which he independently established the theory of statistical mechanics in a manner analogous to that of the great American physicist, J. W. Gibbs. (Statistical mechanics or the kinetic theory of matter derives the thermal properties of matter in bulk from the assumption that matter consists of atoms [ultimate particles] which move according to the laws of mechanics.) The most significant sequel was a third important paper which Einstein wrote in 1905, that on Brownian motion. In it Einstein predicted, on the basis of the kinetic theory, the motion of minute particles suspended in a liquid. (Such a motion had been observed about one hundred years earlier by the English botanist, Robert Brown.) Conversely, the experimental investigation of such motions (in particular the work of the French physicist Perrin, which was inspired by Einstein's theory) led to a verification of the basic hypotheses of the kinetic theory of matter.

PRINCIPLES OF THEORETICAL PHYSICS

Inaugural address before the Prussian Academy of Sciences, 1914. Einstein became a member of the Prussian Academy in 1913. In 1933, after the advent of the Hitler regime, he resigned from the Academy. (See correspondence, pp. 205 ff. of this volume.) Published in Proceedings of the 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 accomplished, 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 deductive 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 by 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 succeed in making permanent progress by our united efforts!

PRINCIPLES OF RESEARCH

Address delivered at a celebration of Max Planck's sixtieth birthday (1918) before the Physical Society in Berlin. Published in Mein Weltbild, *Amsterdam: Querido Verlag, 1934. Max Planck (1858–1947) was for many years professor of theoretical physics at the University of Berlin. By far the most outstanding of his contributions to physics is his quantum theory, which he advanced in 1900 and which has provided the basis for the whole development of modern atomic physics. Next to Planck it was Einstein who did the pioneering work in the young field, above all in his theory of light quanta or photons (1905) and his theory of specific heats (1907). It was he who perceived more than anyone else the fundamental and pervasive character of the quantum concept in all its ramifications.*

In the temple of science are many mansions, and various indeed are they that dwell therein and the motives that have led them thither. Many take to science out of a joyful sense of superior intellectual power; science is their own special sport to which they look for vivid experience and the satisfaction of ambition; many others are to be found in the temple who have offered the products of their brains on this altar for purely utilitarian purposes. Were an angel of the Lord to come and drive all the people belonging to these two categories out of the temple, the assemblage would be seriously depleted, but there would still be some men, of both present and past times, left inside. Our Planck is one of them, and that is why we love him.

I am quite aware that we have just now light-heartedly expelled in imagination many excellent men who are largely, perhaps chiefly, responsible for the building of the temple of science; and in many cases our angel would find it a pretty ticklish job to decide. But of one thing I feel sure: if the types we have just expelled were the only types there were, the temple would never have come to be, any more than a forest can grow which consists of nothing but creepers. For these people any sphere of human activity will do, if it comes to a point; whether they become engineers, officers, tradesmen, or scientists depends on circumstances. Now let us have another look at those who have found favor with the angel. Most of them are somewhat odd, uncommunicative, solitary fellows, really less like each other, in spite of these common characteristics, than the hosts of the rejected. What has brought them to the temple? That is a difficult question and no single answer will cover it. To begin with, I believe with Schopenhauer that one of the strongest motives that leads men to art and science is escape from everyday life with its painful crudity and hopeless dreariness, from the fetters of one's own ever shifting desires. A finely tempered nature longs to escape from personal life into the world of objective perception and thought; this desire may be compared with the townsman's irresistible longing to escape from his noisy, cramped surroundings into the silence of high mountains, where the eye ranges freely through the still, pure air and fondly traces out the restful contours apparently built for eternity.

With this negative motive there goes a positive one. Man tries to make for himself in the fashion that suits him best a simplified and intelligible picture of the world; he then tries to some extent to substitute this cosmos of his for the world of experience, and thus to overcome it. This is what the painter, the poet, the speculative philosopher, and the natural scientist do, each in his own fashion. Each makes this cosmos and its construction the pivot of his emotional life, in order to find in this way the peace and security which he cannot find in the narrow whirlpool of personal experience.

What place does the theoretical physicist's picture of the world occupy among all these possible pictures? It demands the highest possible standard of rigorous precision in the description of relations, such as only the use of mathematical language can give. In regard to his subject matter, on the other hand, the physicist has to limit himself very severely: he must content himself with describing the most simple events which can be brought within the domain of our experience; all events of a more complex order are beyond the power of the human intellect to reconstruct with the subtle accuracy and logical perfection which the theoretical physicist demands. Supreme purity, clarity, and certainty at the cost of completeness. But what can be the attraction of getting to know such a tiny section of nature thoroughly, while one leaves everything subtler and more complex shyly and timidly alone? Does the product of such a modest effort deserve to be called by the proud name of a theory of the universe?

In my belief the name is justified; for the general laws on which the structure of theoretical physics is based claim to be valid for any natural phenomenon whatsoever. With them, it ought to be possible to arrive at the description, that is to say, the theory, of every natural process, including life, by means of pure deduction, if that process of deduction were not far beyond the capacity of the human intellect. The physicist's renunciation of completeness for his cosmos is therefore not a matter of fundamental principle.

The supreme task of the physicist is to arrive at those universal elementary laws from which the cosmos can be built up by pure deduction. There is no logical path to these laws; only intuition, resting on sympathetic understanding of experience, can reach them. In this methodological uncertainty, one might suppose that there were any number of possible systems of theoretical physics all equally well justified; and this opinion is no doubt correct, theoretically. But the development of physics has shown that at any given moment, out of all conceivable constructions, a single one has always proved itself decidedly superior to all the rest. Nobody who has really gone deeply into the matter will deny that in practice the world of phenomena uniquely determines the theoretical system, in spite of the fact that there is no logical bridge between phenomena and their theoretical principles; this is what Leibnitz described so happily as a "pre-established harmony." Physicists often *accuse epistemologists of not paying sufficient attention to this* fact. Here, it seems to me, lie the roots of the controversy carried on some years ago between Mach and Planck.

The longing to behold this pre-established harmony is the source of the inexhaustible patience and perseverance with which Planck has devoted himself, as we see, to the most general problems of our science, refusing to let himself be diverted to more grateful and more easily attained ends. I have often heard colleagues try to attribute this attitude of his to extraordinary will-power and discipline—wrongly, in my opinion. The state of mind which enables a man to do work of this kind is akin to that of the religious worshiper or the lover; the daily effort comes from no deliberate intention or program, but straight from the heart. There he sits, our beloved Planck, and smiles inside himself at my childish playing-about with the lantern of Diogenes. Our affection for him needs no threadbare explanation. May the love of science continue to illumine his path in the future and lead him to the solution of the most important problem in present-day physics, which he has himself posed and done so much to solve. May he succeed in uniting quantum theory with electrodynamics and mechanics in a single logical system.

WHAT IS THE THEORY OF RELATIVITY?

Written at the request of The London Times. *Published November 28, 1919.*

I gladly accede to the request of your colleague to write something for *The Times* on relativity. After the lamentable breakdown of the old active intercourse between men of learning, I welcome this opportunity of expressing my feelings of joy and gratitude toward the astronomers and physicists of England. It is thoroughly in keeping with the great and proud traditions of scientific work in your country that eminent scientists should have spent much time and trouble, and your scientific institutions have spared no expense, to test the implications of a theory which was perfected and published dur-