THE NATURE OF PHYSICAL THEORY

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PUBLISHED ON
THE LOUIS CLARK VANUXEM FOUNDATION

DOVER PUBLICATIONS

NEW YORK

the younger generation of physicists, born since the special theory of relativity was formulated, do seem to have to a large degree just this instinctive ability to proceed safely, and no doubt to them many of our considerations in the following will appear trite and uninteresting. But it seems to me that our present theories, even the successful ones, are not yet constructed so completely in accord with sound principles but that in this day and generation criticism is a most necessary and useful enterprise for the physicist. One could document this contention, if necessary, by a chamber of horrors taken from the work of living physicists.

The physicist cannot lay claim to any essentially new discoveries in his awakening critical self-consciousness, and we cannot pretend that most of what we are discovering to be important has not already been clearly apprehended by some of the great speculative minds among the technical logicians and mathematicians or even the physicists themselves. But certainly any such apprehension has not been very widely disseminated, and has hitherto percolated only to a very small extent in the direction of the ordinary physicist, overwhelmed with all the new factual things crowding about him. In these pages I explicitly disclaim having anything to say to the technical logician; I can speak only from the point of view of the awakening awareness coming to the physicist. I do think, however, that this awakening awareness contains the possibilities of very important reactions on the conduct of our daily lives in domains remote from that of physics, so that perhaps this volume may help in popularizing the ability to handle actual situations, although it may offer no new technical contribution. It may, however, well require generations of intensive education before the rational principles of thought which are necessary for dealing with the simple situations of physics are intuitively grasped and instinctively applied to the complex situations of social life.

II. OPERATIONS

THE incentive to our present burst of critical activity doubtless had its origin in the disconcerting discovery, made in analyzing the reasons for the success of the restricted principle of relativity, that some of our fundamental concepts and modes of thought were incapable of dealing with the enlarged physical situations that were developing. Out of this has come one of the principal demands that the critic must set himself, namely to get his physical thinking on such a secure basis that this sort of thing may not happen again, and to make his methods elastic enough to deal with any sort of factual situation that may present itself. Our analysis of one of the fundamental reasons for the success of the restricted theory of relativity has disclosed a method of meeting this demand which must, I think, remain at the foundation of all our efforts at criticism. This method was suggested by the clear recognition that the ultimately important thing about any theory is what it actually does, not what it says it does or what its author thinks it does, for these are often very different things indeed. The most important technique of criticism is the technique of clearly apprehending and reporting just what one actually does, or what is actually happening in any situation, and this is a technique which is not easy to acquire and in which one becomes more expert only by continual practice. One reason why criticism is now in such a more advantageous position than it was thirty years ago is that it has now so much more material, in the accumulating bulk of physical theories, for the practice of this technique.

A clear-eyed recognition of what actually happens is hindered by most of the mental habits drilled into us by education. For I think it must be conceded that the major part

of education at present consists in acquiring the *intuitive* ability to handle the conceptual instruments which the human race has evolved to meet the situations with which it is confronted, such, for example, as the all embracing instrument of language, whereas it is just these conceptual instruments that enlarged experience is proving are faulty. It is often very difficult indeed to get away from unconscious verbal implications that we have accepted without analysis all our lives, particularly when, as in many cases, our success as social beings depends on the completeness with which these implications are ingrained into our conduct. Not only do verbal implications hinder us in giving an accurate account of situations, but it is often difficult to get rid of the inferences with which we unconsciously dress our direct observation, as an analysis of the circumstantial evidence of many court proceedings would bring out.

Not only is it difficult to strip away the implications and give perfectly straight statements of what happens, but having done this the results are often so distressingly obvious that it is difficult to believe that we have uncovered anything of significance. But the most simple and apparently innocent statements often do contain a wealth of significance that may have bearing on everything that we do. It requires practice, imagination, and insight to perceive that the most obvious observations, such for example, as "thinking is an activity of the human nervous system" may contain revolutionary implications.

Most difficult of all—more difficult than the analysis or the intellectual recognition of significance—is the emotional acceptance of what we have discovered as really making a difference, and altering in accord with such acceptance our inmost convictions and mode of conduct. Probably every one of us has experienced the extreme slowness with which preconceptions which were acquired unconsciously in childhood wear away, even under the most determined and well considered attack by intelligence. Yet it is not until the convictions that we acquire become living convictions or, in everyday language, not until they "get under our skins," do they really matter; not until then can we hope to make real progress with the results of our analysis. In this respect the younger generation is enviably better off than those of us who have had to acquire these things by conscious effort—the younger generation is born with some of these things already under its skin.

There is one phase of the technique by which analysis makes itself conscious of what it actually does in any situation, and which is an outgrowth of relativity theory, which seems to me to be especially important. This technique I have called "operational" and I have discussed certain aspects of it at some length in my book, *The Logic of Modern Physics*, and have elaborated other aspects in other places.[1] This point of view will be implicit in much of what follows, so that it will pay to pause for a brief elaboration of the idea.

The best way to make it apprehensible, perhaps, is to give a paraphrase of what actually happened when Einstein formulated the special theory of relativity. In seeking to set up a theory of certain effects in moving bodies, Einstein found it desirable, as we practically always do in constructing a quantitative theory, to start with mathematical equations. The important step that Einstein made was that in analyzing the connection of the equations with the theory he was led to examine the details of what we do in applying the equations in any specific case. In particular, one of the variables in the equations was the time—what do we do in obtaining the number which replaces the general symbol for time when we apply the equation to a concrete case? As physicists

[1] "A Physicist's Second Reaction to Mengenlehre," *Scripta Mathematica*, Vol. II, 1934.

we know that this number is obtained by reading a clock of some sort, that is, it is a number given by a prescribed physical operation. Or the equations may involve the times of two different events in two different places, and to understand completely what is now involved we must analyze what we do in determining the time of two such events. Analysis shows that we read two clocks, one at each place. A new element now enters, because a complete description of all the manipulations involved demands that we set up some method by which we compare the two clocks with which we measure the two events. Out of the examination of what we do in comparing the clocks we all know came Einstein's revolutionary recognition that the property of two events which hitherto had been unthinkingly called simultaneity involves in the doing a complicated sequence of physical operations which cannot be uniquely specified unless we specify who it is that is reading the clocks. We know that a consequence of this is that different observers do not always get the same result, so that simultaneity is not an absolute property of two events, but is relative to the observing system, that is, the system that does the things that constitute the measurement. What Einstein was in effect doing in this instance was to inquire into the meaning of simultaneity, and he was finding the meaning by analyzing the physical operations employed in applying the concept in any concrete instance. It cannot be claimed, I suppose, that Einstein was the first consciously to use this technique; it is simply that the use of it by him occurred under conditions which dramatically focused attention on its importance, so that physicists are now apparently permanently "reconditioned" in this respect.

Two aspects of the question of "meaning" are involved here. There is in the first place a general aspect; with regard to this it seems to me that as a matter of self-analysis I am

never sure of a meaning until I have analyzed what I do, so that for me meaning is to be found in a recognition of the activities involved. These activities may be diffused and nebulous and on the purely emotional level, as when I recognize that what I mean when I say that I dislike something is that I confront myself with the thing in actuality or in imagination and observe whether the emotion that it arouses is one with which I associate the name "dislike." The emotion awakened which I call "dislike" permits of no further analysis from this point of view, but has to be accepted as an ultimate. Because the unanalyzable "dislike" involves so much, and because the operation of observing whether the emotion is awakened is so simple, the operational aspect of meaning is not very important in cases like this.

The more particular and important aspect of the operational significance of meaning is suggested by the fact that Einstein recognized that in dealing with physical situations the operations which give meaning to our physical concepts should properly be physical operations, actually carried out. For in so restricting the permissible operations, our theories reduce in the last analysis to descriptions of operations actually carried out in actual situations, and so cannot involve us in inconsistency or contradiction, since these do not occur in actual physical situations. Thus is solved at one stroke the problem of so constructing our fundamental physical concepts that we shall never have to revise them in the light of new experience. New experience can demand only an extension of previously held concepts, not a fundamental revision, because at any moment our concepts are coextensive with the system of existing knowledge. The procedure of Einstein was in sharp contrast with the former method of defining concepts, as for example, the celebrated definition of Newton of absolute time as that which flows uniformly, independent of material happenings. In the first place this definition was

in terms of properties, instead of operations, and in the second place the properties themselves had no operational definition in terms of actual physical operations, but were defined in terms of metaphysical and idealized operations, which could therefore contain no assurance that they correspond to what will be found in experience. As a matter of fact they were found not to have such correspondence to a sufficient degree.

In the actual working out of the special theory of relativity much more had to be added than this revised conception of meaning, but the superstructure would not have been possible without the fundamental revision.

It must not be understood that we are maintaining that as a necessity of thought we must always demand that physical concepts be defined in terms of physical operations; we are merely stating that if by convention we agree to use only those concepts in describing physical situations to which we can give a meaning in terms of physical operations, then we are sure that we shall not have to retract. Other sorts of concept may be applicable, but such always require justification, and we cannot be sure that the justification will be forthcoming until we have made the experiment. The convention that physical concepts be defined in terms of physical operations is such an obviously useful one that it is coming to be accepted by physicists and demanded tacitly.

The significance of Einstein's observation about simultaneity and of a similar observation about the measurement of length is often sought in the generalized statement that all measurement is relative, and the implication is that this recognition of the relativity of measurement (which in special relativity means relative to the system of measurement) is intuitively to be accepted. I think there is nothing intuitive or general here, but a detailed and specific examination of what we do in measuring a time or a distance has to be made. The only generalization is that the measurements are relative

to the fundamental operations; this is merely a truism and yields nothing.

We have seen that if we restrict the operations we use in describing physical situations to physical operations actually performed, we shall be certain not to land in contradiction. We have also suggested that we may, if we like, give up the certainty of never making mistakes, and construct our concepts in other ways, defining them perhaps in terms of properties, as is so often done in mathematics, and then experiment with the structures we may erect in terms of such concepts to see whether the concepts are useful. We still have operational meaning for our concepts, but the operations are mental operations, and have no necessary physical validity. The use of such concepts may be very suggestive and stimulating. But even mental operations are subject to certain limitations, and if we transgress these in formulating our tentative concepts we may expect trouble. In particular all mental operations must be made in time, and are therefore ordered in time. Furthermore, no mental operation may assume a knowledge of the future. It can be shown that certain paradoxes arise when these limitations are ignored.

Operational analysis is applicable not only to the meaning of terms or concepts, but to other matters of meaning, as for example, to the meaning of questions. From this point of view I do not know what I mean by a question until I can picture to myself what I would do to check the correctness of an answer which might be presented to me. Analysis of questions from this point of view leads to the recognition that questions can be formulated which allow no possible procedure for checking the correctness of a hypothetical answer. An example is the celebrated question of W. K. Clifford, "Is it possible that as time goes on the dimensions of the universe may be continually changing, but in such a way that we can never detect it, because all our measur-

ing sticks are shrinking in the same way as everything else?" There is no method by which an answer "yes" or "no" to this question could be checked, because by hypothesis, in the question itself, we have ruled out the only method by which the correctness of the answer could be tested. This question must be judged meaningless, therefore. A great many meaningless questions can be formulated, and the clear recognition that meaningless questions are easy to formulate is a great analytical advance.

Not only are there meaningless questions, but many of the problems with which the human intellect has tortured itself turn out to be only "pseudo problems," because they can be formulated only in terms of questions which are meaningless. Many of the traditional problems of philosophy, of religion, or of ethics, are of this character. Consider, for example, the problem of the freedom of the will. You maintain that you are free to take either the right- or the left-hand fork in the road. I defy you to set up a single objective criterion by which you can prove after you have made the turn that you might have made the other. The problem has no meaning in the sphere of objective activity; it only relates to my personal subjective feelings while making the decision.

Continued application of the operational criterion of meaning has proved to be of the greatest assistance in arousing that self-consciousness of what we do in meeting physical situations which is fundamental to criticism.

This book will develop around a few of the simplest possible observations about what we do in dealing with situations. In most cases we shall not endeavor to justify these fundamental observations; it seems to me that they are of such an irreducible simplicity that once stated and apprehended they must command assent. Our main concern will be to examine whether the procedures of our customary practice have sufficiently taken account of these fundamental

observations, and if not, how our point of view will be thereby modified. Our analysis will be occupied at the beginning with a rather more elaborate examination of the properties of our mental processes than would perhaps seem to be necessary. My excuse must be that this is the direction in which my own thought seems to have been impelled in the years since publishing my first book. This impulsion has come, I believe, from the realization that only by this sort of analysis can we understand the failure of our former concepts. Furthermore, I believe we will be increasingly driven in this direction in the future by the emphasis of wave mechanics on the observer as a necessary part of any physical system. The rôle of the observer cannot be adequately understood without an appreciation of the way he must think, although it must be admitted that wave mechanics is still a long way from any treatment of this aspect of the observer.

To start as far back as possible, it is obvious that I can never get outside of myself; direct experience embraces only the things in my consciousness—sense impressions of various sorts and various sorts of cerebrations—and naught else. In the material of direct experience I distinguish features which I describe as external to myself and others which I recognize as internal, and possibly there are features where the decision is difficult, as for example whether the pain in my foot is due to a sliver beneath the skin or due to a stone in my shoe. The external features often arouse in me reactions of adjustment of one sort or another, and there are certain conventional devices which I use in making the adjustments. Success in making these adjustments I recognize as desirable, and is something that I strive for, but I do not always attain the success that I could desire.

There is no such thing as public or mass consciousness. In the last analysis science is only my private science, art is my

private art, religion my private religion, etc. The fact that in deciding what shall be my private science I find it profitable to consider only those aspects of my direct experience in which my fellow beings act in a particular way cannot obscure the essential fact that it is mine and naught else. "Public Science" is a particular kind of the science of private individuals.

This point of view is directly opposed to one which it has recently become popular to emphasize in critical writings, namely that "science" can refer only to the body of knowledge universally held by competent persons. But that there is something more to it, and that there is no getting away from the central position of the individual I believe anyone can see for himself merely by observing that the individual does not regard the following to be a senseless question: "Under what conditions would you draw the conclusion that everyone in the world except yourself had gone crazy?" It is possible to set up criteria for conditions under which this conclusion would be felt to be inevitable. Granted that every individual finds it desirable for his own purposes to concern himself only with what he observes other competent individuals agree on, nevertheless in the last resort every individual must be his own judge of what he shall accept to be satisfactory evidence of competence in another.

This position, which I suppose is the solipsist position, is often felt to be absurd and contrary to common sense. How, it is asked, can there be agreement as to experience unless there are external things which both you and I perceive? Part of the hostility to the solipsist position is, I think, merely due to confusion of thinking, and there is a strong element of the pseudo-problem mixed up here. If I say that an external thing is merely a part of my direct experience to which I find that you react in certain ways, what more is there to be said, or indeed what other operational meaning

can be attached to the concept of an external thing? It seems to me that as I have stated it, the solipsist position, if indeed this be the solipsist position, is a simple statement of what direct observation gives me, and we have got to adjust our thinking so that it will not seem repugnant.

There are two observations on the character of our direct conscious experience which appeal to me as perhaps more fundamental than others. The first is that our experience is composed of activities of one sort or another, that is, that it is not static, but in continual flux. Let one try to imagine what static self-consciousness would be like to convince oneself. The second is that the only possible attitude toward the facts of experience as it unrolls is one of acceptance. In particular, an attitude of acceptance toward the future is the only attitude that one can possibly adopt. Any mental devices that we invent in order to adjust ourselves to our experience must be subject to these restrictions, and if for special purposes we find it convenient to ignore this aspect of experience we must constantly hold in mind that we have a device of only limited applicability. In particular, since there is no means by which we can foresee the future we cannot tell in advance whether any mental device or invention will be successful in meeting new situations, and the only possible way of finding out is to actually try it.