

REMARKS ON THE ROLE OF THEORETICAL PHYSICS

There have been lately a number of new interpretations of quantum mechanics, most of which are equivalent in the sense that they predict the same results for all physical experiments. Since there is therefore no hope of deciding among them on the basis of physical experiments, we must turn elsewhere, and inquire into the fundamental question of the nature and purpose of physical theories in general. Only after we have investigated and come to some sort of agreement upon these general questions, i.e., of the role of theories themselves, will we be able to put these alternative interpretations in their proper perspective.

Every theory can be divided into two separate parts, the formal part, and the interpretive part. The formal part consists of a purely logico-mathematical structure, i.e., a collection of symbols together with rules for their manipulations, while the interpretive part consists of a set of “associations,” which are rules which put some of the elements of the formal part into correspondence with the perceived world. The essential point of a theory, then, is that it is a *mathematical model*, together with an *isomorphism*¹ between the model and the world of experience (i.e., the sense perceptions of the individual, or the “real world” — depending upon one’s choice of epistemology).

The model nature is quite apparent in the newest theories, as in nuclear physics, and particularly in those fields outside of physics proper, such as the Theory of Games, various economic models, etc., where the degree of

¹By isomorphism we mean a mapping of some elements of the model into elements of the perceived world which has the property that the model is faithful, that is, if in the model a symbol A implies a symbol B, and A corresponds to the happening of an event in the perceived world, then the event corresponding to B must also obtain. The word homomorphism would be technically more correct, since there may not be a one-one correspondence between the model and the external world

applicability of the models is still a matter of considerable doubt. However, when a theory is highly successful and becomes firmly established, the model tends to become identified with “reality” itself, and the model nature of the theory becomes obscured. The rise of classical physics offers an excellent example of this process. The constructs of classical physics are just as much fictions of our own minds as those of any other theory we simply have a great deal more confidence in them. It must be deemed a mistake, therefore, to attribute any more “reality” here than elsewhere.

Once we have granted that any physical theory is essentially only a model for the world of experience, we must renounce all hope of finding anything like “*the* correct theory.” There is nothing which prevents any number of quite distinct models from being in correspondence with experience (i.e., all “correct”), and furthermore no way of ever verifying that any model is completely correct, simply because the totality of all experience is never accessible to us.

Two types of prediction can be distinguished; the prediction of phenomena already understood, in which the theory plays simply the role of a device for compactly summarizing known results (the aspect of most interest to the engineer), and the prediction of new phenomena and effects, unsuspected before the formulation of the theory. Our experience has shown that a theory often transcends the restricted field in which it was formulated. It is this phenomenon (which might be called the “inertia” of theories) which is of most interest to the theoretical physicist, and supplies a greater motive to theory construction than that of aiding the engineer.

From the viewpoint of the first type of prediction we would say that the “best” theory is the one from which the most accurate predictions can be most easily deduced — two not necessarily compatible ideals. Classical physics, for example, permits deductions with far greater ease than the more accurate theories of relativity and quantum mechanics, and in such a case

we must retain them all. It would be the worst sort of folly to advocate that the study of classical physics be completely dropped in favor of the newer theories. It can even happen that several quite distinct models can exist which are completely equivalent in their predictions, such that different ones are most applicable in different cases, a situation which seems to be realized in quantum mechanics today. It would seem foolish to attempt to reject all but one in such a situation, where it might be profitable to retain them all.

Nevertheless, we have a strong desire to construct a single all-embracing theory which would be applicable to the entire universe. From what stems this desire? The answer lies in the second type of prediction — the discovery of new phenomena — and involves the consideration of inductive inference and the factors which influence our *confidence* in a given theory (to be applicable outside of the field of its formulation). This is a difficult subject, and one which is only beginning to be studied seriously. Certain main points are clear, however, for example, that our confidence increases with the number of successes of a theory. If a new theory replaces several older theories which deal with separate phenomena, i.e., a comprehensive theory of the previously diverse fields, then our confidence in the new theory is very much greater than the confidence in either of the older theories, since the range of success of the new theory is much greater than any of the older ones. It is therefore this factor of confidence which seems to be at the root of the desire for comprehensive theories.

A closely related criterion is *simplicity* — by which we refer to conceptual simplicity rather than ease in use, which is of paramount interest to the engineer. A good example of the distinction is the theory of general relativity which is conceptually quite simple, while enormously cumbersome in actual calculations. Conceptual simplicity, like comprehensiveness, has the property of increasing confidence in a theory. A theory containing many *ad hoc* constants and restrictions, or many independent hypotheses, in no way

impresses us as much as one which is largely free of arbitrariness.

It is necessary to say a few words about a view which is sometimes expressed, the idea that a physical theory should contain no elements which do not correspond directly to observables. This position seems to be founded on the notion that the only purpose of a theory is to serve as a summary of known data, and overlooks the second major purpose, the discovery of totally new phenomena. The major motivation of this viewpoint appears to be the desire to construct perfectly “safe” theories which will never be open to contradiction. Strict adherence to such a philosophy would probably seriously stifle the progress of physics.

The critical examination of just what quantities are observable in a theory does, however, play a useful role, since it gives an insight into ways of modification of a theory when it becomes necessary. A good example of this process is the development of Special Relativity. Such successes of the positivist viewpoint, when used merely as a tool for deciding which modifications of a theory are possible, in no way justify its universal adoption as a general principle which all theories must satisfy.

In summary, a physical theory is a logical construct (model), consisting of symbols and rules for their manipulation, some of whose elements are associated with elements of the perceived world. The fundamental requirements of a theory are logical consistency and correctness. There is no reason why there cannot be any number of different theories satisfying these requirements, and further criteria such as usefulness, simplicity, comprehensiveness, pictorability, etc., must be resorted to in such cases to further restrict the number. Even so, it may be impossible to give a total ordering of the theories according to “goodness,” since different ones may rate highest according to the different criteria, and it may be most advantageous to retain more than one.

As a final note, we might comment upon the concept of *causality*. It

should be clearly recognized that causality is a property of a model, and not a property of the world of experience. The concept of causality only makes sense with reference to a theory, in which there are logical dependencies among the elements. A theory contains relations of the form “A implies B,” which can be read as “A causes B,” while our experience, uninterpreted by any theory, gives nothing of the sort, but only a *correlation* between the event corresponding to B and that corresponding to A.