18.2 Werner Heisenberg: Uncertainty

Werner Heisenberg of Germany (1901–1976) won the Nobel Prize for physics at the age of thirty-one for his 1927 principle of "uncertainty." He stated that the behavior of subatomic particles cannot be observed or known. Instead, scientists can only work out probabilities for large numbers of them; no single law, therefore, governs all physical phenomena. This almost "chaotic" principle upset the central concept established by Isaac Newton in the seventeenth century that all behavior of the physical universe can be understood and predicted. Heisenberg, in a book written after the Second World War, explores the implications of uncertainty on that world view and for our future. *Source: Werner Heisenberg, Physics and Philosophy: The Revolution in Modern Science, Vol. 19 of the World Perspective Series, ed. Ruth Nanda Anshen, (New York: Harper and Row, 1958), pp. 198–206. Reprinted in Classics of Western Thought: The Twentieth Century, ed. Donald S. Gochberg, (New York: Harcourt Brace Jovanovich, 1980), pp. 304, 308–313.*

... 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 appears not quite adequate to the problem we will try to avoid any rash conclusions.

Furthermore, one of the most important features of the development and the analysis of modern physics is the experience that the concepts of natural language, vaguely defined as they are, seem to be more stable in the expansion of knowledge than the precise terms of scientific language, derived as an idealization from only limited groups of phenomena. This is in fact not surprising since the concepts of natural language are formed by the immediate connection with reality; they represent reality. It is true that they are not very well defined and may therefore also undergo changes in the course of the centuries, just as reality itself did, but they never lose the immediate connection with reality. On the other hand, the scientific concepts are idealizations; they are derived from experience obtained by refined experimental tools, and are precisely defined through axioms and definitions. Only through these precise definitions is it possible to connect the concepts with a mathematical scheme and to derive mathematically the infinite variety of possible phenomena in this field. But through this process of idealization and precise definition the immediate connection with reality is lost. The concepts still correspond very closely to reality in that part of nature which had been the object of the research. But the correspondence may be lost in other parts containing other groups of phenomena.

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The general trend of human thinking in the nineteenth century had been toward an increasing confidence in the scientific method and in precise rational terms, and had led to a general skepticism with regard to those concepts of natural language which do not fit into the closed frame of scientific thought—for instance, those of religion. Modern physics has in many ways increased this skepticism; but it has at the same time turned it against the overestimation of precise specific concepts, against a too-optimistic view on progress in general, and finally against skepticism itself. The skepticism against precise scientific concepts does not mean that there should be a definite limitation for the application of rational thinking. On the contrary, one may say that the human ability to understand may be in a certain sense unlimited. But the existing scientific concepts cover always only a very limited part of reality, and the other part that has not yet been understood is infinite. Whenever we proceed from the known into the unknown we may hope to understand, but we may have to learn at the same time a new meaning of the word "understanding." We know that any understanding must be based finally upon the natural language because it is only 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 naive 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:[1]—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. 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.... 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. [2] 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.... 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 of those cultural and political tensions that create the great danger of our time.... Modern physics plays perhaps only a small role in this dangerous process of unification. But it helps at two very decisive points to guide the development into a calmer kind of evolution. First, it shows that the use of arms in the process would be disastrous and, second, through its openness for all kinds of concepts it raises the hope that in the final state of unification many different cultural traditions may live together and may combine different human endeavors into a new kind of balance between thought and deed, between activity and meditation.

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[1] A Jewish mystical sect founded in Poland around 1750.

[2] Emphasis by the editors.