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Principles of Theoretical Physics

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Prussian Academy of Sciences, 1914

GENTLEMEN,

First of all, I have to thank you most heartily for conferring the greatest benefit on me that anybody can confer on a man like myself. By electing me to your Academy you have freed me from the distractions and cares of a professional life and so made it possible for me to devote myself entirely to scientific studies. I beg that you will continue to believe in my gratitude and my industry even when my efforts seem to you to yield but a poor result.

Perhaps I may be allowed *à propos* of this to make a few general remarks on the relation of my sphere of activity, which is theoretical physics, toward experimental physics. A mathematician friend of mine said to me the other day half in jest: "The mathematician can do a lot of things, but never what you happen to want him to do just at the moment." Much the same often applies to the theoretical physicist when the experimental physicist calls him in. What is the reason for this peculiar lack of adaptability?

The theorist's method involves his using as his foundation general postulates or "principles" from which he can deduce conclusions. His work thus falls into two parts. He must first discover his principles and then draw the conclusions which follow from them. For the second of these tasks he receives an admirable equipment at school. If, therefore, the first of his problems has already been solved for some field or for a complex of related phenomena, he is certain of success, provided his industry and intelligence are adequate. The first of these tasks, namely, that of establishing the principles which are to serve as the starting point of his deduction, is of an entirely different nature. Here there is no method capable of being learned and systematically applied so that it leads to the goal. The scientist has to worm these general principles out of nature by perceiving in comprehensive complexes of empirical facts certain general features which permit of precise formulation.

Once this formulation is successfully aecomplished, inference follows on inference, often revealing unforeseen relations which extend far beyond the province of the reality from which the principles were drawn. But as long as no principles are found on which to base the deduction, the individual empirical fact is of no use to the theorist; indeed he cannot even do anything with isolated general laws abstracted from experience. He will remain helpless in the face of separate results of empirical research, until principles which he can make the basis of deduc tive reasoning have revealed themselves to him.

This is the kind of position in which theory finds itself at present in regard to the laws of heat radiation and molecular motion at low temperatures. About fifteen years ago nobody had yet doubted that a correct account of the electrical, optical, and thermal properties of matter was possible on the basis of Galileo-Newtonian mechanics applied to molecular motion and of Maxwell's theory of the electromagnetic field. Then Planck showed that in order to establish a law of heat radiation consonant with experience, it was necessary to employ a method of calculation whose incompatibility with the principles of classical physics became clearer and clearer. For with this method of calculation, Planck introduced into physics the quantum hypothesis, which has since received brilliant confirmation. With this quantum hypothesis he dethroned classical physics as applied to the case where sufficiently small masses move at sufficiently low speeds and sufficiently high rates of acceleration, so that today the laws of motion propounded by Galileo and Newton can only be accepted as limiting laws. In spite of assiduous efforts, however, the theorists have not yet succeeded in replacing the principles of mechanics hy others which fit in with Planck's law of heat radiation or the quantum hypothesis. No matter how definitely it has been established that heat is to be explained by molecular motion, we have nevertheless to admit today that our position in regard to the fundamental laws of this motion resembles that of astronomers before Newton in regard to the motions of the planets.

I have just now referred to a group of facts for the theoretical treatment of which the principles are lacking. But it may equally well happen that clearly formulated principles lead to conclusions which fall entirely, or almost entirely, outside the sphere of reality at present accessible to our experience. In that case it may need many years of empirical research to ascertain whether the theoretical principles correspond with reality. We have an instance of this in the theory of relativity.

An analysis of the fundamental concepts of space and time has shown us that the principle of the constant velocity of light in empty space, which emerges from the optics of bodies in motion by no means forces us to accept the theory of a stationary luminiferous ether. On the contrary, it has been possible to frame a general theory which takes account of the fact that experiments carried out on the earth never reveal any translatory motion of the earth. This involves using the principle of relativity, which says that the laws of nature do not alter their form when one passes from the original (admissible) system of co-ordinates to a new one which is in uniform translatory motion with respect to it. This theory has received substantial confirmation from experience and has led to a simplification of the theoretical description of groups of facts already connected.

On the other hand, from the theoretical point of view this theory is not wholly satisfactory, because the principle of relativity just formulated favors *uniform* motion. If it is true that no absolute significance must be attached to *uniform* motion from the physical point of view, the question arises whether this statement must not also be extended to non-uniform motions. It has turned out that one arrives at an unambiguous extension of the relativity theory if one postulates a principle of relativity in this extended sense. One is led thereby to a general theory of gravitation which includes dynamics. For the present, however, we have not the necessary array of facts to test the legitimacy of our introduction of the postulated principle.

We have ascertained that inductive physics asks questions of deductive, and vice versa, the answers to which demand the exertion of all our energies. May we soon suceed in making permanent progress by our united efforts!