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THE PHILOSOPHICAL SIGNIFICANCE OF THE THEORY OF RELATIVITY

I

THE philosophical significance of the theory of relativity has been the subject of contradictory opinions. Whereas many writers have emphasized the philosophical implications of the theory and have even tried to interpret it as a sort of philosophical system, others have denied the existence of such implications and have voiced the opinion that Einstein's theory is merely a physical matter, of interest only to the mathematical physicist. These critics believe that philosophical views are constructed by other means than the methods of the scientist and are independent of the results of physics.

Now it is true that what has been called the philosophy of relativity represents, to a great extent, the fruit of misunderstandings of the theory rather than of its physical content. Philosophers who regard it as an ultimate wisdom that everything is relative are mistaken when they believe that Einstein's theory supplies evidence for such a sweeping generalization; and their error is even deeper when they transfer such a relativity to the field of ethics, when they claim that Einstein's theory implies a relativism of men's duties and rights. The theory of relativity is restricted to the cognitive field. That moral conceptions vary with the social class and the structure of civilization is a fact which is not derivable from Einstein's theory; the parallelism between the relativity of ethics and that of space and time is nothing more than a superficial analogy, which blurs the essential logical differences between the fields of volition and cognition. It appears understandable that those who were trained in the precision of mathematico-physical methods wish to divorce physics from such blossoms of philosophizing.

Yet it would be another mistake to believe that Einstein's theory is not a philosophical theory. This discovery of a physicist has radical consequences for the theory of knowledge. It compels us to revise certain traditional conceptions that have played an important part in the history of philosophy, and it offers solutions for certain questions which are as old as the history of philosophy and which could not be answered earlier. Plato's attempt to solve the problems of geometry by a theory of ideas, Kant's attempt to account for the nature of space and time by a "*reine Anschauung*" and by a transcendental philosophy, these represent answers to the very questions to which Einstein's theory has given a different answer at a later time. If Plato's and Kant's doctrines are philosophical theories, then Einstein's theory of relativity is a philosophical and not a merely physical matter. And the questions referred to are not of a secondary nature but of primary import for philosophy; that much is evident from the central position they occupy in the systems of Plato and Kant. These systems are untenable if Einstein's answer is put in the place of the answers given to the same questions by their authors; their foundations are shaken when space and time are not the revelations of an insight into a world of ideas, or of a vision grown from pure reason, which a philosophical apriorism claimed to have established. The analysis of knowledge has always been the basic issue of philosophy; and if knowledge in so fundamental a domain as that of space and time is subject to revision, the implications of such criticism will involve the whole of philosophy.

To advocate the philosophical significance of Einstein's theory, however, does not mean to make Einstein a philosopher; or, at least, it does not mean that Einstein is a philosopher of primary intent. Einstein's primary objectives were all in the realm of physics. But he saw that certain physical problems could not be solved unless the solutions were preceded by a logical analysis of the fundamentals of space and time, and he saw that this analysis, in turn, presupposed a philosophic readjustment of certain familiar conceptions of knowledge. The physicist who wanted to understand the Michelson experiment had to commit himself to a philosophy for which the meaning of a statement is reducible to its verifiability, that is, he had to adopt the verifiability theory of meaning if he wanted to escape a maze of ambiguous questions and gratuitous complications. It is this positivist, or let me rather say, empiricist commitment which determines the philosophical position of Einstein. It was not necessary for him to elaborate on it to any great extent; he merely had to join a trend of development characterized, within the generation of physicists before him, by such names as Kirchhoff, Hertz, Mach, and to carry through to its ultimate consequences a philosophical evolution documented at earlier stages in such principles as Occam's razor and Leibnitz' identity of indiscernibles.

Einstein has referred to this conception of meaning in various remarks, though he has never felt it necessary to enter into a discussion of its grounds or into an analysis of its philosophical position. The exposition and substantiation of a philosophical theory is nowhere to be found in his writings. In fact, Einstein's philosophy is not so much a philosophical system as a philosophical attitude; apart from occasional remarks, he left it to others to say what philosophy his equations entail and thus remained a philosopher by implication, so to speak. That is both his strength and his weakness; his strength, because it made his physics so conclusive; his weakness, because it left his theory open to misunderstandings and erroneous interpretations.

It seems to be a general law that the making of a new physics precedes a new philosophy of physics. Philosophic analysis is more easily achieved when it is applied to concrete purposes, when it is done within the pursuit of research aimed at an interpretation of observational data. The philosophic results of the procedure are often recognized at a later stage; they are the fruit of reflection about the methods employed in the solution of the concrete problem. But those who make the new physics usually do not have the leisure, or do not regard it as their objective, to expound and elaborate the philosophy implicit in their constructions. Occasionally, in popular presentations, a physicist attempts to explain the logical background of his theories; thus many a physicist has been misled into believing that philosophy of physics is the same as a popularization of physics. Einstein himself does not belong to this group of writers who do not realize that what they achieve is as much a popularization of philosophy as it is one of physics, and that the philosophy of physics is as technical and intricate as is physics itself. Nevertheless, Einstein is not a philosopher in the technical sense either. It appears to be practically impossible that the man who is looking for new physical laws should also concentrate on the analysis of his method; he will perform this second task only when such analysis is indispensable for the finding of physical results. The division of labor between the physicist and the philosopher seems to be an inescapable consequence of the organization of the human mind.

It is not only a limitation of human capacities which calls for a division of labor between the physicist and the philosopher. The discovery of general relations that lend themselves to empirical verification requires a mentality different from that of the philosopher, whose methods are analytic and critical rather than predictive. The physicist who is looking for new discoveries must not be too critical; in the initial stages he is dependent on guessing, and he will find his way only if he is carried along by a certain faith which serves as a directive for his guesses. When I, on a certain occasion, asked Professor Einstein how he found his theory of relativity, he answered that he found it because he was so strongly convinced of the harmony of the universe. No doubt his theory supplies a most successful demonstration of the usefulness of such a conviction. But a creed is not a philosophy; it carries this name only in the popular interpretation of the term. The philosopher of science is not much interested in the thought processes which lead to scientific discoveries; he looks for a logical analysis of the completed theory, including the relationships establishing its validity. That is, he is not interested in the context of discovery, but in the context of justification. But the critical attitude may make a man incapable of discovery; and, as long as he is successful, the creative physicist may very well prefer his creed to the logic of the analytic philosopher.

The philosopher has no objections to a physicist's beliefs, so long as they are not advanced in the form of a philosophy. He knows that a personal faith is justified as an instrument of finding a physical theory, that it is but a primitive form of guessing, which is eventually replaced by the elaborate theory, and that it is ultimately subject to the same empirical tests as the theory. The philosophy of physics, on the other hand, is not a product of creed but of analysis. It incorporates the physicist's beliefs into the psychology of discovery; it endeavors to clarify the meanings of physical theories, independently of the interpretation by their authors, and is concerned with logical relationships alone.

Seen from this viewpoint it appears amazing to what extent the logical analysis of relativity coincides with the original interpretation by its author, as far as it can be constructed from the scanty remarks in Einstein's publications. In contradistinction to some developments in quantum theory, the logical schema of the theory of relativity corresponds surprisingly with the program which controlled its discovery. His philosophic clarity distinguishes Einstein from many a physicist whose work became the source of a philosophy different from the interpretation given by the author. In the following pages I shall attempt to outline the philosophical results of Einstein's theory, hoping to find a friendly comment by the man who was the first to see all these relations, even though he did not always formulate them explicitly. And the gratitude of the philosopher goes to this great physicist whose work includes more implicit philosophy than is contained in many a philosophical system.

II

The logical basis of the theory of relativity is the discovery that many statements, which were regarded as capable of demonstrable truth or falsity, are mere definitions.

This formulation sounds like the statement of an insignificant technical discovery and does not reveal the far-reaching implications which make up the philosophical significance of the theory. Nonetheless it is a complete formulation of the *logical* part of the theory.

Consider, for instance, the problem of geometry. That the unit of measurement is a matter of definition is a familiar fact; everybody knows that it does not make any difference whether we measure distances in feet or meters or light-years. However, that the comparison of distances is also a matter of definition is known only to the expert of relativity. This result can also be formulated as the definitional character of congruence. That a certain distance is congruent to another distance situated at a different place can never be proved to be true; it can only be maintained in the sense of a definition. More precisely speaking, it can be maintained as true only after a definition of congruence is given; it therefore depends on an original comparison of distances which is a matter of definition. A comparison of distances by means of the transport of solid bodies is but one definition of congruence. Another definition would result if we regarded a rod, once it had been transported to another location, as twice as long, thrice transported as three times as long, and so on. A further illustration refers to time: that the simultaneity of events occurring at distant places is a matter of definition was not known before Einstein based his special theory of relativity on this logical discovery.

The definitions employed for the construction of space and time are of a particular kind: they are co-ordinative definitions. That is, they are given by the co-ordination of a physical object, or process, to some fundamental concept. For instance, the concept "equal length" is defined by reference to a physical object, a solid rod, whose transport lays down equal distances. The concept "simultaneous" is defined by the use of light-rays which move over equal distances. The definitions of the theory of relativity are all of this type; they are co-ordinative definitions.

In the expositions of the theory of relativity the use of different definitions is often illustrated by a reference to different observers. This kind of presentation has led to the erroneous conception that the relativity of space-time measurements is connected with the subjectivity of the observer, that the privacy of the world of sense perception is the origin of the relativity maintained by Einstein. Such Protagorean interpretation of Einstein's relativity is utterly mistaken. The definitional character of simultaneity, for instance, has nothing to do with the perspective variations resulting for observers located in different frames of reference. That we co-ordinate different definitions of simultaneity to different observers merely serves as a simplification of the presentation of logical relationships. We could as well interchange the co-ordination and let the observer located in the "moving" system employ the time definition of the observer located in the system "at rest," and vice versa; or we could even let both employ the same time definition, for instance that of the system "at rest." Such variations would lead to different transformations; for instance, the last mentioned definition would lead, not to the Lorentz transformation, but to the classical transformation from a system at rest to a moving system. It is convenient to identify one definitional system with one observer; to speak of different observers is merely a mode of speech expressing the plurality of definitional systems. In a logical exposition of the theory of relativity the observer can be completely eliminated.

Definitions are arbitrary; and it is a consequence of the definitional character of fundamental concepts that with the change of the definitions various descriptional systems arise. But these systems are equivalent to each other, and it is possible to go from each system to another one by a suitable transformation. Thus the definitional character of fundamental concepts leads to a plurality of equivalent descriptions. A familiar illustration is given by the various descriptions of motion resulting when the system regarded as being at rest is varied. Another illustration is presented by the various geometries resulting, for the same physical space, through changes in the definition of congruence. All these descriptions represent different languages saying the same thing; equivalent descriptions, therefore, express the same physical content. The theory of equivalent descriptions is also applicable to other fields of physics; but the domain of space and time has become the model case of this theory.

The word "relativity" should be interpreted as meaning "relative to a certain definitional system." That relativity implies plurality follows because the variation of definitions leads to the plurality of equivalent descriptions. But we see that the plurality implied is not a plurality of different views, or of systems of contradictory content; it is merely a plurality of equivalent languages and thus of forms of expression which do not contradict each other but have the same content. Relativity does not mean an abandonment of truth; it only means that truth can be formulated in various ways.

I should like to make this point quite clear. The two statements "the room is 21 feet long" and "the room is 7 yards long" are quivalent descriptions; they state the same fact. That the simple truth they express can be formulated in these two ways does not eliminate the concept of truth; it merely illustrates the fact that the number characterizing a length is relative to the unit of measurement. All relativities of Einstein's theory are of this type. For instance, the Lorentz transformation connects different descriptions of space-time relations which are equivalent in the same sense as the statements about a length of 21 feet and a length of 7 yards.

Some confusion has arisen from considerations referring to the property of simplicity. One descriptional system can be simpler than another; but that fact does not make it "truer" than the other. The decimal system is simpler than the yard-foot-inch system; but an architect's plan drawn in feet and inches is as true a description of a house as a plan drawn in the decimal system. A simplicity of this kind, for which I have used the name of *descriptive simplicity*, is not a criterion of truth. Only within the frame of inductive considerations can simplicity be a criterion of truth; for instance, the simplest curve between observational data plotted in a diagram is regarded as "truer," i.e., more probable, than other connecting curves. This *inductive simplicity*, however, refers to non-equivalent descriptions and does not play a part in the theory of relativity, in which only equivalent descriptions are compared. The simplicity of descriptions used in Einstein's theory is therefore always a descriptive simplicity. For instance, the fact that non-Euclidean geometry often supplies a simpler description of physical space than does Euclidean geometry does not make the non-Euclidean description "truer."

Another confusion must be ascribed to the theory of conventionalism, which goes back to Poincaré. According to this theory, geometry is a matter of convention, and no empirical meaning can be assigned to a statement about the geometry of physical space. Now it is true that physical space can be described by both a Euclidean and a non-Euclidean geometry; but it is an erroneous interpretation of this relativity of geometry to call a statement about the geometrical structure of physical space meaningless. The choice of a geometry is arbitrary only so long as no definition of congruence is specified. Once this definition is set up, it becomes an empirical question *which* geometry holds for a physical space. For instance, it is an empirical fact that, when we use solid bodies for the definition of congruence, our physical space is practically Euclidean within terrestrial dimensions. If, in a different part of the universe, the same definition of congruence were to lead to a non-Euclidean geometry, that part of universal space would have a geometrical structure different from that of our world. It is true that a Euclidean geometry could also be introduced for that part of the universe; but then the definition of congruence would no longer be given by solid bodies.[1] The combination of a statement about a geometry with a statement of the co-ordinative definition of congruence employed is subject to empirical test and thus expresses a property of the physical world. The conventionalist overlooks the fact that only the incomplete statement of a geometry, in which a reference to the definition of congruence is omitted, is arbitrary; if the statement is made complete by the addition of a reference to the definition of congruence, it becomes empirically verifiable and thus has physical content.

Instead of speaking of conventionalism, therefore, we should speak of the relativity of geometry. Geometry is relative in precisely the same sense as other relative concepts. We might call it a convention to say that Chicago is to the left of New York; but we should not forget that this conventional statement can be made objectively true as soon as the point of refer-

[1] Poincaré believed that the definition of a solid body could not be given without reference to a geometry. That this conception is mistaken, is shown in the present author's *Philosophie der Raum-Zeit-Lehre* (Berlin, 1928) §5.

ence is included in the statement. It is not a convention but a physical fact that Chicago is to the left of New York, seen, for instance, from Washington, D.C. The relativity of simple concepts, such as left and right, is well known. That the fundamental concepts of space and time are of the same type is the essence of the theory of relativity.

The relativity of geometry is a consequence of the fact that different geometries can be represented on one another by a one-to-one correspondence. For certain geometrical systems, however, the representation will not be continuous throughout, and there will result singularities in individual points or lines. For instance, a sphere cannot be projected on a plane without a singularity in at least one point; in the usual projections, the North Pole of the sphere corresponds to the infinity of the plane. This peculiarity involves certain limitations for the relativity of geometry. Assume that in one geometrical description, say, by a spherical space, we have a normal causality for all physical occurrences; then a transformation to certain other geometries, including the Euclidean geometry, leads to violations of the principle of causality, to *causal anomalies*. A light signal going from a point A by way of the North Pole to a point B in a finite time will be so represented within a Euclidean interpretation of this space, that it moves from A in one direction towards infinity and returns from the other side towards B, thus passing through an infinite distance in a finite time. Still more complicated causal anomalies result for other transformations.[2] If the principle of normal causality, i.e., a continuous spreading from cause to effect in a finite time, or *action by contact*, is set up as a necessary prerequisite of the description of nature, certain worlds cannot be interpreted by certain geometries. It may well happen that the geometry thus excluded is the Euclidean one; if Einstein's hypothesis of a closed universe is correct, a

[2] Cf. the author's *Philosophie der Raum-Zeit-Lehre* (Berlin, 1928), §12. It has turned out that within the plurality of descriptions applicable to quantum mechanics the problem of causal anomalies plays an even more important part, since we have there a case where no description exists which avoids causal anomalies. (Cf. also the author's *Philosophic Foundations of Quantum Mechanics*, Berkeley, 1944), §§5-7, §26.

Euclidean description of the universe would be excluded for all adherents of a normal causality.

It is this fact which I regard as the strongest refutation of the Kantian conception of space. The relativity of geometry has been used by Neo-Kantians as a back door through which the apriorism of Euclidean geometry was introduced into Einstein's theory: if it is always possible to select a Euclidean geometry for the description of the universe, then the Kantian insists that it be this description which should be used, because Euclidean geometry, for a Kantian, is the only one that can be visualized. We see that this rule may lead to violations of the principle of causality; and since causality, for a Kantian, is as much an *a priori* principle as Euclidean geometry, his rule may compel the Kantian to jump from the frying pan into the fire. There is no defense of Kantianism, if the statement of the geometry of the physical world is worded in a complete form, including all its physical implications; because in this form the statement is empirically verifiable and depends for its truth on the nature of the physical world.[8]

It should be clear from this analysis that the plurality of equivalent description does not rule out the possibility of true empirical statements. The empirical content of statements about space and time is only stated in a more complicated way.

III

Though we now possess, in Einstein's theory, a complete statement of the relativity of space and time, we should not forget that this is the result of a long historical development. I mentioned above Occam's razor and Leibnitz' identity of indiscernibles in connection with the verifiability theory of meaning. It is a matter of fact that Leibnitz applied his principle successfully to the problem of motion and that he arrived at a relativity of motion on logical grounds. The famous correspondence between Leibnitz and Clarke,—the latter a contemporary defender of Newton's absolutism,—presents us with the same type of discussion which is familiar from the modern discussions

[8] This refutation of Kantianism was presented in the author's *Relativitätstheorie und Erkenntnis Apriori* (Berlin, 1920).

of relativity and reads as though Leibnitz had taken his arguments from expositions of Einstein's theory. Leibnitz even went so far as to recognize the relationship between causal order and time order.[4] This conception of relativity was carried on at a later time by Ernst Mach, who contributed to the discussion the important idea that a relativity of rotational motion requires an extension of relativism to the concept of inertial force. Einstein has always acknowledged Mach as a forerunner of his theory.

Another line of development, which likewise found its completion through Einstein's theory, is presented by the history of geometry. The discovery of non-Euclidean geometries by Gauss, Bolyai, and Lobachewski was associated with the idea that physical geometry might be non-Euclidean; and it is known that Gauss tried to test the Euclidean character of terrestrial geometry by triangular measurements from mountain tops. But the man to whom we owe the philosophical clarification of the problem of geometry is Helmholtz. He saw that physical geometry is dependent on the definition of congruence by means of the solid body and thus arrived at a clear statement of the nature of physical geometry, superior in logical insight to Poincaré's conventionalism developed several decades later. It was Helmholtz, too, who clarified the problem of a visual presentation of non-Euclidean geometry by the discovery that visualization is a fruit of experiences with solid bodies and light-rays. We find in Helmholtz' writings the famous statement that imagining something visually means depicting the series of sense perceptions which one would have if one lived in such a world. That Helmholtz did not succeed in dissuading contemporary philosophers from a Kantian apriorism of space and time is not his fault. His philosophical views were known only among a small group of experts. When, with Einstein's theory, the public interest turned toward these problems, philosophers began to give in and to depart from Kant's apriorism. Let us hope that this development will continue and eventually include even those philosophers who in our day still defend an apriorist philosophy against the attacks of the mathematical physicist.

[4] For an analysis of Leibnitz' views see the author's "Die Bewegungslehre bei Newton, Leibnitz und Huyghens," *Kantstudien* [vol. 29, 1924], 416.

Although there exists a historical evolution of the concepts of space and motion, this line of development finds no analogue in the concept of time. The first to speak of a relativity of the measure of time, i.e., of what is called the uniform flow of time, was Mach. However, Einstein's idea of a relativity of simultaneity has no forerunners. It appears that this discovery could not be made before the perfection of experimental methods of physics. Einstein's relativity of simultaneity is closely associated with the assumption that light is the fastest signal, an idea which could not be conceived before the negative outcome of such experiments as that by Michelson.

It was the combination of the relativity of time and of motion which made Einstein's theory so successful and led to results far beyond the reach of earlier theories. The discovery of the special theory of relativity, which none of Einstein's forerunners had thought of, thus became the key to a general theory of space and time, which included all the ideas of Leibnitz, Gauss, Riemann, Helmholtz, and Mach, and which added to them certain fundamental discoveries which could not have been anticipated at an earlier stage. In particular, I refer to Einstein's conception according to which the geometry of physical space is a function of the distribution of masses, an idea entirely new in the history of geometry.

This short account shows that the evolution of philosophical ideas is guided by the evolution of physical theories. The philosophy of space and time is not the work of the ivory tower philosopher. It was constructed by men who attempted to combine observational data with mathematical analysis. The great synthesis of the various lines of development, which we owe to Einstein, bears witness to the fact that philosophy of science has taken over a function which philosophical systems could not perform.

IV

The question of what is space and time has fascinated the authors of philosophical systems over and again. Plato answered it by inventing a world of "higher" reality, the world of ideas, which includes space and time among its ideal objects and reveals their relations to the mathematician who is able to perform the necessary act of vision. For Spinoza space was an attribute of God. Kant, on the other hand, denied the reality of space and time and regarded these two conceptual systems as forms of visualization, i.e., as constructions of the human mind, by means of which the human observer combines his perceptions so as to collect them into an orderly system.

The answer we can give to the question on the basis of Einstein's theory is very different from the answers of these philosophers. The theory of relativity shows that space and time are neither ideal objects nor forms of order necessary for the human mind. They constitute a relational system expressing certain general features of physical objects and thus are descriptive of the physical world. Let us make this fact quite clear.

It is true that, like all concepts, space and time are inventions of the human mind. But not all inventions of the human mind are fit to describe the physical world. By the latter phrase we mean that the concepts refer to certain physical objects and differentiate them from others. For instance, the concept "centaur" is empty, whereas the concept "bear" refers to certain physical objects and distinguishes them from others. The concept "thing," on the other hand, though not empty, is so general that it does not differentiate between objects. Our examples concern one-place predicates, but the same distinction applies to two-place predicates. The relation "telepathy" is empty, whereas the relation "father" is not. When we say that non-empty one-place predicates like "bear" describe real objects, we must also say that non-empty many-place predicates like "father" describe real relations.

It is in this sense that the theory of relativity maintains the reality of space and time. These conceptual systems describe relations holding between physical objects, namely, solid bodies, light-rays, and watches. In addition, these relations formulate physical laws of great generality, determining some fundamental features of the physical world. Space and time have as much reality as, say, the relation "father" or the Newtonian forces of attraction.

The following consideration may serve as a further explanation why geometry is descriptive of physical reality. As long as only one geometry, the Euclidean geometry, was known, the fact that this geometry could be used for a description of the physical world represented a problem for the philosopher; and Kant's philosophy must be understood as an attempt to explain why a structural system derived from the human mind can account for observational relations. With the discovery of a plurality of geometries the situation changed completely. The human mind was shown to be capable of inventing all kinds of geometrical systems, and the question, which of the systems is suitable for the description of physical reality, was turned into an empirical question, i.e., its answer was ultimately left to empirical data. Concerning the empirical nature of this answer we refer the reader to our considerations in Section II; it is the combined statement of geometry and co-ordinative definitions which is empirical. But, if the statement about the geometry of the physical world is empirical, geometry describes a property of the physical world in the same sense, say, as temperature or weight describe properties of physical objects. When we speak of the reality of physical space we mean this very fact.

As mentioned above, the objects whose general relationship is expressed in the spatio-temporal order are solid bodies, light-rays, and natural watches, i.e., closed periodic systems, like revolving atoms or revolving planets. The important part which light-rays play in the theory of relativity derives from the fact that light is the fastest signal, i.e., represents the fastest form of a causal chain. The concept of causal chain can be shown to be the basic concept in terms of which the structure of space and time is built up. The spatio-temporal order thus must be regarded as the expression of the causal order of the physical world. The close connection between space and time on the one hand and causality on the other hand is perhaps the most prominent feature of Einstein's theory, although this feature has not always been recognized in its significance. Time order, the order of *earlier* and *later*, is reducible to causal order; the cause is always earlier than the effect, a relation which cannot be reversed. That Einstein's theory admits of a reversal of time order for certain events, a result known from the relativity of simultaneity, is merely a consequence of this fundamental fact.

Since the speed of causal transmission is limited, there exist events of such a kind that neither of them can be the cause or the effect of the other. For events of this kind a time order is not defined, and either of them can be called earlier or later than the other.

Ultimately even spatial order is reducible to causal order; a space point *B* is called closer to *A* than a space point *C*, if a direct light-signal, i.e., a fastest causal chain, from *A* to *C* passes by *B*. For a construction of geometry in terms of light-rays and mass-points, i.e., a light-geometry, I refer to another publication.[5]

The connection between time order and causal order leads to the question of the direction of time. I should like to add some remarks about this problem which has often been discussed, but which has not always been stated clearly enough. The relation between cause and effect is an asymmetrical relation; if *P* is the cause of *Q*, then *Q* is not the cause of *P*. This fundamental fact is essential for temporal order, because it makes time a serial relation. By a serial relation we understand a relation that orders its elements in a linear arrangement; such a relation is always asymmetrical and transitive, like the relation "smaller than." The time of Einstein's theory has these properties; that is necessary, because otherwise it could not be used for the construction of a serial order.

But what we call the direction of time must be distinguished from the asymmetrical character of the concepts "earlier" and "later." A relation can be asymmetrical and transitive without distinguishing one direction from the opposite one. For instance, the points of a straight line are ordered by a serial relation which we may express by the words "before" and "after." If *A* is before *B*, then *B* is not before *A*, and if *A* is before *B* and *B* is before *C*, then *A* is before *C*. But which direction of the line we should call "before" and which one "after" is not indicated by the nature of the line; this definition can only be set up by an arbitrary choice, for instance, by pointing into one direction and calling it the direction of "before." In other words, the relations "before" and "after" are structurally indistinguish-

[5] H. Reichenbach, *Philosophie der Raum-Zeit-Lehre* (Berlin, 1928), §27.

able and therefore interchangeable; whether we say that point *A* is before point *B* or after point *B* is a matter of arbitrary definition. It is different with the relation "smaller than" among real numbers. This relation is also a serial relation and thus asymmetrical and transitive; but in addition, it is structurally different from its converse, the relation "larger than," a fact expressible through the difference of positive and negative numbers. The square of a positive number is a positive number, and the square of a negative number is also a positive number. This peculiarity enables us to define the relation "smaller than:" a number which cannot be the square of another number is smaller than a number which is the square of another number. The series of real numbers possesses therefore a direction: the direction "smaller than" is not interchangeable with the direction "larger than;" these relations are therefore not only asymmetrical but also *unidirectional.*

The problem of the time relation is whether it is unidirectional. The relation "earlier than" which we use in everyday life is structurally different from the relation "later than." For instance, we may make up our mind to go to the theatre tomorrow; but it would be nonsensical to make up our mind to go to the theatre yesterday. The physicist formulates this distinction as the *irreversibility of time:* time flows in one direction, and the flow of time cannot be reversed. We see that, in the language of the theory of relations, the question of the irreversibility of time is expressed, not by the question of whether time is an asymmetrical relation, but by the question of whether it is a unidirectional relation.

For the theory of relativity, time is certainly an asymmetrical relation, since otherwise the time relation would not establish a serial order; but it is not unidirectional. In other words, the irreversibility of time does not find an expression in the theory of relativity. We must not conclude that that is the ultimate word which the physicist has to say about time. All we can say is that, as far as the theory of relativity is concerned, we need not make a qualitative distinction between the two directions of time, between the "earlier" and "later." A physical theory may very well abstract from certain properties of the physical world; that does not mean that these properties do not exist. The irreversibility of time has so far been dealt with only in thermodynamics, where it is conceived as being merely of a statistical nature, not applicable to elementary processes. This answer is none too satisfactory; particularly in view of the fact that it has led to certain paradoxes. Quantum physics so far, however, has no better answer. I would like to say that I regard this problem as at present unsolved and do not agree with those who believe that there is no genuine problem of the direction of time.

It is an amazing fact that the mathematico-physical treatment of the concept of time formulated in Einstein's theory has led to a clarification which philosophical analysis could not achieve. For the philosopher such concepts as time order and simultaneity were primitive notions inaccessible to further analysis. But the claim that a concept is exempt from analysis often merely springs from an inability to understand its meaning. With his reduction of the time concept to that of causality and his generalization of time order toward a relativity of simultaneity, Einstein has not only changed our conceptions of time; he has also clarified the meaning of the classical time concept which preceded his discoveries. In other words, we know better today what absolute time means than anyone of the adherents of the classical time conceptions. Absolute simultaneity would hold in a world in which there exists no upper limit for the speed of signals, i.e., for causal transmission. A world of this type is as well imaginable as Einstein's world. It is an empirical question to which type our world belongs. Experiment has decided in favor of Einstein's conception. As in the case of geometry, the human mind is capable of constructing various forms of a temporal schema; the question which of these schemes fits the physical world, i.e., is true, can only be answered by reference to observational data. What the human mind contributes to the problem of time is not one definite time order, but a plurality of possible time orders, and the selection of one time order as the real one is left to empirical observation. Time is the order of causal chains; that is the outstanding result of Einstein's discoveries. The only philosopher who anticipated this result was Leibnitz; though, of course, in his day it was impossible to conceive of a relativity of simultaneity. And Leibnitz was a mathematician as well as a philosopher. It appears that the solution of the problem of time and space is reserved to philosophers who, like Leibnitz, are mathematicians, or to mathematicians who, like Einstein, are philosophers.

V

From the time of Kant, the history of philosophy shows a growing rift between philosophical systems and the philosophy of science. The system of Kant was constructed with the intention of proving that knowledge is the resultant of two components, a mental and an observational one; the mental component was assumed to be given by the laws of pure reason and conceived as a synthetic element different from the merely analytic operations of logic. The concept of a *synthetic a priori* formulates the Kantian position: there is a *synthetic a priori* part of knowledge, i.e., there are non-empty statements which are absolutely necessary. Among these principles of knowledge Kant includes the laws of Euclidean geometry, of absolute time, of causality and of the conservation of mass. His followers in the 19th century took over this conception, adding many variations.

The development of science, on the other hand, has led away from Kantian metaphysics. The principles which Kant regarded as *synthetic a priori* were recognized as being of a questionable truth; principles contradictory to them were developed and employed for the construction of knowledge. These new principles were not advanced with a claim to absolute truth but in the form of attempts to find a description of nature fitting the observational material. Among the plurality of possible systems, the one corresponding to physical reality could be singled out only by observation and experiment. In other words, the synthetic principles of knowledge which Kant had regarded as *a priori* were recognized as *a posteriori*, as verifiable through experience only and as valid in the restricted sense of empirical hypotheses.

It is this process of a dissolution of the *synthetic a priori* into which we must incorporate the theory of relativity, when we desire to judge it from the viewpoint of the history of philosophy. A line which began with the invention of non-Euclidean geometries 20 years after Kant's death runs uninterruptedly right up and into Einstein's theory of space and time. The laws of geometry, for 2000 years regarded as laws of reason, were recognized as empirical laws, which fit the world of our environment to a high degree of precision; but they must be abandoned for astronomic dimensions. The apparent self-evidence of these laws, which made them seem to be inescapable presuppositions of all knowledge, turned out to be the product of habit; through their suitability to all experiences of everyday life these laws had acquired a degree of reliability which erroneously was taken for absolute certainty. Helmholtz was the first to advocate the idea that human beings, living in a non-Euclidean world, would develop an ability of visualization which would make them regard the laws of non-Euclidean geometry as necessary and self-evident, in the same fashion as the laws of Euclidean geometry appear self-evident to us. Transferring this idea to Einstein's conception of time, we would say that human beings, in whose daily experiences the effects of the speed of light would be noticeably different from those of an infinite velocity, would become accustomed to the relativity of simultaneity and regard the rules of the Lorentz-transformation as necessary and self-evident, just as we regard the classical rules of motion and simultaneity self-evident. For instance, if a telephone connection with the planet Mars were established, and we would have to wait a quarter of an hour for the answer to our questions, the relativity of simultaneity would become as trivial a matter as the time difference between the standard times of different time zones is today. What philosophers had regarded as laws of reason turned out to be a conditioning through the physical laws of our environment; we have ground to assume that in a different environment a corresponding conditioning would lead to another adaptation of the mind.

The process of the dissolution of the *synthetic a priori* is one of the significant features of the philosophy of our time. We should not commit the mistake of considering it a breakdown of human abilities, if conceptions which we regarded as absolutely true are shown to be of limited validity and have to be abandoned in certain fields of knowledge. On the contrary, the fact that we are able to overcome these conceptions and to replace them by better ones reveals unexpected abilities of the human mind, a versatility vastly superior to the dogmatism of a pure reason which dictates its laws to the scientist.

Kant believed himself to possess a proof for his assertion that his *synthetic a priori* principles were necessary truths: According to him these principles were necessary conditions of knowledge. He overlooked the fact that such a proof can demonstrate the truth of the principles only if it is taken for granted that knowledge within the frame of these principles will always be possible. What has happened, then, in Einstein's theory is a proof that knowledge within the framework of Kantian principles is not possible. For a Kantian, such a result could only signify a breakdown of science. It is a fortunate fact that the scientist was not a Kantian and, instead of abandoning his attempts of constructing knowledge, looked for ways of changing the so-called *a priori* principles. Through his ability of dealing with space-time relations essentially different from the traditional frame of knowledge, Einstein has shown the way to a philosophy superior to the philosophy of the *synthetic a priori*.

It is the philosophy of empiricism, therefore, into which Einstein's relativity belongs. It is true, Einstein's empiricism is not the one of Bacon and Mill, who believed that all laws of nature can be found by simple inductive generalizations. Einstein's empiricism is that of modern theoretical physics, the empiricism of mathematical construction, which is so devised that it connects observational data by deductive operations and enables us to predict new observational data. Mathematical physics will always remain empiricist as long as it leaves the ultimate criterion of truth to sense perception. The enormous amount of deductive method in such a physics can be accounted for in terms of analytic operations alone. In addition to deductive operations there is, of course, an inductive element included in the physics of mathematical hypotheses; but even the principle of induction, by far the most difficult obstacle to a radical empiricism, can be shown today to be justifiable without a belief in a *synthetic a priori*. The method of modern science can be completely accounted for in terms of an empiricism which recognizes only sense perception and the analytic principles of logic as sources of knowledge. In spite of the enormous mathematical apparatus, Einstein's theory of space and time is the triumph of such a radical empiricism in a field which had always been regarded as a reservation for the discoveries of pure reason.

The process of the dissolution of the *synthetic a priori* is going on. To the abandonment of absolute space and time quantum physics has added that of causality; furthermore, it has abandoned the classical concept of material substance and has shown that the constituents of matter, the atomic particles, do not possess the unambiguous nature of the solid bodies of the macroscopic world. If we understand by metaphysics the belief in principles that are non-analytic, yet derive their validity from reason alone, modern science is anti-metaphysical. It has refused to recognize the authority of the philosopher who claims to know the truth from intuition, from insight into a world of ideas or into the nature of reason or the principles of being, or from whatever super-empirical source. There is no separate entrance to truth for philosophers. The path of the philosopher is indicated by that of the scientist: all the philosopher can do is to analyze the results of science, to construe their meanings and stake out their validity. Theory of knowledge is analysis of science.

I said above that Einstein is a philosopher by implication. That means that making the philosophic implications of Einstein's theory explicit is the task of the philosopher. Let us not forget that it is implications of an enormous reach which are derivable from the theory of relativity, and let us realize that it must be an eminently philosophical physics that lends itself to such implications. It does not happen very often that physical systems of such philosophical significance are presented to us; Einstein's predecessor was Newton. It is the privilege of our generation that we have among us a physicist whose work occupies the same rank as that of the man who determined the philosophy of space and time for two centuries. If physicists present us with implicational philosophies of such excellence, it is a pleasure to be a philosopher. The lasting fame of the philosophy of modern physics will justly go to the man who made the physics rather than to those who have been at work deriving the implications of his work and who are pointing out its position in the history of philosophy. There are many who have contributed to the philosophy of Einstein's theory, but there is only one Einstein.

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Albert Einstein

Philosopher-Scientist

Volume VII in the Library of Living Philosophers

MJF BOOKS
NEW YORK

Published by MJF Books
Fine Communications
Two Lincoln Square
60 West 66th Street
New York, NY 10023

Albert Einstein: Philosopher-Scientist
LC Control Number 00-135984
ISBN 1-56731-432-5

The Library of Living Philosophers is published under the sponsorship of Southern Illinois University at Carbondale.

This edition published by arrangement with Open Court Publishing Company.

Manufactured in the United States of America on acid-free paper

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