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THE PHILOSOPHY OF PHYSICS[1]

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In appearing here to speak on the philosophy of physics I am in a rather dangerous position. Those of you who are philosophers will want to know by what right I speak on such a subject without having mastered the classical philosophies and without knowing the various traditional answers which have been given to the problems I shall discuss. On the other hand, physicists will accuse me of having left the austere and narrow path of physics to wander aimlessly, or at least uselessly, among the byways of philosophical verbiage. For most physicists have a traditional mistrust of philosophy. A definition of philosophy which usually provokes much self-satisfied mirth among physicists is as follows: Philosophy is the systematic misuse of a terminology especially invented for the purpose.

Yet in spite of this state of mind, the rapid changes in the concepts with which physics deals have almost forced some consideration by physicists of problems which were formerly regarded as belonging to the exclusive domain of philosophers. This consideration has been in the light of experimental results and because of this fact may be of value to the philosophers themselves. As a variation on the proverb that "Truth is stranger than fiction," may I suggest that experiment reveals stranger things than man's imagination has ever invented. Possibly some of the new results of experimental physics may reveal new aspects of old philosophical problems. Hence I propose to describe not so much any one unified philosophy of physics as a series of results of physics which I believe may have some bearing on philosophical problems.

One of the problems which has occupied the minds of philosophers is concerned with the nature of existence. Does there exist a material world, and can any-

[1] An address delivered in a series on "Outlooks in Philosophy" at the California Institute of Technology.

thing be learned about it? On the whole physicists have taken a very naive view of such matters. To my mind it has been this fact, this naiveté of view-point, which has contributed much to the successful development of physics.

When physics entered the experimental phase about the time of Galileo, troublesome questions of existence were ignored, and it was assumed, often without adequate consideration, to be sure, that there existed an outside material world which could be contacted through the senses. It was also assumed that these sense contacts could be reliably interpreted and that an observer could actually learn the nature of this outside world through his observations. To the scholars of Galileo's day this was not at all a self-evident proposition. It seems self-evident to some of us to-day because we have been brought up that way, but three hundred years ago people were apparently much more impressed with the possibility that things are not what they seem than with the simpler problem of at least seeing what they seem to be.

As is often the case with apparently simple statements, the simplicity becomes less obvious when the matter is considered more carefully. If one considers the statement that there exists an outside material world, the question arises, "what is it outside of?" Is it everything outside of the person who is speaking or is it outside of something else also? An active physicist rarely stopped or stops now to consider such a question. He is so busy observing things in this outside world that he has no time to bother about its strict delimitation, although he probably realizes instinctively that there must be a division somewhere between himself and this world which he is to observe. He is usually willing to admit that his hands and his feet belong to the outside world. He can apply to their movements the laws of mechanics, and he is willing to suppose that the physiological processes which go on in them can be objectively described. When he has a sore throat or a headache he is willing to consider himself as an onlooker observing these things. On the other hand, he certainly thinks of himself as something apart from these physiological phenomena, something in the nature of an observer who can watch the outside world go by. The naive view must also recognize the fact that there are other observers, and it assumes that they all see essentially the same things, and in fact can tell each other about them.

Thus I think that, largely without a formal organization of their thoughts, most physicists regard the world as made up of two kinds of things: (*a*) Physicists and, if pressed, other persons or potential physicists will be included in this select group, and (*b*) the outside material world which can be studied and discovered. It is true, of course, that there are variations on this division. There are those who in the attempt to be consistent will include all other persons in the group of things called the outside world, and others pushing still more firmly toward the apparently logical necessity will want to include themselves also in this outside world. I doubt, however, if these two latter groups are really motivated by the philosophy which they defend. I have heard psychologists complain of lack of sympathy from physicists in the attempt to apply the methods of physics to psychology, and I suspect that this lack of sympathy was due to the probably subconscious feeling that the psychologists were not properly recognizing this division of the world into two kinds of things and were getting themselves mixed up with the part of the world they wished to study.

Because of the simplicity of the physicist's attitude, the difficulties in his dualism were not at first troublesome. For instance, the question as to how a sensation got from the obviously material body of the observer to the obviously non-material observer himself was not a troublesome question: every one could see that the sensation did get across the boundary line, and so what more was there to be said about it? Nevertheless, a little consideration of this problem makes it very formidable. Although it may seem quite clear that there are two kinds of things, observers and the material world which is observed, a little consideration shows that not only the nature of the boundary between the two but even the location of this boundary is obscure. As far as the results of physical science are concerned it seems possible to put this boundary at almost any desired point. The observer can with apparent consistency include any desired amount of this outside world in what he may wish to call merely extensions of his senses. The part remaining beyond appears to follow the laws of physics in a perfectly satisfactory manner, and there exists in the laws of physics no reason for assuming the boundary to be one place rather than another.

Consider, for example, that I wish to observe this desk. I am on one end and the desk is on the other end of a chain of interactions. Where shall I draw the line between myself and the thing observed? In the first place, I can draw the line at the surface of the desk and say that the scattering of light from the surface constitutes the act of observing the desk. I can say that the source of light, the light itself, and all the mechanism necessary for the perception of the light is part of me, is an extension of my sense organs. On the other hand, I could also say that what I really observe is the light which strikes the retina of my eye, that this is the point at which the observation really takes place, and that here must be drawn the line dividing the observed things from myself. But I can go still farther and say that the action of the light on the retina is a purely physical process which can be described by known laws and that the dividing line must be placed at a point at which the nerve impulse reaches the brain. The fact that none of these places seems satisfactory might suggest that there should be no dividing line at all, except for the uncomplicated feeling that there must be made some such division. On the other hand, no one of these interactions shows any characteristics which distinguish it from the others as long as only the classical physics is used, but one of the contributions which has come from the interpretation of the modern quantum mechanics is the recognition of the fact that, although the interaction which may be selected as the dividing line between observer and object is entirely arbitrary and may be put at any desired point, it is nevertheless necessary to put such a dividing line at some point and to treat the interaction at this point in a unique fashion. To make clear the nature of this difference may I outline briefly the method used in the quantum mechanical description of the behavior of an isolated part of the world.

According to the present theory, the state of a mechanical system is described or represented by a mathematical symbol which I shall call the wave function. This symbol carries all the information which can be known about the system in the particular state in which it is. This symbol changes with the time in accordance with a differential equation, known as the Schroedinger equation, in a perfectly definite way. If the state of the system is known at one time it can be predicted for any future time by means of this equation. In case the system is composed of two or more parts, the interactions and mutual influences of these parts are entirely described by this equation. But now suppose I want to examine the system. Suppose I want to see if everything is going on according to the rules, and for this purpose I want to make a measurement of some quantity which pertains to the system. As soon as I touch the system with a measuring instrument, as soon as I make any kind of contact with it sufficiently vigorous to learn anything about it, the symbolic wave function explodes in my face. The interaction between the system and myself in the form of a measuring instrument can not be made gentle enough to leave the system undisturbed and at the same time strong enough to give me some information; and this interaction can not be described by the same Schroedinger equation which described the behavior of the system as long as I did not touch it. The interaction with the observing instrument is subject only to the restriction of Heisenberg's principle of indetermination, which merely states that if the interaction is strong enough to do any good in the way of really making a measurement, it is so strong that the symbolic wave function which previously described the state of the system is no longer of any use.

On the other hand, if an observation of the right kind is made, it results in a knowledge of the state of the system after the measurement and the possibility of assigning to it the proper symbolic wave function. This state will then develop again in the manner prescribed by the equation of motion until another observer interferes with the orderly process. Thus there is a distinct difference in the treatment accorded interactions which take place within an isolated system itself and those which take place with the observer or the observer's extended senses in the form of measuring instruments, and it is just possible that this difference in treatment may be of significance beyond the regions in which it has thus far been applied.

One of the subjects often discussed in connection with the implications of physics is the problem of causality. One hears frequent statements about the principle of causality, the law of causality and more recently about the disappearance of causality from the world of science. The principal difficulty with this subject seems to be to find out what one is really talking about. It seems to be possible to make up a statement of causality which is true, *i.e.*, is in accordance with the observations, but which does not seem to be of much importance. It is also probably possible to make up a statement which seems to be of importance, but which is probably not true. But it is easiest of all to make a statement which sounds well but has no precise content whatever. Most of the few statements of causality which I have read belong to the latter class.

Apparently one of the essential elements of causality is that events shall have some connection in time, that the occurrence of a certain event now is necessarily followed by a certain other event at some later time. I do not mean that this is all that causality implies, but this seems to be at least one thing. However, it seems to me that the existence of some kind of a relationship of this nature is essential to the existence of a science, for the essential element of a science is that the known facts shall be classified. No body of facts, no matter how large or how well authenticated, can properly be called a science until these facts are brought under a suitable system. This system must certainly involve relations in time as well as in other ways, and so a kind of causality must be imposed if it is not already obvious, in order that there can be a science. Many of those subjects of study which aspire to be called sciences but which are not yet properly such, lack just this essential element. When a historian can read the papers to-day and tell what will happen to-morrow, then history will be a science, and no one will question the application of the term.

As I have already indicated, this causality, this uniform development in time, has been assigned in quantum mechanics to the symbolic wave function which describes the state of that part of the outside world under consideration. This symbolic wave function and its law of change carry within themselves the usual conservation laws, such as the conservation of energy, the conservation of momentum and the conservation of angular momentum. On these conservation laws rests the usual idea of determinism. The symbolic wave function does not carry, however, a detailed space-time description of the motions of the particles of which the mechanical system is composed. This wave function is quite an abstract thing. It can not be observed directly, and its connection with observations to be made on the system is, in general, only statistical. Thus it is true that the present mechanics does not permit an exact prediction of the result of a measurement to be performed to-morrow. It permits only statistical or probability predictions to be made in most cases.

Does this mean that there is no causality in physics? This still depends entirely upon what you mean by causality, upon what you want causality to do for you. To many persons the term causality is associated with the ideas of determinism and free-will, and the significance to be attached to the problem is because of its connection with ideas of moral responsibility.

At the time of the rapid development of Newtonian mechanics and its phenomenal success in describing and predicting the motions of the members of the solar system, there grew up the belief that all problems were to be solved by such essentially mechanical means. In particular it was concluded that our conscious mental processes were to be determined and described in terms of motions of atoms in our brains. Although this conclusion is clearly at variance with the simple dualism in terms of which physicists normally think, there were many persons who believed it to be a direct consequence of the thinking of physicists. The discovery of the statistical element in the predictions of quantum mechanics was seized upon by some as a means of escape from these unpleasant conclusions. It was suggested that although natural laws operate in all phenomena, they are not to be regarded as determinative, but merely as restrictive. Inside the range permitted by the statistical laws, free-will might be supposed to act.

In spite of this suggestion, I think it is now agreed by most physicists who have considered the matter that the conclusions from Newtonian mechanics to a materialistic determinism in phenomena of consciousness as well as the conclusion from quantum mechanics to a possible freedom of will are entirely without any justification in physics. In reaching such conclusions the naiveté of the physicist has over-reached itself and has produced a very superficial answer to a poorly understood problem.

Nevertheless, there has grown up under the influence of Bohr a recognition that certain aspects of the methods of quantum mechanics may provide a point of view useful in problems of this kind. As I have already indicated, the machinery of quantum mechanics provides for certain conservation laws, but does not at the same time provide a detailed space-time description of events. There are in the problems of atomic physics two complementary but mutually exclusive aspects, both of which are necessary to a complete description of the phenomena, but neither of which is adequate by itself. For instance, an electron is found to behave under certain circumstances as a wave, and under other circumstances to appear to have a clearly localized position as if it were a small particle. The achievement of the theory is in renouncing any attempt to describe one of these aspects in terms of the other or to establish any detailed connection between them, and in the recognition of this complementarity as fundamental. Certainly waves and particles are not the same thing; in fact, they are mutually exclusive things, and the recognition that in spite of this an electron has properties of both kinds is a real change in modes of thinking. In some such way one might imagine that problems of consciousness may have two complementary aspects. One of these aspects might suitably be described by such words as freedom of choice, while the other might be described in terms of physical or chemical reactions. The progress in understanding would come with the recognition that one of these descriptions does not exclude the other, but that they represent entirely different aspects of the problem. This rather surprising point of view which has been forced upon us by the results of actual experience may be one of the major contributions which physics has to make to philosophy.

May I now turn to another point. During the past fifty years much of the attention of physicists has been devoted to the structure of matter. Some twenty-five hundred years ago the philosophy of atomism was quite in favor, and it is now in favor again. The idea that all matter is made up of a few kinds of atoms was apparently recommended to the ancients as a method of getting some order into an apparently chaotic universe. Certainly until recently there was no more immediate reason for such a belief.

The essential idea of atomism is that the properties of matter can be explained in terms of relationships between elementary atoms. If this is to be done satisfactorily the atoms themselves must have very few and very simple properties, and it must be their combinations in various ways which produce the wide variety of phenomena which are observed. When the atoms of the chemical elements were discovered well over a century ago they were moderately satisfactory in this respect. There were only a few varieties of them and their principal properties were a definite weight and a definite combining power. However, this simplicity did not last long. It became necessary to ascribe to the atoms themselves all sorts of special properties, and the study of atomic physics has led to the conception of a chemical atom as a very complex dynamic system. Nevertheless, the search for and the belief in ultimate indivisible atoms has gone on. At the present time there is again a small number of relatively simple atoms which one might call fundamental or ultimate. These are the positive and negative electrons, the proton, the neutron and possibly the neutrino. These are relatively simple. They each have a characteristic mass, a characteristic electric charge, and they each act on other particles with characteristic forces. In addition each of them appears to have a spin and a magnetic moment. Out of these basic atoms can be built, it is believed, all the varied and complex material world with which we are acquainted.

In so far as this can be done the picture is satisfactory. It looks as though the goal of the ancient atomists has been closely approached and statements have been heard to the effect that physics is finished, that there is nothing more left to do.

Usually when one is discussing indivisible atoms there comes along a cheerful soul who wants to know the structure of these ultimate atoms. He wants to know how big an electron is and what a proton is made of. The very asking of such a question is a denial of the fundamental nature of the particle in question. If a proton is really a fundamental atom there can not be anything smaller of which it can be made; there can not be any units in terms of which its size can be measured. As soon as it becomes necessary or desirable to talk about the structure of these ultimate particles their usefulness as ultimate particles is gone. It remains yet to be seen, of course, and will always remain to be seen experimentally, whether we shall have to have sub-electrons or sub-protons to explain how the electrons and protons work. Considerable effort has already been expended on the problem of the existence of an electrical charge smaller than that of an electron, but no such has been found. One can say that with the present experimental techniques an electron must always be taken whole.

However, the thing which I believe is of some general interest is that theoretical physics has developed methods for handling this kind of a situation. There have been adopted mathematical symbols and rules for interpreting them which describe the behavior of electrons and the other basic atoms in use. Within the framework of these rules there is at present no place for questions as to the structure of the particles involved. To the question how many electrons are there in this certain region the answer will always be one or two or three or some other integer. The theory is so built that the answer 1.5 can never be given. This is to my mind a real advance in the method of dealing with atoms. Whether it remains satisfactory can only be determined in the future, but the fact that it seems useful in a wide variety of fields suggests that possibly a limit is being approached in the process of subdividing matter, and that further subdivision may be unnecessary.

Thus far I have been discussing the results of physics which may have some bearing on philosophical problems. This should not be taken to imply that philosophers have ignored the results of physics. Such an implication would be far from the truth. As I have already stated, the remarkable successes of the mechanics of Newton were so impressive that various mechanistic philosophies were based on them. In this development the experimental physicists apparently played a secondary rôle. They seemed content to make their discoveries in the slow and laborious manner in which such discoveries must be made and to leave the generalizations to others. But the philosophers whose business it was to take a large scale view of things eagerly seized upon the laws of Newtonian mechanics as the long-sought-for ultimate and eternal truth. Upon the assumption that it would be possible in the future to discover suitable mechanical laws governing all phenomena, and with this assumption bolstered up by the successes of Newtonian mechanics, the advocates of materialistic and mechanistic philosophies wrote weighty tomes expounding their views. There developed at the same time, however, exponents of idealism or subjectivism who eagerly joined battle. I think that the apparently endless debates between opposing schools of philosophers have had much to do with the development of that distrust which most experimental scientists seem to feel for philosophy.

Curiously enough, this distrust of philosophy led in the latter part of the nineteenth century to another philosophy. It has been called a philosophy to end all philosophies, and it is designated by its proponents as the only true scientific view of the world. Although it has numerous opponents, it is more or less the official philosophy of physics to-day.

This philosophy designates as meaningless many of the questions ordinarily considered by philosophers. Only those problems are credited with significance which can be answered in terms of experiments or observations. This point of view has been called positivism.

The central feature of positivism is its insistence upon empirical or experimental data as the only object of scientific study and its emphasis upon the descriptive feature of scientific theories. According to a positivist the object of a scientific theory is to classify and describe quantitatively and precisely the sensations which we experience. The use of the term "explain" in this connection is undesirable, because it carries with it connotations of some real world in terms of which the explanation is to be made and in terms of which things can be understood.

An extreme positivist tends to be a subjectivist. He denies the existence of a material world and will admit the reality only of sensations which it is his task to classify and describe. A more reasonable positivist says that the question as to the existence of an outside world has no meaning. It is impossible to give any satisfactory definition of the term existence except as a symbol by means of which experiences can be classified. A working physicist says, "I don't care whether there is an external world or not. It appears as though there were one and I can get results by assuming its existence."

The position of a positivist is a very strong one. He formulates the rules of the game so that any question which he can not answer can be declared to be meaningless. His point of view permits him to formulate satisfactorily such apparently irrational concepts as those of the theory of relativity and the quantum theory without talking so much about revolutions in physics as do the exponents of other philosophical systems. For these revolutions have not really been in physics but in the philosophies based on the physics. They have not disturbed the physicists so much as the philosophers. It is sometimes said that Einstein has superseded Newton and that the theory of relativity has eliminated Newtonian mechanics. If this were true our students might well demand their money back, for our hard-boiled faculty insists that they grind their noses on Newtonian mechanics for many long years. Furthermore, very few designers of machinery find it necessary to use Einstein's mechanics in writing their specifications. To a positivist this is all as it should be. The Newtonian mechanics was a means of classifying a certain set, and a very large set, of experiences. But when the Michelson-Morley experiment was performed, when the unexpected precession of the orbit of Mercury was established, when the bending of light around the sun was observed, it became necessary to adopt some wider, some more general scheme of classification which would include these additional facts as well. This was of course a revolution to those who had extrapolated Newtonian mechanics to cover all phenomena, but it was no revolution to a physicist and it would not perturb a positivist.

It is possible to illustrate the difficulties which a philosophy based on the existence of a real material world may have with the theory of relativity. According to this theory, which, it must be remembered, is merely an abstract statement of observed experimental facts, the length of an object depends upon its motion relative to the physicist who measures it. When measured by different observers moving relative to it with different velocities it appears to have different lengths. What, then, is the true length of the object? The theory of relativity and the positivist philosopher says it has no true length. One measurement is as good as another for determining the length, and the business of the theory is to state the connection between the different observations. The exponent of a real material world which is being discovered by means of the measurement will find himself in a difficult position. He can, it is true, say that length is not a fundamental attribute of objects in the real world but is a secondary quality such as color. When he does this, however, the suspicion keeps creeping in that it may be impossible to discover any attributes of the real world which are satisfactory in this sense.

In quantum mechanics the situation is even worse. The experiments on light have shown that at times light behaves as though it were a train of waves, while at other times it acts as a stream of corpuscles. The positivist is not displeased with this. He merely proceeds to build up a system of classification and description which will include all the observations, and after having built up such a system he is happy. His only further objective is to build a system of description which will include as many phenomena as possible, ultimately to include all phenomena. He would then have a complete philosophy. A philosopher of another persuasion, however, will want to know something of the nature of the reality behind this apparent paradox, and this desire will put him in a bad predicament, for waves and corpuscles are essentially different things. They have in fact mutually exclusive properties and as far as I know no one has yet been able to formulate an adequate picture of a reality to be behind these sensations.

As I have said, positivism is logically a very strong position. As far as I know, it is the only position completely tenable in the face of the experimental facts of relativity and quantum mechanics. Yet it is not without difficulties and has its strong opponents. In the first place, there is the usual difficulty with the position that all truth is sensation or experience. For different persons have different experiences and no two see alike. In order, then, to avoid a complete solipsism in which each philosopher is his own universe it is necessary to select in some way the experience which is more or less common to a number of observers. As soon, however, as this is done the whole question of the real difference between those sensations on which different persons can agree and those on which they differ comes up and the problem is open again. So positivism seems to face the dangers of all subjective philosophies.

Positivism has also been attacked as a philosophy of resignation and defeat, as a refusal to admit the existence of problems for which no solution can immediately be seen. Fifty years ago the positivists denied the reality of atoms. Atoms, they said, are convenient means by which to describe the results of observation, but they are by their very nature such that it will be impossible ever to isolate and observe one. It has no sense to speak of their existence. Experience since then has not justified this position. Those who have made advances in physics have been those who took the atoms seriously, who went out and found methods by which individual atoms could really be observed, and if to-day a positivist still maintains that atoms and electrons are only useful fictions, he must admit that they are at least as useful and necessary as anything else whose reality he would affirm.

Thus while positivism is a philosophy which a physicist can easily defend, I am inclined to believe that it is not the philosophy which really motivates him. I am inclined to believe that those most effectively active in physics to-day have the very naive view which I mentioned at the beginning. They tend to believe that there is a real world which can be discovered, and they propose to discover it.

THE URSI PROGRAMS OF SHORT-WAVE STATION W1XAL

By Dr. A. E. KENNELLY

PROFESSOR EMERITUS OF HARVARD UNIVERSITY AND THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE Union Radio-Scientifique Internationale (abbreviation URSI), as its name indicates, is an International Union, founded in 1919 under the auspices of the International Research Council, for world study of radio science. It has sections in some twelve countries of the world and its Secretariat is at 54, Avenue des Arts, Brussels, Belgium. The Secretariat of the American Section is at the National Bureau of Standards, Washington, D. C. It has two official languages, French and English, for its reports, papers and discussions.

The URSI seeks to build up and to spread international knowledge of the scientific principles of radio communication and has held plenary meetings at two- or three-year intervals, the first in 1922, at Brussels, and later in Washington, D. C., London, Brussels and Copenhagen.

It was soon recognized that radio communication is affected by certain changes in cosmic phenomena such as (1) spots on the surface of the sun, (2) electric and magnetic disturbances on the earth, as well as in the upper regions of our atmosphere. In order to bring such cosmic changes promptly to the notice of radio observers in various parts of the world, the French Government in 1928, at the suggestion of the late General Ferrié, the founder and first president of the URSI, inaugurated a daily service of radio-cosmic bulletins, broadcast from the Eiffel Tower Station in Paris, which bulletins came to be known as Ursigrams. These Ursigrams, emitted in international dot-dash signals, were expressed in cipher code groups containing data of solar and terrestrial surface changes affecting radio. These messages, picked up in various countries by radio observers, and recorded by them in cipher code, were decoded into the languages of the various countries. Since 1929 these Eiffel Tower Ursigrams have been repeated daily in broadcasts from the long-wave radio station at Lafayette near Bordeaux and the shortwave station at Pontoise near Paris.

In 1929 the American Section of the URSI, recognizing the value of the Ursigram service in radio communication, enlisted the cooperation of a number of scientific institutions in America for the establishing of an American daily Ursigram service. These institutions have been the U. S. Coast and Geodetic Survey, the National Bureau of Standards at Washington, Smithsonian Institution, Carnegie Institution, Mount Wilson Observatory, assisted by the United States Government departments of Army, Navy and Weather Bureau.

Through the aid of Science Service at Washington, D. C., these institutions were enabled to collaborate for the emission of a daily Ursigram in international dot-dash signals from the U. S. Navy Station NAA at Arlington, Va., near Washington, D. C. Changes in the solar surface were reported from Mount Wilson Observatory; changes in the solar radiation intensity at the earth's surface were reported by the Smithsonian Institution; terrestrial magnetic observations by the Coast and Geodetic Survey; observations of aurora borealis in Alaska were supplied by the Car-