useful relations in which it can serve adequately so long as it retains its fine old English meanings.

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ALTERATIONS IN THE FOUNDATIONS OF THE EXACT SCIENCES IN MODERN TIMES

IN an article appearing in the October 5 issue of *Die Naturwissenschaften* under the title, "Wandlung der Grundlagen der Exacten Naturwissenschaften in jungster Zeit," Professor W. Heisenberg, theoretical physicist of the University of Leipzig and recent Nobel prize winner, has presented his views on the effects induced in the general scheme of exact sciences by the revolutionary physical discoveries of the past thirty-five years. This presentation is a particularly inviting one, coming as it does from one of the young leaders in theoretical physics, for to such a man, who will undoubtedly be a prominent figure for many years to come, it must be considered an urgent necessity that the importance of the field of science in which he has worked is clearly understood and appreciated. For this reason Heisenberg is careful to point out the various links between the exact sciences themselves and between these and the affairs of everyday life. The manner in which this is done is probably best illustrated by a survey of the text of the article. Such a survey is given in the following paragraphs.

The two major additions to the fields of physics which have been made in the past thirty-five years are those summed up in the expressions, "Relativity Theory" and "Quantum Theory," and were heralded by the discovery of the quantum of action by Planck and the propounding of the special theory of relativity by Einstein. Previous to this, in the period of so-called classical physics, all fields were underlain by a set of basic conceptions which were taken as unquestioned facts and which were the guiding principles of all investigations. In the words of Heisenberg:

> . . . Physics dealt with the behavior of real entities in space and their variation in time. Although merely the character of experiences underlying physics was specified by this, a number of conclusions were drawn concerning the properties of such entities at the same time. One was led to the unexpressed viewpoint that the occurrence of events in time and space is independent of observation, and moreover, that space and time constitute mutually independent classifying categories of events and in this rôle represent an objective reality that is common to all men.

The underlying assumptions of classical physics were contested by the special theory of relativity which found its experimental basis in the well-known work of Michelson and Morley that yielded results contradicting the classical concepts. From the new view-point the classical concepts of an absolute past and future, separated by an instantaneous present that is the same for all observers, were abolished and supplanted by the view that the absolute past and future of two observers is separated by a finite stretch of time which depends upon the relative conditions of observers. These newer views have since received abundant enough experimental verifications that they may now be taken as definite facts of the exact sciences in the same sense as that in which the principles of classical mechanics and thermodynamics are accepted.

In order to emphasize the fundamental importance of this change in attitude Heisenberg states:

> The extraordinary significance of these facts lies, in the first place, in the completely unexpected realization that the natural result of following the route indicated by classical physics compels a change in the foundations of this field. . . . Modern theories do not arise out of revolutionary ideas that are, so to speak, brought in from the outside of exact sciences; they are the results of investigations undertaken with the desire to carry out the program of classical physics. Therefore, at this point one can not compare the beginnings of modern physics with the great revolutions of the past, that is, for example with the work of Copernicus; the ideas of Copernicus were, to a great extent, introduced into the conceptual scheme of contemporary physics from the outside. . . .

The general theory of relativity has revised the concepts of the geometrical properties of space-time and has established a connection between the geometry of the world and the distribution of matter in it. Its experimental justification is not as firmly established as that of special relativity, but it has met no contradiction. The principal conviction of its truth lies in the fact that it presents many stimulating view-points that were previously overlooked. The fact that the fundamental postulate that the geometry of the world depends upon the distribution of matter does lead to a completely self-consistent picturization of gravitational phenomena causes one to anticipate that additional progress will be made on the basis of this theory rather than from a wholly new one, even if experimental contradictions do appear in the future.

The foundations of quantum theory, like those of relativity, arise out of the attempt to extend the classical domain rather than from the introduction of radically new ideas. On the basis of Planck's discovery, the investigations of Lenard and Einstein necessarily led to the adoption of a corpuscular view-point, that is, the classical wave theory was contradicted in performing an experiment suggested by classical reasoning. In exactly the same way, each stage of development of quantum theory up to the present time has been required by contradictions in the previously accepted scheme. Heisenberg believes in the permanence of many elements of the present theory, in which there exists a curious division between the laws describing the observing apparatus and observed object, the first being discussed naturally in terms of classical views and the second in terms of a complex mathematical formulation, since he regards the second as almost unique. If this is granted, then he believes that the statistical interpretation of quantum theory is almost unavoidable, since it is the only means of bridging the gap between the rigid determinism of classical physics, on the one hand, and the fact that the influence of the measuring apparatus on the observed object is indeterminate because of the nature of the quantum laws, on the other. In answer to the question often asked as to whether or not there exists a set of purely deterministic laws of such a nature that the present-day quantum mechanics takes the same position as Boltzmann mechanics did in the classical theory, Heisenberg answers:

> An exact investigation of this hypothesis indicated at once that these natural laws will be in contradiction with the results of quantum mechanics which are already rigorously established; at no place does quantum mechanics leave room for an extension of its consequences, for the only point at which it contains an indefinite feature is at the division mentioned previously. If one would remove the indefiniteness of quantum theory by extensions at any point defined by natural processes, it would be necessary to remove the division from the place which we have assigned it, and the contradictions between quantum theory and the extension sought for would become apparent.

Just as the voyages of Columbus and Magellan brought to an end a period of belief in which the hypothesis of a flat earth was accepted, so in Heisenberg's opinion the new theories have brought the period of classical physics to an end. That is, the concepts of absolute time and determinacy are to be considered as out of place in the new physics as the concept of "the end of the earth" is to-day. However, the discovery of Columbus did not affect the geography of the Mediterranean Basin in any important respect and in the same way we may believe that certain fields of classical physics, such as mechanics, optics and thermodynamics, will remain unaltered.

The general importance to civilization of modern developments in physics may be classified in two groups on the basis of the following facts: First, the range of pure science that is available for practical use in the applied sciences is now increased by those fields in which modern physics has stimulated research, and second, the philosophical principles which the new physics yields for exploitation are major additions to the whole of human thought.

The development of classical physics brought with it the advances of western civilization that go with the harnessing of power and its use in machines. Since modern physics finds an *experimental* basis in the natural course of classical physics, it is to be expected that as great technological strides will follow from it as did from the development of older fields. That is, it is just the essential continuity of the step from the physics of the last century to that of the present that makes this applicability inevitable. Moreover, since pure science is the spring that feeds all the applied sciences, it is essential for the sake of the continued development of the latter that the former be kept in a state of continuous activity. The neglect of this fact can lead only to technological stagnation and the death of all scientific advance.

The changes which modern physics has brought to philosophical thought are elaborated considerably by Heisenberg, who has a very deep appreciation of this offspring of the recent work. The central topic with which his discussion deals is a general examination of the manner in which modern views curtailed the conclusions that might have been drawn from a complete extrapolation of classical thought. That is, the basis of classical physics was mechanistic in essence and if one exploited these concepts to the limit in a purely abstract way, it was necessary to conclude that the entire universe is to be likened to one machine started at an indefinite period in the past and running toward a fixed destination which can not be altered by means of any internal agency. However, the practical attempt made at carrying these principles to the limit led, as we have seen, to the modern developments, from the standpoint of which the extrapolation is meaningless.

In a similar way, one might have attempted to approach an understanding of ultimate reality through classical lines, and again succeeding developments would compel one to abandon any conclusions that might have been drawn. The general view to be gained from facts of this kind is that any field of thought may be expected to yield the answer to only a limited field of questions. An attempt made at extension in a purely abstract manner will lead to results that can not be true. In this connection Heisenberg states:

> Thus Nature influences modern natural science more than the earlier form in such a way as to place the old question of the realization of reality upon a new basis and to answer it in a new manner. Previously the pattern of exact science led to a philosophical system in which a definite truth—perhaps the "Cogito, ergo sum," of Descartes—was the starting point from which all problems of world-view were to be attacked. Nature in modern physics has reminded us clearly, however, that we

may not hope to reach the entire region of the understandable from such a fixed basis of operation. Instead, we shall always come to essentially new knowledge in the manner of Columbus who had the courage to leave everything but the knowledge of known land behind with the determined and devout hope of finding land again on the other side.

Just to what extent this view may be continued is of course an unanswerable question, but at any rate it indicates the path which the science of the near future must follow and may lead to a further unification of those concepts of existence with which science can deal.

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FURTHER COMMENTS ON THE TRIHYDROL CONTROVERSY

IN a recent review[1] of the properties of water and their possible biological significance by Dr. Jahn and myself, we made the following remark (p. 326): "It is hoped that our work on the biological effect of ice- and steam water will stimulate more extensive research on the properties of water even if this proves fatal to our present working hypothesis that trihydrol aggregates play an essential rôle in certain types of living cells." At the time of the first experiments indicating the stimulating action of ice water the only published physical test of the rate of attainment of polymer equilibrium indicated a considerable hysteresis effect during the exhaustion of the ice-forming power of water. Since that time several chemists and physicists, although skeptical of the stimulating action of ice water, have afforded ample evidence of the psychological stimulation of our work on water research. Menzies, LaMer and Miller, Ellis and Sorge and more recently Dole and Wiener, although not repeating our procedure, have published what they consider to be negative evidence.

Dole and Wiener[2] tested my trihydrol hypothesis by determining the density of recently condensed water which had been partially frozen. Under these conditions no difference in density was found. Only four fifths of the water was frozen, and moreover these rapidly frozen small samples of water do not yield large crystals from which the best biological results are obtained. Dole points out that trihydrol is supposed to have a lower density than dihydrol, but he completely overlooks the fact that the lower polymer monohydrol, which may be enriched in recently condensed steam water, has like trihydrol a low density. Density determinations then would be of very ambiguous significance for the comparison of two water samples, each supposedly having a slightly enriched polymer of low density. That monohydrol has a bulky structure is seen in the solution volume curves of Bousfield and Lowry, in which a contraction appears at higher temperatures resembling the contraction at lower temperatures due to the breakdown of the trihydrol molecules of large specific volume. Moreover a slight change in the configuration of the quartz-like structure of water of Bernal and Fowler would not show great density differences. It is also possible that the H–O–H angle or the activity of auxiliary fields undergoes a temporary change.

Dole and Wiener also determined the density of water from recently melted clear block ice in which crystal growth had occurred. This water had an excess density of 2.4 parts per million compared to recently condensed water. In this connection the authors fail to consider the hypothesis of Uhlmann that the sublimation of aged ice may concentrate the heavy hydrogen isotope, which may possibly account for the enhanced biological effect of water from old samples of natural ice. Moreover, Gilfillan[3] finds that fractional crystalization of water concentrates the heavy hydrogen isotope to a slight extent (which, however, is complicated by the fact that 0^{16} is concentrated in respect to 0^{18}).

It should also be pointed out that Dole and Wiener worked at a higher temperature (23°) than that at which our biological experiments are usually carried out (10°). There is evidence that the attainment of polymer equilibrium is more rapid at higher temperatures. Also in some of our tests a continuous stream of ice water was used or the cells were temporarily exposed to the ice water at a lower temperature than that of the recently condensed water.

There are, of course, several positive tests for the differences between ice water and steam water. On the physical side it has been found that the onset of freezing, the exhaustion of the ice-forming power of water and the diamagnetic susceptibility indicate a polymer lag. On the biological side the most recent evidence is that of Hegarty and Rahn, who find that recently condensed water retards bacterial growth which can not be an impurity effect, for this property disappears after a few hours. Moreover, the water samples were bubbled with air to prevent a gas effect. Even Professor Menzies, an ever-vigilant critic of my ice-water work, admits the possibility that the biological method may be more sensitive than some of the physical tests.

It appears that all these difficulties are in large part due to the unsatisfactory state of our knowledge of matter in the liquid state. Maass and Steacie[4]

[1] T. C. Barnes and T. L. Jahn, *Quart. Rev. Biol.*, 9: 292, 1934. This review contains references to papers mentioned in this note.

[2] M. Dole and B. Z. Wiener, SCIENCE, 81: 45, 1935.

[3] E. S. Gilfillan, *Jour. Am. Chem. Soc.*, 56: 2201, 1934.

[4] O. Maass and E. W. R. Steacie, "An Introduction to Physical Chemistry," New York, 1931.