

## REICHENBACH, HANS

(1891-1953)

Hans Reichenbach was a leading philosopher of science and a proponent of logical positivism. He made important contributions to the theory of probability and to the philosophical interpretation of the theory of relativity, quantum mechanics, and thermodynamics.

### LIFE

Reichenbach studied civil engineering, physics, mathematics, and philosophy at Berlin, Göttingen, and Munich in 1910s. Among his teachers were neo-Kantian philosopher Ernst Cassirer, mathematician David Hilbert, and physicists Max Planck, Max Born, and Arnold Sommerfeld. Reichenbach received his degree in philosophy from the Friedrich-Alexander University of Erlangen-Nürnberg in 1915 with a dissertation on the theory of probability titled *Der Begriff der Wahrscheinlichkeit für die mathematische Darstellung der Wirklichkeit* (The Concept of Probability for the mathematical Representation of Reality), published in 1916. Between 1917 and 1920, while he was working as a physicist and engineer, Reichenbach attended Albert Einstein's lectures on the theory of relativity at Berlin. He was fascinated by the theory of relativity and in few years published four books about this subject: *The Theory of Relativity and A Priori Knowledge* (1920), *Axiomatization of the Theory of Relativity* (1924), *From Copernicus to Einstein* (1927) and *The Philosophy of Space and Time* (1928). In 1920 he began teaching at the Technische Hochschule at Stuttgart as private docent.

With the help of Einstein, Planck, and Max von Laue, in 1926 Reichenbach became assistant professor in the physics department of Berlin University. In 1930 he undertook the editorship of the journal *Erkenntnis* (Knowledge) with Rudolf Carnap. In 1933, soon after Adolf Hitler became chancellor of Germany, Reichenbach was dismissed from Berlin University because his family had Jewish origin. He emigrated to Turkey, where was appointed chief of the philosophy department of Istanbul University with a five-year contract. During his stay in Turkey he published *The Theory of Probability* (1935). In 1938 he moved to the United States, where

became professor at the University of California at Los Angeles. In the following years Reichenbach published *Experience and Prediction* (1938), *Philosophic Foundations of Quantum Mechanics* (1944), *Elements of Symbolic Logic* (1947), “The Philosophical Significance of the Theory of Relativity” in *Albert Einstein: Philosopher-Scientist* (1949), edited by Paul Arthur Schilpp, and *The Rise of Scientific Philosophy* (1951). Reichenbach died in 1953 while he was working on the nature of scientific laws and on the philosophy of time. The two books that came from this work, *Nomological Statements and Admissible Operations* (1954) and *The Direction of Time* (1956), were published posthumously.

## COORDINATIVE DEFINITIONS

An important tool introduced by Reichenbach for the philosophical analysis of scientific theories is that of coordinative definitions. According to Reichenbach, a mathematical theory differs from a physical theory because the latter uses a specific type of definition, named coordinative definition, which coordinates (that is associates) some concepts of the theory with physical objects or processes. An example of a coordinative definition is the definition of the standard unit of length in the metric system, which connects the meter with a rod housed in the International Bureau of Weights and Measures in Sèvres, or with a well-defined multiple of the wavelength of a determined chemical element. Another example is the definition of the straight line as the path of a ray of light in vacuum. A scientific theory acquires a physical interpretation only by means of coordinative definitions. Without such type of definitions a theory lacks of a physical interpretation and it is not verifiable, but it is an abstract formal system, whose only requirement is axioms’ consistency.

Geometry well illustrates the role of coordinative definitions. In Reichenbach’s opinion, there are two different kinds of theories concerning geometry, namely mathematical geometry and physical geometry. Mathematical geometry is a formal system that does not deal with the truth of axioms, but with the proof of theorems - that is, it only searches for the consequences of axioms. Physical geometry is concerned with the real geometry in the physical world; it searches for the truth or falsity of axioms using the methods of the empirical science. The physical geometry derives from the mathematical geometry when appropriate coordinative definitions are added. For example, if the concept of straight line is coordinated with the path of a ray of light in

vacuum, the theory of relativity shows that the real geometry is a non-Euclidean geometry. Without coordinative definitions, Euclidean and non-Euclidean geometry are nothing but formal systems; with coordinative definitions, they are empirically testable. Coordinative definitions are conventions, because it is admissible to choose a different definition for a concept of a theory. In the case of geometry, with a different definition for the straight line, Euclidean geometry is true. In a sense, choosing between Euclidean and non-Euclidean geometry is not a matter of facts, but a matter of convention.

### RELATIVITY OF GEOMETRY

Reichenbach insists on the importance of the coordinative definitions in his philosophical analysis of the theory of relativity, especially in connection with the problem of determining the geometry of this world. In principle, scientists can discriminate between different geometry by means of measurements. For example, on the surface of a sphere, the ratio of the circumference of a circle to its diameter is less than  $\pi$ , whereas on the surface of a plane this ratio is equal to  $\pi$ . With a simple measurement of a circumference and of its diameter, we can discover we live on a sphere (the surface of Earth) and not on a plane. In the same way, using more subtle measurements, scientists can discover we live in a non-Euclidean space. However, there is a fundamental question: is measuring a matter of facts or does it depend on definitions? Reichenbach proposes the following problem, discussed in *The Philosophy of Space and Time*. Is the length of a rod altered when the rod is moved from one point of space, say A, to another point, say B? We know many circumstances in which the length is altered. For example, the temperature in A can differ from the temperature in B. However, the temperature acts in a different way on different substances. If the temperature is different in A and in B, then two rods of different material, such as wood and steel, which have the same length in A, will have a different length in B. So we can recognize a difference in temperature and use suitable procedures to eliminate variations in measurement due to variations in temperature. In general, this is also possible for every differential force - that is, for every force that acts in a different way on different substances. But there is also another type of forces, called universal forces, which produce the same effect on all types of matter.

The best known universal force is gravity, whose effect is the same on all bodies. What

happens if a universal force alters the length of all rods, in the same way, when they are moved from A to B? By the very definition of universal forces, there are no observable effects. If we do not exclude universal forces, we cannot know whether the length of two measuring rods, which are equal when they are in the same point of space, is the same when the two rods are in two different points of space. Excluding universal forces is nothing but a coordinative definition. We can also adopt a different definition, in which the length of a rod depends on the point of space in which the rod stays. So the result of a measurement depends on the coordinative definition we choose. As a consequence, the geometrical form of a body, which depends on the result of measurements, is a matter of definition. The most important philosophical consequence of this analysis concerns the relativity of geometry. If a set of measurements supports a geometry G, we can arbitrarily choose a different geometry G' and adopt a different set of coordinative definitions so that the same set of measurements supports G' too. This is the principle of relativity of geometry, which states that all geometrical systems are equivalent. According to Reichenbach, it falsifies the alleged *a priori* character of Euclidean geometry and thus falsifies the Kantian philosophy of space.

#### CAUSAL ANOMALIES

The principle of relativity of geometry is true for metric relationships - that is, for geometric properties of bodies depending on the measurement of distances, angles, and areas. The situation seems different when we are concerned about topology, which deals with the order of space - that is, the way in which the points of space are placed in relation to one another. A typical topological relationship is "point A is between point B and C." The surface of a sphere and the surface of a plane are equivalent with respect to metrics, provided an appropriate choice of the coordinative definitions, but they differ from a topological point of view. Consider the following example presented by Reichenbach in *The Philosophy of Space and Time*. Intelligent beings living on the surface of a sphere can adopt coordinative definitions that, from a metric point of view, transform the surface of the sphere into the surface of a plane. However, there is an additional difficulty: because the surface of a sphere is finite, it is possible to do a round-the-world tour, walking along a straight line from a point A and eventually returning to the point A itself. Of course this is impossible on a plane, and thus it would seem that these intelligent beings

have to abandon their original idea that they are living on a plane and instead must recognize they are on a sphere. But this is not true, because another explanation is possible: they can assert that they had walked in a straight line to point B, which is different from point A but, in all other respects, is identical to A. They can also fabricate a fictitious theory of preestablished harmony - according to which everything that occurs in A immediately occurs in B - in order to explain the similarity between A and B. This last possibility entails an anomaly in the law of causality. We can reject causal anomalies, but only by means of an arbitrary definition. Thus topology depends on coordinative definitions, and the principle of relativity of geometry also holds for topology. According to Reichenbach, this example is another falsification of Kantian theory of synthetic *a priori*. In Kantian philosophy, the Euclidean geometry and the law of causality are both *a priori*, but if Euclidean geometry is an *a priori* truth, normal causality can be false; if normal causality is an *a priori* truth, Euclidean geometry can be false. We arbitrarily can choose the geometry, or we arbitrarily can choose the causality, but we cannot choose both.

## QUANTUM MECHANICS

Quantum mechanics differs from the other scientific theories because in this theory there is no possibility to introduce normal causality. No set of coordinative definitions can give an exhaustive interpretation of quantum mechanics free from causal anomalies.

It is important to explain some concepts used by Reichenbach in *Philosophical Foundations of Quantum Mechanics*, his main work about quantum mechanics. Using a wider sense of the word “observable,” some events occurring in quantum mechanics are observable; they are events consisting in coincidences between particles or between particles and macroscopic material, like the collision of an electron on a screen, signaled by a flash of light. Events between such types of coincidences are unobservable; an example is the path of an electron between the source and the screen on which it collides. Quantum observable events are called, by Reichenbach, phenomena, whereas unobservable ones are called interphenomena. Reichenbach explains that there are three main interpretations concerning interphenomena: wave interpretation, according to which matter consists of waves; corpuscular interpretation, according to which matter consists of particles; and Bohr-Heisenberg interpretation, according to which statements about interphenomena are

meaningless. The first two interpretations are called exhaustive interpretations, because they include a complete description of interphenomena. The last is a restricted interpretation, because it prohibits assertions about interphenomena. A normal system is an interpretation in which the laws of nature are the same for phenomena and interphenomena. This definition of a normal system is modeled on a basic property of classical physics: the laws of nature are the same whether or not the object is observed.

With these definitions, it is possible to formulate Reichenbach's principle of anomaly in quantum mechanics: there is no normal system. Thus causal anomalies cannot be removed from quantum mechanics. However, there is another peculiarity in quantum mechanics: for every experiment there exists an exhaustive interpretation - which is a wave or a corpuscular interpretation - that provides a normal system, although limited to this experiment. In other words, there does not exist an interpretation free from all causal anomalies, but for every causal anomaly there does exist an interpretation that ruled out this anomaly. For example, if we adopt the corpuscular interpretation, we have to face causal anomalies raising from some experiments, such as the two-slits experiment. In this experiment a beam of electrons is directed toward a diaphragm with two open slits and an interference pattern is produced on a screen behind the diaphragm; the probability that an electron, passing through an open slit, will reach the screen at a given point, is depending on whether the other slit is open or closed - with the electron behaving as if it is informed about the state of the other slit.

This causal anomaly is eliminated if we adopt the wave interpretation, according to which the interference patterns are produced by waves in conformity with Huygens's principle. The wave interpretation is in turn affected by other anomalies raising from the so-called reduction of the wave packet: the wave originating from an open slit occupies a hemisphere centered on the slit, but when the wave hits the screen, a flash is produced in a point only and the wave disappears in all other points. Apparently all physical properties transported by the wave, such as momentum and energy, suddenly materialized in a single point, even if they were distant from this point. This situation is explained without anomalies by the corpuscular interpretation. According to Reichenbach, in every experiment about quantum mechanics we can adopt an interpretation free from causal anomalies, but we have to use a different interpretation in a different experiment.

Only two interpretations are required: the wave and the corpuscular interpretation. This is the real meaning of the duality of wave and corpuscle in quantum physics. The possibility of eliminating causal anomalies from every quantum experiment is called, by Reichenbach, the principle of eliminability of causal anomalies.

The Bohr-Heisenberg restricted interpretation of interphenomena named after Danish physicist Niels Bohr and German physicist Werner Karl Heisenberg, states that speaking about values of unmeasured physical quantities is meaningless. Reichenbach criticizes the Bohr-Heisenberg interpretation on two points. First, Heisenberg's indeterminacy principle becomes a meta-statement about the semantics of the language of physics; second, this interpretation implies the presence of meaningless statements in the language of physics.

Using a three-valued logic, in which admissible truth values are *truth*, *falsehood*, and *indeterminacy*, Reichenbach constructs another restrictive interpretation in which a statement about an unmeasured physical quantity can be neither true nor false, but indeterminate.

#### INTERPRETATIONS OF REICHENBACH'S PHILOSOPHY

An open question regards the relation between Reichenbach and conventionalism. His insistence on the major role played by the coordinative definitions, the relativity of geometry, the equivalence between wave and corpuscular interpretation of quantum mechanics has suggested that his philosophy can be ascribed to conventionalism. In Reichenbach's works there are some points corroborating this view. For example, he asserts that the philosophical meaning of the theory of relativity is that this theory proves the necessity of coordinative definitions, which are arbitrary, in situations in which empirical relations had been previously assumed. But there are also some elements against the conventionalist reading of Reichenbach's philosophy, as seen in the last paragraph of *The Philosophy of Space and Time*, in which Reichenbach affirms that the reality of space and time is an irrefutable consequence of his epistemological analysis; it is an assertion apparently incompatible with conventionalism. As an example of the debate about Reichenbach's attitude toward conventionalism, it is possible to mention the conventionalist interpretation of Reichenbach's philosophy developed by Adolf Grünbaum in *Philosophical Problems of Space and Time* (1973) and Hilary Putnam's counterarguments offered in "The Refutation of Conventionalism" (1975).

A different explication of Reichenbach's philosophy, based on an analysis of the role of the coordinative definitions in the light of Kantian philosophy, is advanced by Michael Friedman and exposed in *Reconsidering Logical Positivism* (1999, pp. 59-70). According to Friedman's interpretation, Reichenbach, in his first published work on the theory of relativity (*Theory of Relativity and A Priori Knowledge*), distinguishes two different meanings of synthetic *a priori*, which are united in Kantian philosophy. In the first meaning, a synthetic *a priori* judgment is necessary and thus not modifiable; in the second meaning, a synthetic *a priori* statement is constitutive of the object. The coordinative definitions are not necessary judgments, because we can make use of a different definition. Moreover, all coordinative definitions are subjected to changes with the evolution of knowledge, so they are modifiable. Thus they are not *a priori* in the first meaning present in Kantian philosophy. But the coordinative definitions are required to give an empirical interpretation to a theory and so they are constitutive of the object of knowledge. Thus they are synthetic *a priori* in the second meaning present in Kantian philosophy. Friedman calls this type of *a priori* judgment "constitutive, *relativized a priori*" (p. 62), because they are *a priori* in the constitutive sense, relative to a given theory.

Surely Kantian philosophy exerts a great influence on Reichenbach. He professes admiration for Kant in his first works. In the article "Kant und die Naturwissenschaft" (1933) he says: "There is no doubt that he [Kant] was one of the few thinkers whose work showed the way on which the contemporary philosophy of natural science continues to proceed" (p. 626). According to Reichenbach, Kantian philosophy of nature is a meaningful theory, although it is superseded by the outcomes of contemporary physics. Later, Reichenbach accentuates his departure from Kant, stressing his criticism of synthetic *a priori* and developing many arguments against Kantian philosophy.

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