the one hand, we have been able to account for the multitude of diverse properties of bulk matter, such as hardness, color, superconductivity, and even life, on the basis of rather simple properties of electrons and nuclei. On the other hand, by experiments with bulk matter, we have been able to discover its elementary constituents, even though these are many orders of magnitude smaller than the objects with which we deal, and display quite different behavior. For the most part, the reasoning has been indirect, although in the last stages of the search there have been discovered effects on a macroscopic scale, such as superconductivity, in which the quantum properties of the electrons and nuclei play an essential role. It is interesting that superconductivity and the superfluidity of liquid helium were in some sense the last phenomena of meta-atomic physics to become understood qualitatively.

The fact that it is possible to understand bulk matter by using only simple properties of electrons and nuclei does not mean that the latter are themselves simple. On the contrary, the physics of the past thirty years has been largely concerned with the study of those objects and others associated with them. Along the way it has been found that these "elementary particles" have some rather unexpected properties of their own. It may indeed be that the physics of elementary particles is as rich a field as the physics of bulk matter has been. Nevertheless, it appears that the two fields are almost disjoint.

III. THE "IRRELEVANCE" OF ELEMENTARY PARTICLES

In the past thirty years, liberal amounts of time, thought, and the taxpayers' money have been invested in the study of what are called "elementary particles." For the present purpose, we may take as an elementary particle anything apart from a hydrogen atom with a definite angular momentum and a mass less than that of a deuterium nucleus. From this study have come many remarkable experimental results, a few glimpses of theoretical understanding, and much confusion. Perhaps the salient feature of the elementary particles discovered until now is that there are a large number of distinct varieties of particles (some 137 at present) and that, when enough energy is available, they charge into each other freely without regard to number and kind, except insofar as they are constrained by certain conservation laws. This has led some physicists to doubt that any of the particles are more fundamental than any other and to state that the proton is no more or less a composite than the uranium nucleus. I do not intend to enter into this interesting question here. I would, however, like to remark that, of the properties displayed by the particles in high-energy experiments, only a small number are relevant to determining the structure of bulk matter. Indeed, only a small number of the particles seem relevant to this problem.

Let us see how one is led to this view. In order to recognize that atoms are composed of electrons and nuclei, it is sufficient to do experiments at very low energy. (The kinetic energy of the atoms can be of the order of electron volts.) With experiments at such low energy, say with thermal neutrons on U-235, one can even show that nuclei are composite objects. The particles that are found by disintegrating atoms in this way are neutrons, protons, and electrons. The particles of these kinds which come from a particular atom in some sense were not created in the process of disintegration, but were there all the time. It is difficult to make this notion precise for a quantum-mechanical system, but at least two important criteria are satisfied. One is that properties of the atom such as charge and mass are very nearly equal to the sums of these quantities for the particles that are found in this way. The other is that the number of neutrons, protons, and electrons obtained from a given atom is the same even if we use different low-energy probes to examine the atom. On this basis it seems reasonable to conclude that these particles are not created in the process of analyzing the atom, but were there all along. It is unlikely that this notion can be given much more precision in view of the famous interference of the measuring process with the system observed, characteristic of quantum mechanics.

It seems, furthermore, to be the case that ordinary matter contains only these three particles. The sense of this is that, if we analyze matter with probes whose kinetic energy is well below the threshold for creating one of the other 130 particles, none of these other particles will be found. An apparent exception to this comes if we use probes made of antimatter, such as antiprotons. In this case, even if the antiprotons have very low kinetic energy, they can still annihilate with the protons and neutrons in matter, producing many of the unstable particles. I do not think this vitiates the analysis, since it does not seem feasible to consider the annihilation products as pre-existent in the proton and antiproton. Instead one must, as in other cases in particle physics, allow for the creation of particles that were not there previously. Thus if we restrict our considerations to that domain of physics where the average kinetic energy per particle is small compared to the muon rest energy, which is the smallest energy necessary to create one of the unstable particles, the only particles that appear in real form are electrons, protons, neutrons. In addition to these, there are the particlelike photons, whose properties are well understood, and the neutrinos, which interact so weakly with matter that they are unimportant for Thales' problem. Now, in most of the universe, the average energy per particle is very small compared to the rest energy of the muon. For example, at a temperature of 1.2×10^{10} degrees Kelvin, hotter than the center of any known star, the average kinetic energy per particle is only 1 per cent of the muon rest energy. Hence, only on particle in 10^{40} will have an energy equal to the muon rest energy. Only in cosmic rays and in man-made accelerators are energies high enough to create the other unstable particles, so far as we know.

It follows that any effect of these other particles on the properties of ordinary matter can come only through their occurrence in virtual states. That is to say, it is possible to create the other particles for a very short time, in which case, by the uncertainty principle, energy conservation need not apply.

There are of course effects of such short-time creation and annihilation of particles. For example, the creation and destruction of pions is mainly responsible for the nuclear forces. However, it would be misleading to conclude from this that we must understand the pion and the other unstable particles in great detail before we can understand "how the nucleus holds together." Insofar as we are willing to treat the nuclear force phenomenologically, we can learn about it from a study of nuclei themselves, without reference to where the force comes from. Even if we wish to derive the nuclear force from the theory of pions, what is mainly relevant is the existence of particles with a certain mass and angular momentum, not the details of high-energy-scattering cross sections or the other phenomena of interest to particle physicists. It therefore seems unlikely to me that further discoveries concerning the elementary particles or the addition of new members to that family will shed any real light on the properties of nuclei. The still unsolved problems of detail in that field are more likely to be understood through the discovery of subsystems of nuclei, such as the shells, in terms of which simple approximations can be made.

I expect that it is even less likely that the details of elementary-particle physics are relevant to phenomena not involving nuclear transformations. Most of the phenomena that take place on earth and in the outer layers of stars are in this category. Unless our present ideas are wholly misleading, a knowledge of electromagnetic and gravitational forces, together with a knowledge of the existence of nuclei and electrons, is sufficient for the understanding of these phenomena.

I have said that the details of particle physics are irrelevant to the structure of bulk matter. The unsolved problems regarding the structure of matter come because we are applying the known principles to complicated systems. One remaining question one might raise about the Thales problem is the possibility that the application of these principles might at some stage fail to explain either some known phenomenon or some yet undiscoveed phenomenon involving bulk matter. Both of these occurred in the late nineteenth and early twentieth century, the former with regard to optical spectra, and the latter with regard to radioactivity. In this regard, some physicists have argued that the laws of quantum mechanics are insufficient to explain living phenomena (Elsasser) or mental phenomena (Wigner). I think that it is premature to draw these conclusions, as the detailed study of living phenomena with the full use of physics and chemistry is rather recent, and its spectacular progress is such that predictions of impotence may soon be falsified.

One cannot rule out on a priori grounds the possible discovery of new macroscopic phenomena inexplicable by the atomic theory, but I am inclined to await their discovery skeptically. I think that the parallel with the situation in the late nineteenth century is not really valid. At that time, there were many phenomena known for which not even an order-of-magnitude explanation was available, such as spectra. On the contrary, at present I would say that all macroscopic physical phenomena are understood at least qualitatively. Also, in the late nineteenth century, atoms were still rather mysterious, and no idea of their internal structure existed. It might have then been anticipated that new effects might be discovered involving this internal structure. Although it may involve a lack of vision on my part, I cannot see any such unknown regions on our present map of nature. In view of this, it seems to me that we now have a model of the structure of bulk matter which is fairly complete and unlikely to change in its essential aspects. Only perhaps on a cosmic scale are we likely to find new laws of nature in the behavior of large bodies.

IV. THE FUTURE OF PHYSICS

In this final section, I shall briefly discuss some problems which I think physics will deal with in the future and which I think have some possibility of being fundamental ones. The list is not meant to be exhaustive, and I shall restrict myself to two areas, one involving very small objects, and the other the universe at large.

The first of the future problems might be succinctly phrased: "Are particles elementary?" By this I do not mean the questions

I mentioned earlier about whether certain of the known particles are to be considered composites of others. Rather, the question is whether particles are the simplest structures that appear in nature or whether, instead, the particles we observe are somehow manifestations of an underlying structure we have not yet detected. This might be expressed poetically by saying that particles are like ripples on a yet unfathomed ocean. Of course, there is no evidence whatever for this point of view. It is not even obvious how to go about testing it. Yet there seems to me something suggestive about the idea. As I have said earlier, one of the most striking characteristics of particles is that they are, at high energy, very easily created and destroyed or transformed into each other. It seems strange to me that this would occur if particles were really fundamental. However, in the transformations that take place when particles interact, some things remain constant. These are the conserved quantities, such as electric charge and energy. Other quantities change very slowly, such as parity. There is, furthermore, the mysterious fact that the electric charges of apparently unrelated particles such as protons and positrons are equal. If indeed there is a substratum underlying particle physics, the quantities must be properties of the underlying ''stuff.'' Perhaps when we understand the conservation laws better we will get some hint of whether the substratum really exists.

Another problem that I think physics will have to deal with is the interrelation of the universe in the large with the behavior of objects in the laboratory. This problem is sometimes referred to as ''Mach's principle,'' because Mach raised the issue in connection with the inertial properties of matter. At first sight, this problem would seem contrary to the history of physics since the time of Galileo. In this period, physics has been fairly successful in accounting for laboratory phenomena taking into account only the effects of nearby objects. Many physicists would regard any contrary assumption as a form of astrology. However, Mach in the last century and Einstein in this have pointed out that the assumption, that physical laws in a universe containing only a few objects would be the same as they are in our universe, may lead to difficulties. For example, Einstein points out that if the earth were alone in the universe and Newton's laws were still valid, it would be possible for an observer on the earth to determine whether the earth was rotating by measuring the flattening of the poles. This conclusion seems counterintuitive, since one is inclined to ask, rotating relative to what?

One possible way out of this problem is that suggested by Einstein, who said that the inertial properties of matter occur when a body is accelerated relative to the average distribution of matter in the universe. According to this view, the inertial effects come from the gravitational force exerted on a body in the laboratory by the remaining bodies in the universe. This force depends, among other things, on the relative acceleration of two bodies. It also appears that the main contribution to the force on a given body comes from the distant background of galaxies. It is not yet clear whether the gravitational force of these galaxies is quantitatively sufficient to account for the inertia.

If this is indeed the correct explanation of inertia, a new problem arises. In order to know that the laws used to calculate the inertial effects are correct, we would have to know how all physical laws, including the law of gravitation, depend on the distribution of matter in the universe. That is, we would have to know the laws of physics for all conceivable distributions of matter, from an empty universe to one filled with matter in arbitrary motion. Now, the orthodox view would be that the fundamental laws are independent of the distribution of matter. This leads to problems like that of the solitary rotating earth cited previously. It may be possible to find the laws of motion for any distribution of matter, although to do this it will be necessary to assume that some laws are invariant to the distribution. If this can be done, we might be in a position to understand some apparently accidental features of our world, such as the fact that space has three dimensions. However, the distribution of matter would still have to be prescribed arbitrarily.

There is another possible approach to the connection between the distribution of matter and the laws of motion. This has been emphasized by D. Sciama in his brilliant book, *The Unity of the Universe*. According to Sciama, it may be that the connection between the laws of motion and the distribution of matter is so rigid a connection that there is only one possible set of laws and one possible distribution of matter, that of the universe we inhabit. This is an extension of the view of Leibniz, who argued that, out of logical necessity, the universe could only be the way it actually is. Similar views have been expressed in the context of particle physics by G. Chew and his ''bootstrap'' school.

Clearly, this approach also has its problems. In particular, it seems easy to imagine logically consistent universes, very different from ours, such as a world with no bodies in it at all or a world with particles permanently fixed. Perhaps, in order to rule out these worlds, it is necessary to supplement the requirement of logical consistency with the requirement of the possibility of an observer to make measurements.

In any case, it seems that the problem of the relation between the universe and the laboratory will be a knotty one to unravel, and perhaps it may replace the Thales problem as the central question in physics. Hopefully, it will take us less than 2500 years to solve it.

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AN ARGUMENT FOR THE IDENTITY THEORY

I. INTRODUCTION

THE (Psychophysical) Identity Theory is the hypothesis that —not necessarily but as a matter of fact—every experience[1] is identical with some physical state.[2] Specifically, with some neurochemical state. I contend that we who accept the materialistic working hypothesis that physical phenomena have none but purely physical explanations must accept the identity theory. This is to say more than do most friends of the theory, who say only that we are free to accept it, and should for the sake of some sort of economy or elegance. I do not need to make a case for the identity theory on grounds of economy,[3] since I believe it can and should rest on a stronger foundation.

My argument is this: The definitive characteristic of any (sort of) experience as such is its causal role, its syndrome of most typical causes and effects. But we materialists believe that these causal roles which belong by analytic necessity to experiences belong in fact to certain physical states. Since those physical states possess the definitive characteristics of experience, they must be the experiences.

My argument parallels an argument which we will find uncontroversial. Consider cylindrical combination locks for bicycle chains. The definitive characteristic of their state of being unlocked is the causal role of that state, the syndrome of its most typical causes and effects: namely, that setting the combination typically causes the lock to be unlocked and that being unlocked

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[1] Experiences herein are to be taken in general as universals, not as abstract particulars.

[2] States also are to be taken in general as universals. I shall not distinguish between processes, events, phenomena, and states in a strict sense.

[3] I am therefore invulnerable to Brandt's objection that the identity theory is not clearly more economical than a certain kind of dualism. "Doubts about the Identity Theory," in *Dimensions of Mind*, Sidney Hook, ed. (New York: NYU Press, 1960), pp. 57–67.