VII. PHYSICS

A Non-Causal Approach to Physical Time

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SUMMARY

It is contended that since causality is originally a metaphysical principle, it should be possible, in general, to formulate physical theories without recourse to this principle. The best known example for such an approach might be the theory of action at a distance, where the description of physical phenomena naturally takes an unfamiliar, non-causal form. The Machian aspect inherent in this approach is emphasized. The recent discovery of violation of time-reversal symmetry of the fundamental physical laws is discussed from the above viewpoint. It is hoped that this kind of non-causal approach will enable us to study some further aspects of time which otherwise are masked by, and intermingled with, causality.

1. TIME AND CAUSALITY

One of the main purposes of physics, or of physical sciences in general, is to find the regularities that may exist in the correlations between different physical phenomena. Such regularities, when quantitatively formulated in mathematical terms, are called physical laws. And it is customary, in most cases of dynamical theories, to express such physical laws in the form of differential equations, through which the physical quantities concerned, say $F$, are related to a continuous variable $t$ that is called time.

It should be noted in this respect that this variable $t$ used in physics has primarily not so much to do with any philosophical concepts, but is simply defined in reference to the dynamical states of some appropriate physical objects. Thus, the variable $t$ represents, for example, the number of swings $n$ of a pendulum, or the location $l$ of a star in the sky. That is to say, $t$ is defined as $t = t_1(n)$ or $t = t_2(l)$. The functional dependence of $F$ on $t$, or $F = F(t)$, being determined by the above-mentioned differential equations, should therefore be interpreted as representing $F = F_1(n)$ or $F = F_2(l)$. In this sense, we may say that what is described by the physical laws for $F$ is essentially the correlation between $F$ and $n$ or $l$. On the other hand, we know, of course, the correlation that exists between $n$ and $l$, that is, $n = n(l)$ or $l = l(n)$, so that $F = F_1(n)$ can immediately be converted into $F = F_2(l)$ and vice-versa. Thus, to express the quantity $F$ we may use any of the variables $n, l, ...$, whose representative is then denoted by $t$. That is to say, $t$ is the variable abstracted from the concrete variables $n, l, ...$.
Causality is one of the basic principles which underlie all physical theories. Here I am using the word ‘causality’ in the usual, most naive sense, specifying that a cause will lead to an effect at a later time. This is a principle of a metaphysical nature, and in this respect, it should be clearly distinguished from other principles that are of a properly physical nature. I am particularly emphasizing this point since many authors in physics maintain an ambiguous attitude toward such a distinction. The causality principle provides us with the basic framework in which our thinking is formed and developed. And we humans, especially physicists, have become so accustomed to this causal way of thinking that it is nowadays quite rare to ask a question such as: “Which part of our knowledge in physical sciences is due to this particular way of thinking, and which part is really specific to the nature of the physical world?”

Such questions have been partly answered by Watanabe, who constantly emphasizes the importance of the particular role that causality plays in physical sciences. According to him, we have an inborn mental habit — being intimately bound up with causality — of formulating propositions in such a form as: “If the object is in state A, then it will be in state B at a later time”, and physical theories provide the conditional probability for the process $A \rightarrow B$. Once such an attitude is taken, the symmetry with respect to past and future that originally existed in the physical laws will be lost: Prediction (of future) is always possible, but retrodiction (of past) is not. He goes on even to argue that the asymmetry or one-way-ness in the flow of time in the macroscopic world, which is exhibited, for example, by the increase of entropy, is also a natural consequence of this. I quite agree with him in this respect, except, however, that what he says might not perhaps be the only reason for the asymmetry in question.

The problem I would like to discuss mainly in this article is the following. In view of the above-mentioned nature of the causality principle, I believe that physical laws could alternatively be formulated without recourse to causality. Naturally, it should be expected from the outset that we would then have to change the pattern of our thinking in a drastic manner and to speak a language quite unfamiliar and unconventional. I believe, however, that in this way it would become possible to study some further aspects of time which otherwise are masked by, and intermingled with, causality. At this point I must hasten to add that when saying this I am not going to propose any new theory by myself, but merely to call attention to one of the old theories in physics which has remained rather unpopular in the orthodox school of physicists, that is, the theory of action at a distance.

2. CAUSAL DESCRIPTION: FIELD

In order to appreciate fully the unfamiliar features of a non-causal description of physical phenomena, let me begin with the conventional, causal description by specifically referring to the case of electromagnetism. The most characteristic features of the causal description of physical phenomena may be summarized as follows: The state of a given physical system at a certain instant $t_0$, to be denoted below by $S(t_0)$, can be uniquely determined by specifying the values of a set of quantities $q_1(t_0)$, $q_2(t_0)$, ..., which we call the general coordinates. It should be noticed here that to completely specify $S(t_0)$ we need not refer to those quantities at other times than $t_0$, such as $q_1(t)$, $q_2(t)$, ... with $t \leq t_0$. Thus, the prediction of the state of the system in the future, $S(t)$ with $t > t_0$, amounts to that of the quantities $q_1(t)$, $q_2(t)$, ..., and this is generally carried out by means of dynamical laws. As already mentioned in Section One such laws are usually given as a set of differential equations with