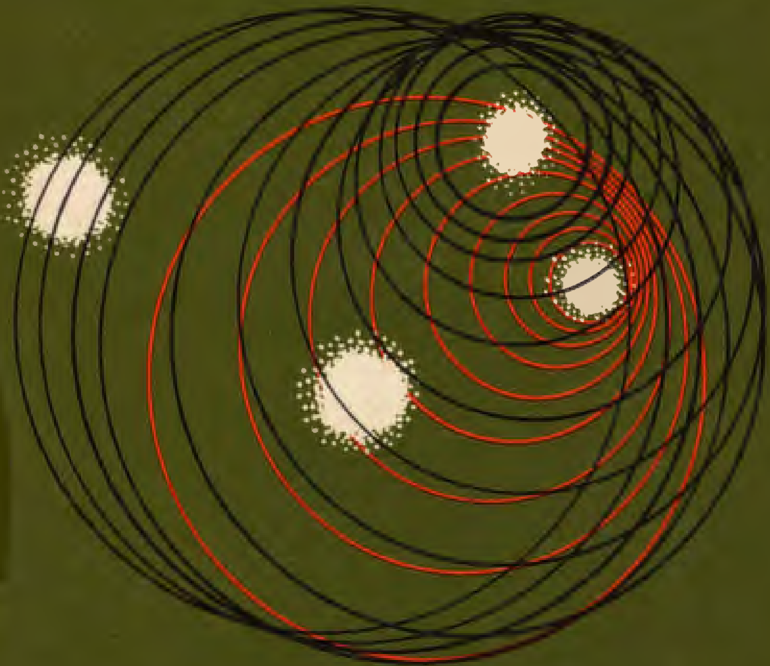
Physics and Philosophy

The Revolution in Modern Science

Werner Heisenberg

Introduction by F.S.C. Northrop



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WERNER HEISENBERG

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Contents

state. The latter knowledge of the future state may be obtained either by waiting until it arrives or by having seen the future or final state of similar systems in the past. When such is the case, causality is teleological. Changes of the system with time are determined by the final state or goal of the system. The physical system which is an acorn in the earlier state t^1 and an oak tree in the later state t^2 is an example. The connection between these two states seems to be a necessary one. Acorns never change into maple trees or into elephants. They change only into oaks. Yet, given the properties of this physical system in the acorn state of the earlier time t^1, no scientist has as yet been able to deduce the properties of the oak tree which the system will have at the later time t^2. Aristotelian physics affirmed that all causal relations are teleological.

Another possibility is that the relation between the states of any object, or any system of objects, at different times is a relation of necessary connection such that, given knowledge of the initial state of the system, assuming isolation, its future state can be deduced. Stated in more technical mathematical language, this means that there exists an indirectly verified, axiomatically constructed theory whose postulates (1) specify a state-function, the independent variables of which completely define the state of the system at any specific instant of time, and (2) provide a time-equation relating the numerical empirical values of the independent variables of this function at any earlier time t^1 to their numerical empirical values at any specific later time t^2 in such a way that by introducing the operationally determined t^1 set of numbers into the time-equation the future t^2 numbers can be deduced by merely solving the equation. When this is the case, the temporal relation between states is said to exemplify mechanical causation.

should be separated in this respect from the tools used to study the phenomenon. This again emphasizes a subjective element in the description of atomic events, since the measuring device has been constructed by the observer, and we have to remember that what we observe is not nature in itself but nature exposed to our method of questioning. Our scientific work in physics consists in asking questions about nature in the language that we possess and trying to get an answer from experiment by the means that are at our disposal. In this way quantum theory reminds us, as Bohr has put it, of the old wisdom that when searching for harmony in life one must never forget that in the drama of existence we are ourselves both players and spectators. It is understandable that in our scientific relation to nature our own activity becomes very important when we have to deal with parts of nature into which we can penetrate only by using the most elaborate tools.

model started from the assumption that one can describe the world without speaking about God or ourselves. This possibility soon seemed almost a necessary condition for natural science in general.

But at this point the situation changed to some extent through quantum theory and therefore we may now come to a comparison of Descartes's philosophical system with our present situation in modern physics. It has been pointed out before that in the Copenhagen interpretation of quantum theory we can indeed proceed without mentioning ourselves as individuals, but we cannot disregard the fact that natural science is formed by men. Natural science does not simply describe and explain nature; it is a part of the interplay between nature and ourselves; it describes nature as exposed to our method of questioning. This was a possibility of which Descartes could not have thought, but it makes the sharp separation between the world and the I impossible.

If one follows the great difficulty which even eminent scientists like Einstein had in understanding and accepting the Copenhagen interpretation of quantum theory, one can trace the roots of this difficulty to the Cartesian partition. This partition has penetrated deeply into the human mind during the three centuries following Descartes and it will take a long time for it to be replaced by a really different attitude toward the problem of reality.

The position to which the Cartesian partition has led with respect to the "res extensa" was what one may call metaphysical realism. The world, i.e., the extended things, "exist." This is to be distinguished from practical realism, and the different forms of realism may be described as follows: We "objectivate" a statement if we claim that its content does not depend on the sophic systems of the past, which of course were meant to hold in a much wider field. What we have learned especially from the discussion of the philosophies of Descartes and Kant may perhaps be stated in the following way:

Any concepts or words which have been formed in the past through the interplay between the world and ourselves are not really sharply defined with respect to their meaning; that is to say, we do not know exactly how far they will help us in finding our way in the world. We often know that they can be applied to a wide range of inner or outer experience, but we practically never know precisely the limits of their applicability. This is true even of the simplest and most general concepts like "existence" and "space and time." Therefore, it will never be possible by pure reason to arrive at some absolute truth.

The concepts may, however, be sharply defined with regard to their connections. This is actually the fact when the concepts become a part of a system of axioms and definitions which can be expressed consistently by a mathematical scheme. Such a group of connected concepts may be applicable to a wide field of experience and will help us to find our way in this field. But the limits of the applicability will in general not be known, at least not completely.

Even if we realize that the meaning of a concept is never defined with absolute precision, some concepts form an integral part of scientific methods, since they represent for the time being the final result of the development of human thought in the past, even in a very remote past; they may even be inherited and are in any case the indispensable tools for doing scientific work in our time. In this sense they can be practically a priori. But further limitations of their applicability may be found in the future.

time shown that the particles can be created from other particles or simply from the kinetic energy of such particles, and they can again disintegrate into other particles. Actually the experiments have shown the complete mutability of matter. All the elementary particles can, at sufficiently high energies, be transmuted into other particles, or they can simply be created from kinetic energy and can be annihilated into energy, for instance into radiation. Therefore, we have here actually the final proof for the unity of matter. All the elementary particles are made of the same substance, which we may call energy or universal matter; they are just different forms in which matter can appear.

If we compare this situation with the Aristotelian concepts of matter and form, we can say that the matter of Aristotle, which is mere "potentia," should be compared to our concept of energy, which gets into "actuality" by means of the form, when the elementary particle is created.

Modern physics is of course not satisfied with only qualitative description of the fundamental structure of matter; it must try on the basis of careful experimental investigations to get a mathematical formulation of those natural laws that determine the "forms" of matter, the elementary particles and their forces. A clear distinction between matter and force can no longer be made in this part of physics, since each elementary particle not only is producing some forces and is acted upon by forces, but it is at the same time representing a certain field of force. The quantum-theoretical dualism of waves and particles makes the same entity appear both as matter and as force.

All the attempts to find a mathematical description for the laws concerning the elementary particles have so far started from the quantum theory of wave fields. Theoretical work on theories of this type started early in the thirties. But the very first one to the pragmatic one. One was not so much interested in nature as it is; one rather asked what one could do with it. Therefore, natural science turned into technical science; every advancement of knowledge was connected with the question as to what practical use could be derived from it. This was true not only in physics; in chemistry and biology the attitude was essentially the same, and the success of the new methods in medicine or in agriculture contributed essentially to the propagation of the new tendencies.

In this way, finally, the nineteenth century developed an extremely rigid frame for natural science which formed not only science but also the general outlook of great masses of people. This frame was supported by the fundamental concepts of classical physics, space, time, matter and causality; the concept of reality applied to the things or events that we could perceive by our senses or that could be observed by means of the refined tools that technical science had provided. Matter was the primary reality. The progress of science was pictured as a crusade of conquest into the material world. Utility was the watchword of the time.

On the other hand, this frame was so narrow and rigid that it was difficult to find a place in it for many concepts of our language that had always belonged to its very substance, for instance, the concepts of mind, of the human soul or of life. Mind could be introduced into the general picture only as a kind of mirror of the material world; and when one studied the properties of this mirror in the science of psychology, the scientists were always tempted—if I may carry the comparison further—to pay more attention to its mechanical than to its optical properties. Even there one tried to apply the concepts of classical physics, primarily that of causality. In the same way life was to be explained as a physical and chemical process, governed by natural laws, completely determined by causality. Darwin's concept of evolution provided ample evidence for this interpretation. It was especially difficult to find in this framework room for those parts of reality that had been the object of the traditional religion and seemed now more or less only imaginary. Therefore, in those European countries in which one was wont to follow the ideas up to their extreme consequences, an open hostility of science toward religion developed, and even in the other countries there was an increasing tendency toward indifference toward such questions; only the ethical values of the Christian religion were excepted from this trend, at least for the time being. Confidence in the scientific method and in rational thinking replaced all other safeguards of the human mind.

Coming back now to the contributions of modern physics, one may say that the most important change brought about by its results consists in the dissolution of this rigid frame of concepts of the nineteenth century. Of course many attempts had been made before to get away from this rigid frame which seemed obviously too narrow for an understanding of the essential parts of reality. But it had not been possible to see what could be wrong with the fundamental concepts like matter, space, time and causality that had been so extremely successful in the history of science. Only experimental research itself, carried out with all the refined equipment that technical science could offer, and its mathematical interpretation, provided the basis for a critical analysis—or, one may say, enforced the critical analysis—of these concepts, and finally resulted in the dissolution of the rigid frame.

This dissolution took place in two distinct stages. The first was the discovery, through the theory of relativity, that even

such fundamental concepts as space and time could be changed and in fact must be changed on account of new experience. This change did not concern the somewhat vague concepts of space and time in natural language; but it did concern their precise formulation in the scientific language of Newtonian mechanics, which had erroneously been accepted as final. The second stage was the discussion of the concept of matter enforced by the experimental results concerning the atomic structure. The idea of the reality of matter had probably been the strongest part in that rigid frame of concepts of the nineteenth century, and this idea had at least to be modified in connection with the new experience. Again the concepts so far as they belonged to the natural language remained untouched. There was no difficulty in speaking about matter or about facts or about reality when one had to describe the atomic experiments and their results. But the scientific extrapolation of these concepts into the smallest parts of matter could not be done in the simple way suggested by classical physics, though it had erroneously determined the general outlook on the problem of matter.

These new results had first of all to be considered as a serious warning against the somewhat forced application of scientific concepts in domains where they did not belong. The application of the concepts of classical physics, e.g., in chemistry, had been a mistake. Therefore, one will nowadays be less inclined to assume that the concepts of physics, even those of quantum theory, can certainly be applied everywhere in biology or other sciences. We will, on the contrary, try to keep the doors open for the entrance of new concepts even in those parts of science where the older concepts have been very useful for the understanding of the phenomena. Especially at those points where the application of the older concepts seems somewhat forced or there that we can be certain to touch reality, and hence we must be skeptical about any skepticism with regard to this natural language and its essential concepts. Therefore, we may use these concepts as they have been used at all times. In this way modern physics has perhaps opened the door to a wider outlook on the relation between the human mind and reality.

This modern science, then, penetrates in our time into other parts of the world where the cultural tradition has been entirely different from the European civilization. There the impact of this new activity in natural and technical science must make itself felt even more strongly than in Europe, since changes in the conditions of life that have taken two or three centuries in Europe will take place there within a few decades. One should expect that in many places this new activity must appear as a decline of the older culture, as a ruthless and barbarian attitude, that upsets the sensitive balance on which all human happiness rests. Such consequences cannot be avoided; they must be taken as one aspect of our time. But even there the openness of modern physics may help to some extent to reconcile the older traditions with the new trends of thought. For instance, the great scientific contribution in theoretical physics that has come from Japan since the last war may be an indication for a certain relationship between philosophical ideas in the tradition of the Far East and the philosophical substance of quantum theory. It may be easier to adapt oneself to the quantum-theoretical concept of reality when one has not gone through the naïve materialistic way of thinking that still prevailed in Europe in the first decades of this century.

Of course such remarks should not be misunderstood as an underestimation of the damage that may be done or has been done to old cultural traditions by the impact of technical progress. But since this whole development has for a long time passed far beyond any control by human forces, we have to accept it as one of the most essential features of our time and must try to connect it as much as possible with the human values that have been the aim of the older cultural and religious traditions. It may be allowed at this point to quote a story from the Hasidic religion: There was an old rabbi, a priest famous for his wisdom, to whom all people came for advice. A man visited him in despair over all the changes that went on around him, deploring all the harm done by so-called technical progress. "Isn't all this technical nuisance completely worthless," he exclaimed "if one considers the real values of life?" "This may be so," the rabbi replied, "but if one has the right attitude one can learn from everything." "No," the visitor rejoined, "from such foolish things as railway or telephone or telegraph one can learn nothing whatsoever." But the rabbi answered, "You are wrong. From the railway you can learn that you may by being one instant late miss everything. From the telegraph you can learn that every word counts. And from the telephone you can learn that what we say here can be heard there." The visitor understood what the rabbi meant and went away.

Finally, modern science penetrates into those large areas of our present world in which new doctrines were established only a few decades ago as foundations for new and powerful societies. There modern science is confronted both with the content of the doctrines, which go back to European philosophical ideas of the nineteenth century (Hegel and Marx), and with the phenomenon of uncompromising belief. Since modern physics must play a great role in these countries because of its practical applicability, it can scarcely be avoided that the narrowness of the doctrines is felt by those who have really understood modern physics and its philosophical meaning. Therefore, at this point an interaction between science and the general trend of thought may take place. Of course the influence of science should not be overrated; but it might be that the openness of modern science could make it easier even for larger groups of people to see that the doctrines are possibly not so important for the society as had been assumed before. In this way the influence of modern science may favor an attitude of tolerance and thereby may prove valuable.

On the other hand, the phenomenon of uncompromising belief carries much more weight than some special philosophical notions of the nineteenth century. We cannot close our eyes to the fact that the great majority of the people can scarcely have any well-founded judgment concerning the correctness of certain important general ideas or doctrines. Therefore, the word "belief" can for this majority not mean "perceiving the truth of something" but can only be understood as "taking this as the basis for life." One can easily understand that this second kind of belief is much firmer, is much more fixed than the first one, that it can persist even against immediate contradicting experience and can therefore not be shaken by added scientific knowledge. The history of the past two decades has shown by many examples that this second kind of belief can sometimes be upheld to a point where it seems completely absurd, and that it then ends only with the death of the believer. Science and history can teach us that this kind of belief may become a great danger for those who share it. But such knowledge is of no avail, since one cannot see how it could be avoided, and therefore such belief has always belonged to the great forces in human history. From the scientific tradition of the nineteenth century one would of course be inclined to hope that all belief should be based on a

rational analysis of every argument, on careful deliberation; and that this other kind of belief, in which some real or apparent truth is simply taken as the basis for life, should not exist. It is true that cautious deliberation based on purely rational arguments can save us from many errors and dangers, since it allows readjustment to new situations, and this may be a necessary condition for life. But remembering our experience in modern physics it is easy to see that there must always be a fundamental complementarity between deliberation and decision. In the practical decisions of life it will scarcely ever be possible to go through all the arguments in favor of or against one possible decision, and one will therefore always have to act on insufficient evidence. The decision finally takes place by pushing away all the arguments—both those that have been understood and others that might come up through further deliberation—and by cutting off all further pondering. The decision may be the result of deliberation, but it is at the same time complementary to deliberation; it excludes deliberation. Even the most important decisions in life must always contain this inevitable element of irrationality. The decision itself is necessary, since there must be something to rely upon, some principle to guide our actions. Without such a firm stand our own actions would lose all force. Therefore, it cannot be avoided that some real or apparent truth form the basis of life; and this fact should be acknowledged with regard to those groups of people whose basis is different from our own.

Coming now to a conclusion from all that has been said about modern science, one may perhaps state that modern physics is just one, but a very characteristic, part of a general historical process that tends toward a unification and a widening of our present world. This process would in itself lead to a diminution