Einstein as a Philosopher of Science

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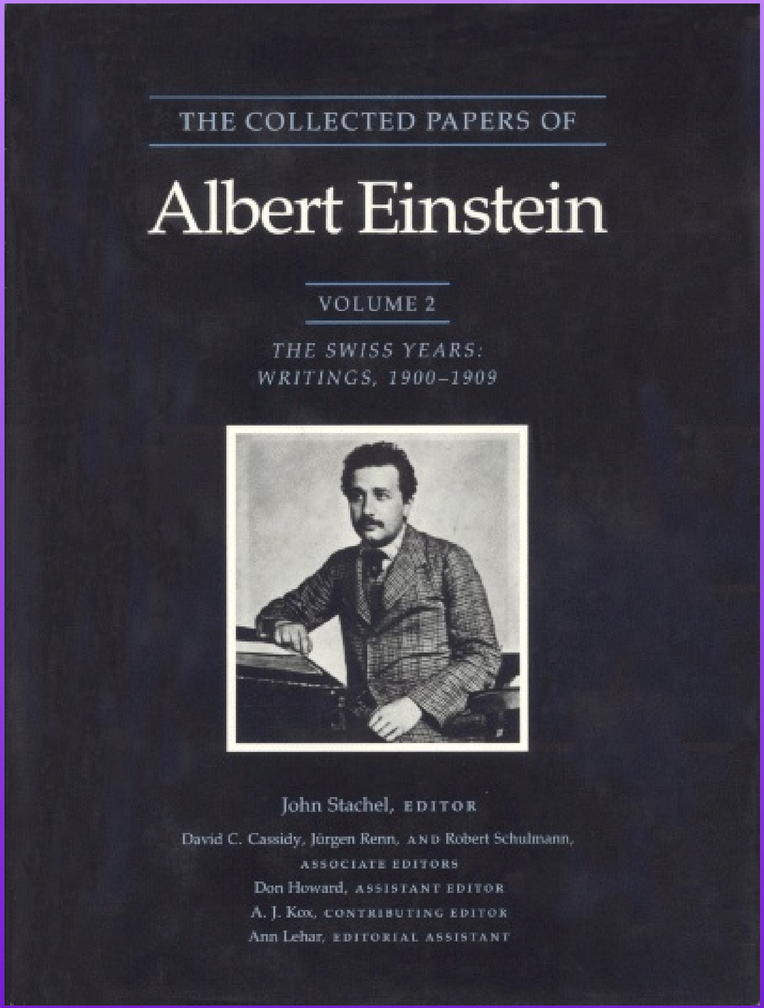
Einstein's Annus Mirabilis

Albert Einstein. "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt." *Annalen der Physik* 17 (1905), 132-148.

Albert Einstein. "Über die von der molekular-kinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen." *Annalen der Physik* 17 (1905), 549-560.

Albert Einstein. "Zur Elektrodynamik bewegter Körper." *Annalen der Physik* 17 (1905), 891-921.



Some General References

Don Howard. “Einstein’s Philosophy of Science.” In *The Cambridge Companion to Einstein*. Michel Janssen and Christoph Lehner, eds. New York: Cambridge University Press, 2005 (forthcoming).

Don Howard. “Einstein's Philosophy of Science.” *The Stanford Encyclopedia of Philosophy* (Spring 2004 Edition), Edward N. Zalta (ed.). <http://plato.stanford.edu/archives/spr2004/entries/einstein-philscience/>.

Albert Einstein. "Remarks Concerning the Essays Brought together in this Co-operative Volume." In *Albert Einstein: Philosopher-Scientist.* Paul Arthur Schilpp, ed. The Library of Living Philosophers, vol. 7. Evanston, IL: The Library of Living Philosophers, 1949.

The reciprocal relationship of epistemology and science is of noteworthy kind. They are dependent upon each other. Epistemology without contact with science becomes an empty scheme. Science without epistemology is—insofar as it is thinkable at all—primitive and muddled. However, no sooner has the epistemologist, who is seeking a clear system, fought his way through to such a system, than he is inclined to interpret the thought-content of science in the sense of his system and to reject whatever does not fit into his system. The scientist, however, cannot afford to carry his striving for epistemological systematic that far. He accepts gratefully the epistemological conceptual analysis; but the external conditions, which are set for him by the facts of experience, do not permit him to let himself be too much restricted in the construction of his conceptual world by the adherence to an epistemological system. He therefore must appear to the systematic epistemologist as a type of unscrupulous opportunist: he appears as realist insofar as he seeks to describe a world independent of the acts of perception; as idealist insofar as he looks upon the concepts and theories as free inventions of the human spirit (not logically derivable from what is empirically given); as positivist insofar as he considers his concepts and theories justified only to the extent to which they furnish a logical representation of relations among sensory experiences. He may even appear as Platonist or Pythagorean insofar as he considers the viewpoint of logical simplicity as an indispensible and effective tool of his research.

Albert Einstein. "Physik und Realität." ***Journal of The Franklin Institute*** **221 (1936), 313-347.**

It has often been said, and certainly not without justification, that the man of science is a poor philosopher. Why then should it not be the right thing for the physicist to let the philosopher do the philosophizing? Such might indeed be the right thing at a time when the physicist believes he has at his disposal a rigid system of fundamental concepts and fundamental laws which are so well established that waves of doubt can not reach them; but it can not be right at a time when the very foundations of physics itself have become problematic as they are now. At a time like the present, when experience forces us to seek a newer and more solid foundation, the physicist cannot simply surrender to the philosopher the critical contemplation of the theoretical foundations; for, he himself knows best, and feels more surely where the shoe pinches. In looking for a new foundation, he must try to make clear in his own mind just how far the concepts which he uses are justified, and are necessities.

Einstein to Robert Thornton, 7 December 1944.

I fully agree with you about the significance and educational value of methodology as well as history and philosophy of science. So many people today—and even professional scientists—seem to me like somebody who has seen thousands of trees but has never seen a forest. A knowledge of the historic and philosophical background gives that kind of independence from prejudices of his generation from which most scientists are suffering. This independence created by philosophical insight is—in my opinion—the mark of distinction between a mere artisan or specialist and a real seeker after truth.

Albert Einstein. "Ernst Mach." *Physikalische Zeitschrift* 17 (1916), 101-104.

How does it happen that a properly endowed natural scientist comes to concern himself with epistemology? Is there no more valuable work in his specialty? I hear many of my colleagues saying, and I sense it from many more, that they feel this way. I cannot share this sentiment. When I think about the ablest students whom I have encountered in my teaching, that is, those who distinguish themselves by their independence of judgment and not merely their quick-wittedness, I can affirm that they had a vigorous interest in epistemology. They happily began discussions about the goals and methods of science, and they showed unequivocally, through their tenacity in defending their views, that the subject seemed important to them. Indeed, one should not be surprised at this.

Einstein as a Philosopher of Science

1. Einstein's Early Acquaintance with Philosophy

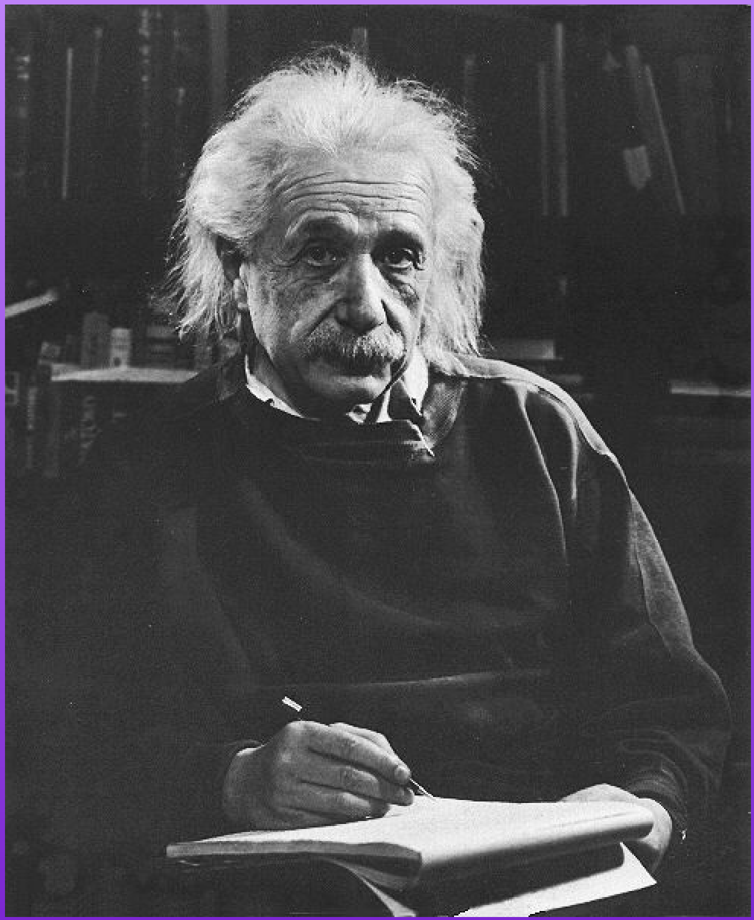
2. Kant and Schopenhauer on Space, Time, and the Individuation of Physical Systems

3. Mach, Duhem, and the Empirical Interpretation of Scientific Theories

4. Schlick, Petzoldt, and the Univocal Determination of a Spacetime Event Ontology

5. Einstein's Methodological Critique of Weyl's Unified Field Theory

6. Einstein's Critique of the Quantum Theory



Einstein's Early Acquaintance with Philosophy

(OK—Not that early)

Einstein ca. age 4

Einstein's Early Acquaintance with Philosophy

But, yes, this early

Einstein's Graduating Class, Aargauer Kantonsschule, 1896

Einstein's Early Acquaintance with Philosophy

Circa age 12-13:

Aaron Bernstein. *Aus dem Reiche der Naturwissenschaft. Für Jedermann aus dem Volke*. (12 vols., 1853-1857).
Aaron Bernstein. *Naturwissenschaftliche Volksbücher*. (1870).

Circa age 16 (thanks to Max Talmey):

Immanuel Kant. *Kritik der reinen Vernunft*.
Immanuel Kant. *Kritik der praktischen Vernunft*.
Immanuel Kant. *Kritik der Urteilskraft*.

Einstein's Early Acquaintance with Philosophy

While a student at the ETH (1896-1900):

Ernst Mach. *Die Mechanik in ihrer Entwickelung historisch-kritisch dargestellt*. (1883; 3rd ed., 1897).
Ernst Mach. *Die Principien der Wärmelehre. Historisch-kritisch entwickelt*. (1896).
Arthur Schopenhauer. *Parerga und Paralapomena. Kleine Philosophische Schriften*. (1851).

Lectures by August Stadler (Student of Friedrich Albert Lange in Zurich; Ph.D. under the Marburg neo-Kantian, Hermann Cohen):

Sommersemester 1897 — Die Philosophie Kants
Wintersemester 1897 — Theorie des wissenschaftlichen Denkens ("obligatorisches Fach")

Friedrich Albert Lange. *Geschichte des Materialismus*. (1873-1875).
Eugen Dühring. *Kritische Geschichte der Principien der Mechanik*. (1887).
Ferdinand Rosenberger. *Isaac Newton und seine physikalischen Prinzipien*. (1895).

Physikalisches Institut, ETH Zürich

Einstein's Early Acquaintance with Philosophy

Akademie Olympia (ca. 1903-1905)

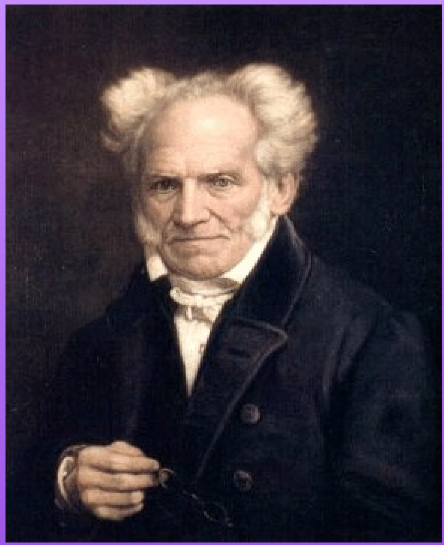
Richard Avenarius. *Kritik der reinen Erfahrung*. (1888, 1890).
Richard Dedekind. *Was sind und was sollen die Zahlen?* (2nd ed. 1893).
David Hume. *A Treatise of Human Nature*. (1739; German trans. 1895; 2nd ed. 1904)
Ernst Mach. *Die Analyse der Empfindungen und das Verhältnis des Physischen zum Psychischen*. (2nd ed. 1900; 3rd enl. ed. 1902; 4th enl. ed. 1903).
John Stuart Mill. *A System of Logic*. (1872; German trans. 1877 and 1884-1887).
Karl Pearson. *The Grammar of Science*. (1900).
Henri Poincaré. *La science et l'hypothèse*. (1902; German trans. 1904).

The Olympia Academy, Bern, ca. 1904. From left: Conrad Habicht, Maurice Solovine, Albert Einstein.

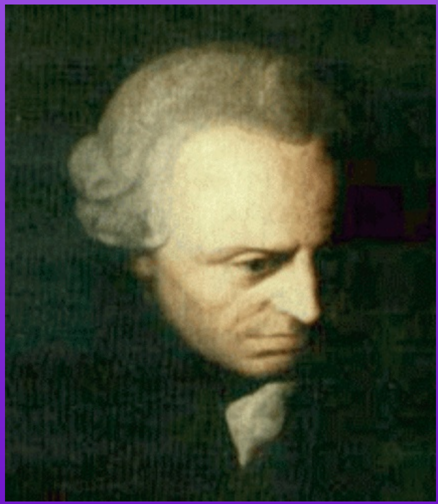
Kant and Schopenhauer on Space, Time, and the Individuation of Physical Systems

Don Howard. "Einstein, Kant, and the Origins of Logical Empiricism." In *Language, Logic, and the Structure of Scientific Theories*. Proceedings of the Carnap-Reichenbach Centennial, University of Konstanz, 21-24 May 1991. Wesley Salmon and Gereon Wolters, eds. Pittsburgh: University of Pittsburgh Press; Konstanz: Universitätsverlag, 1994, pp. 45-105.

Don Howard. "A Peek behind the Veil of Maya: Einstein, Schopenhauer, and the Historical Background of the Conception of Space as a Ground for the Individuation of Physical Systems." In *The Cosmos of Science: Essays of Exploration*. John Earman and John D. Norton, eds. Pittsburgh-Konstanz Series in the Philosophy and History of Science, vol. 6. Pittsburgh: University of Pittsburgh Press; Konstanz: Universitätsverlag, 1997, pp. 87-150.



Arthur Schopenhauer (1788-1860)



Immanuel Kant (1724-1804)

Kant and Schopenhauer on Space, Time, and the Individuation of Physical Systems

Kant:

Space and time as a priori forms of outer and inner intution, respectively.

Schopenhauer:

Space and time as the *principium individuationis*.

Arthur Schopenhauer. *Die Welt als Wille und Vorstellung*. Leipzig: F. A. Brockhaus, 1819; 2nd ed. 1844; 3rd impr. and enl. ed. 1859.

Albert Einstein. “Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt.” *Annalen der Physik* 17 (1905), 132-148.

Monochromatic radiation of low density (within the domain of validity of Wien's radiation formula) behaves from a thermodynamic point of view as if it consisted of mutually independent energy quanta of the magnitude $R\beta\nu / N$.

If we have two systems S_1 and S_2 that do not interact with each other, we can put

$$S_1 = \phi_1(W_1),$$
$$S_2 = \phi_2(W_2).$$

If these two systems are viewed as a single system of entropy S and probability W, we have

$$S = S_1 + S_2 = \phi(W)$$

and

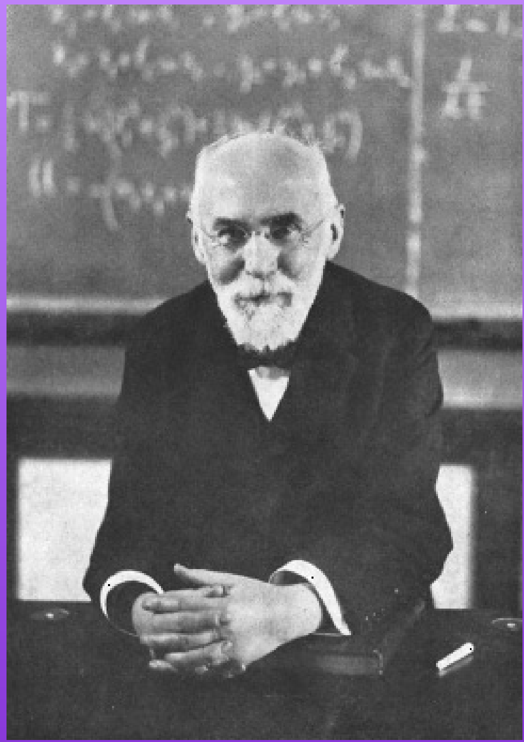
$$W = W_1 \quad W_2.$$

The last relation tells us that the states of the two systems are mutually independent events.

Einstein to H. A. Lorentz, 23 May 1909 (EA 16-419).

I must have expressed myself unclearly in regard to the light quanta. That is to say, I am not at all of the opinion that one should think of light as being composed of mutually independent quanta localized in relatively small spaces. This would be the most convenient explanation of the Wien end of the radiation formula. But already the division of a light ray at the surface of refractive media absolutely prohibits this view. A light ray divides, but a light quantum indeed cannot divide without change of frequency.

As I already said, in my opinion one should not think about constructing light out of discrete, mutually independent points. I imagine the situation somewhat as follows: . . . I conceive of the light quantum as a point that is surrounded by a greatly extended vector field, that somehow diminishes with distance. Whether or not when several light quanta are present with mutually overlapping fields one must imagine a simple superposition of the vector fields, that I cannot say. In any case, for the determination of events, one must have equations of motion for the singular points in addition to the differential equations for the vector field.



H. A. Lorentz (1853-1928)

Kant and Schopenhauer on Space, Time, and the Individuation of Physical Systems

In the Wien regime, light behaves "as if" it were composed of mutually independent quanta of electromagnetic energy. But that assumption about the physical nature of light would not constitute a basis for the derivation of the Planck formula for the energy density of black body radiation. Thus, what about the physical nature of light from the point of view of its behavior in other than the high energy domain?

Albert Einstein. "Quantentheorie des einatomigen idealen Gases." *Preussische Akademie der Wissenschaften* (Berlin). *Physikalisch-mathematische Klasse. Sitzungsberichte* (1924), 261-267.

Albert Einstein. "Quantentheorie des einatomigen idealen Gases. Zweite Abhandlung." *Preussische Akademie der Wissenschaften* (Berlin). *Physikalisch-mathematische Klasse. Sitzungsberichte* (1925), 3-14.

Albert Einstein. "Zur Quantentheorie des idealen Gases." *Preussische Akademie der Wissenschaften* (Berlin). *Physikalisch-mathematische Klasse. Sitzungsberichte* (1925), 18-25.

Einstein to Erwin Schrödinger, 28 February 1925 (EA 22-002).

In the Bose statistics employed by me, the quanta or molecules are not treated as being independent of one another. . . . A complexion is characterized through giving the number of molecules that are present in each individual cell. The number of the complexions so defined should determine the entropy. According to this procedure, the molecules do not appear as being localized independently of one another, but rather they have a preference to sit together with another molecule in the same cell. One can easily picture this in the case of small numbers. [In particular] 2 quanta, 2 cells:

Bose-statistics

	1st cell	2nd cell
1st case	●●	–
2nd case	●	●
3rd case	–	●●

independent molecules

	1st cell	2nd cell
1st case	I II	–
2nd case	I	II
3rd case	II	I
4th case	–	I II

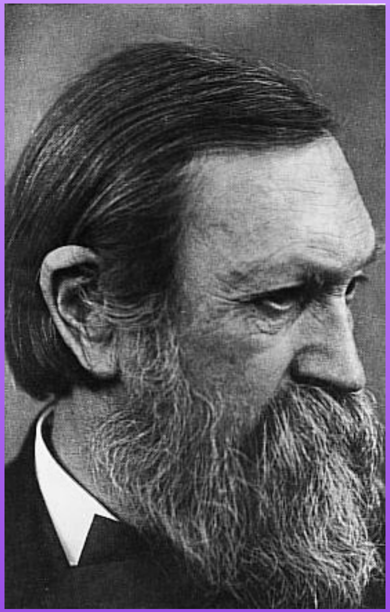
Erwin Schrödinger
(1887-1961)

According to Bose the molecules stack together relatively more often than according to the hypothesis of the statistical independence of the molecules.

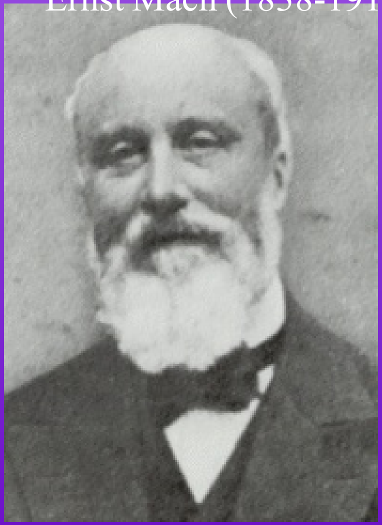
Mach, Duhem, and the Empirical Interpretation of Scientific Theories

Don Howard. "Einstein and Duhem." In *Pierre Duhem: Historian and Philosopher of Science*. Proceedings of the Conference at Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 16-18 March 1989. Roger Ariew and Peter Barker, eds. Synthese 83 (1990), 363-384.

John Norton. "How Hume and Mach Helped Einstein Find Special Relativity." Paper presented at the conference, "Synthesis and the Growth of Knowledge," October 1-3, 2004, University of South Carolina.



Ernst Mach (1838-1916)



Pierre Duhem (1861-1916)

Mach, Duhem, and the Empirical Interpretation of Scientific Theories

Pierre Duhem. *La Théorie physique, son objet et sa structure*. Paris: Chevalier & Rivière. (1906).
Pierre Duhem. *Ziel und Struktur der physikalischen Theorien*. Friedrich Adler, trans. Foreword by Ernst Mach. Leipzig: Johann Ambrosius Barth. (1908).

Ernst Mach. *Erkenntnis und Irrtum. Skizzen zur Psychologie der Forschung*. Leipzig: Johann Ambrosius Barth, 1905; 2nd ed.1906.

Friedrich Adler (1879-1906)

Mach, Duhem, and the Empirical Interpretation of Scientific Theories

The Issue:

Do physical theories acquire their empirical content

a. term by term and, hence, statement by statement in which case, the empirical truth or falsity of each individual assertion in a theory is, in principle, univocally determinable on the basis of the corresponding experience (Mach? Schlick and the logical empiricists). Epistemological atomism; verificationist theory of meaning.

or

b. only as whole theories, in which case the empirical truth or falsity of no individual assertion is univocally determinable on the basis of experience alone (Duhem, Weyl, and Einstein). Epistemological holism; underdetermination of theory choice by logic and evidence; choice among alternative, empirically equivalent theories a matter of convention.

Albert Einstein. "Lecture Notes for Course on Electricity and Magnetism, University of Zurich, Winter Semester 1910-1911."

We have seen how experience led to the introduction of the concept of electrical charge. It was defined with the help of forces that electrified bodies exert on each other. But now we extend the application of the concept to cases in which the definition finds no direct application as soon as we conceive electrical forces as forces that are exerted not on material particles but on electricity. We establish a conceptual system whose individual parts do not correspond immediately to experiential facts. Only a certain totality of theoretical materials corresponds again to a certain totality of experimental facts.

We find that such an el[ectrical] continuum is always applicable only for representing relations inside ponderable bodies. Here again we define the vector o[f] el[ectrical] field strength as the vector of the mech[anical] force that is exerted on a unit of pos[istive] electr[ical] charge inside a ponderable body. But the force thus defined is no longer immediately accessible to exp[eriment]. It is a part of a theoretical construction that is true or false, i.e., corresponding or not corresponding to experience, only as a whole.

Schlick, Petzoldt, and the Univocal Determination of a Spacetime Event Ontology

Don Howard. "Realism and Conventionalism in Einstein's Philosophy of Science: The Einstein-Schlick Correspondence." *Philosophia Naturalis* 21 (1984), 616-629.

Don Howard. "Einstein and Eindeutigkeit: A Neglected Theme in the Philosophical Background to General Relativity." In Jean Eisenstaedt and A. J. Kox, eds. *Studies in the History of General Relativity*. Boston: Birkhäuser, 1992, 154–243.

Don Howard. "Point Coincidences and Pointer Coincidences: Einstein on Invariant Structure in Spacetime Theories." In *History of General Relativity IV: The Expanding Worlds of General Relativity*. Hubert Goenner, Jürgen Renn, Jim Ritter, and Tilman Sauer, eds., Boston: Birkhäuser, 1999, pp. 463-500.

Moritz Schlick (1882-1936)

Josef Petzoldt (1862-1929)

Schlick, Petzoldt, and the Univocal Determination of a Spacetime Event Ontology

Joseph Petzoldt. "Das Gesetz der Eindeutigkeit." *Vierteljahrsschrift für wissenschaftliche Philosophie und Soziologie* 19 (1895), 146-203.

Joseph Petzoldt. "Die Relativitätstheorie im erkenntnistheoretischer Zusammenhange des relativistischen Positivismus." *Deutsche Physikalische Gesellschaft. Verhandlungen* 14 (1912), 1055-1064.

Joseph Petzoldt. *Das Weltproblem vom Standpunkte des relativistischen Positivismus aus, historisch-kritisch dargestellt*. Leipzig and Berlin: B. G. Teubner, 1912.

Joseph Petzoldt. "Die Relativitätstheorie der Physik." *Zeitschrift für positivistische Philosophie* 2 (1914), 1-53.

Joseph Petzoldt. "Verbietet die Relativitätstheorie Raum und Zeit als etwas Wirkliches zu denken?" *Deutsche Physikalische Gesellschaft. Verhandlungen* 20 (1918), 189-201.

Moritz Schlick. "Die philosophische Bedeutung des Relativitätsprinzips." *Zeitschrift für Philosophie und philosophische Kritik* 159 (1915), 129-175.

Moritz Schlick. *Raum und Zeit in den gegenwärtigen Physik. Zur Einführung in das Verständnis der allgemeinen Relativitätstheorie*. Berlin: Julius Springer, 1917.

Moritz Schlick. *Allgemeine Erkenntnislehre*. Berlin: Julius Springer, 1918.

Einstein's Methodological Critique of Weyl's Unified Field Theory

Thomas Ryckman. *The Reign of Relativity: Philosophy in Physics, 1915-1925*. Oxford: Oxford University Press, 2005.

Hermann Weyl (1885-1955)

Einstein’s Methodological Critique of Weyl’s Unified Field Theory

Hermann Weyl. “Gravitation und Elektrizität.” *Königlich Preussische Akademie der Wissenschaften* (Berlin). *Sitzungsberichte* (1918), 465-478, 478-480.
Hermann Weyl. *Raum. Zeit. Materie. Vorlesungen über allgemeine Relativitätstheorie*. Berlin: Julius Springer, 1918; 5th ed. 1923.

Weyl theory:

Length transforms under parallel displacement according to

$$dl = l d\varphi,$$

where

$$d\varphi = \varphi_i dx^i$$

is a linear differential form whose components, φ_i, become the components of the electromagnetic four-potential.

Einstein's Methodological Critique of Weyl's Unified Field Theory

Einstein:

Path dependence of length would imply that the theory is incapable of being given a determinate empirical interpretation via coordinating the geometrical notion of a segment of a straight line with the physical notion of a practically-rigid measuring rod.

Weyl:

Only the theory as a whole has empirical content.

Einstein, Berlin, 1920s

Albert Einstein. *Geometrie und Erfahrung. Erweiterte Fassung des Festvortrages gehalten an der Preussischen Akademie der Wissenschaften zu Berlin am 27. Januar 1921*. Berlin: Julius Springer, 1921.

Why is the equivalence of the practically-rigid body and the body of geometry–which suggests itself so readily–rejected by Poincaré and other investigators? Simply because under closer inspection the real solid bodies in nature are not rigid, because their geometrical behavior, that is, their possibilities of relative disposition, depend upon temperature, external forces, etc. Thus, the original, immediate relation between geometry and physical reality appears destroyed, and we feel impelled toward the following more general view, which characterizes Poincaré's standpoint. Geometry (G) predicates nothing about the behavior of real things, but only geometry together with the totality (P) of physical laws can do so. Using symbols, we may say that only the sum of (G) + (P) is subject to experimental verification. Thus (G) may be chosen arbitrarily, and also parts of (P); all these laws are conventions. All that is necessary to avoid contradictions is to choose the remainder of (P) so that (G) and the whole of (P) are together in accord with experience. Envisaged in this way, axiomatic geometry and the part of natural law which has been given a conventional status appear as epistemologically equivalent.

Sub specie aeterni Poincaré, in my opinion, is right. The idea of the measuring rod and the idea of the clock coordinated with it in the theory of relativity do not find their exact correspondence in the real world. It is also clear that the solid body and the clock do not in the conceptual edifice of physics play the part of irreducible elements, but that of composite structures, which must not play any independent part in theoretical physics. But it is my conviction that in the present stage of development of theoretical physics these concepts must still be employed as independent concepts; for we are still far from possessing such certain knowledge of the theoretical principles of atomic structure as to be able to construct solid bodies and clocks theoretically from elementary concepts.

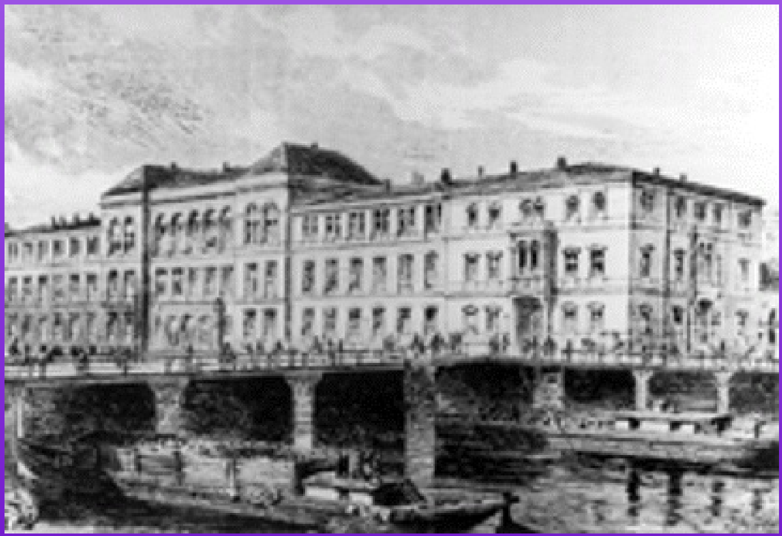
Albert Einstein. Review of Alfred Elsbach. *Kant und Einstein. Untersuchungen über das Verhältnis der modernen Erkenntnistheorie zur Relativitätstheorie*. Berlin and Leipzig: Walter de Gruyter. 1924. *Deutsche Literaturzeitung* 45 (1924), 1685-1692.

[Question: can deviations from Euclidean geometry be accounted for by making changes in physical laws?]

The position that one takes on these claims depends on whether one grants reality to the practically-rigid body. If yes, then the concept of the interval corresponds to something experiential. Geometry then contains assertions about possible experiments; it is a physical science that is directly underpinned by experimental testing (standpoint A). If the practically-rigid measuring body is accorded no reality, then geometry alone contains no assertions about experiences (experiments), but instead only geometry with physical sciences taken together (standpoint B). Until now physics has always availed itself of the simpler standpoint A and, for the most part, is indebted to it for its fruitfulness; physics employs it in all of its measurements. . . . But if one adopts standpoint B, which seems overly cautious at the present stage of the development of physics, then geometry alone is not experimentally testable. There are then no geometrical measurements whatsoever. But one must not, for that reason, speak of the "ideality of space." "Ideality" pertains to all concepts, those referring to space and time no less and no more than all others. Only a complete scientific conceptual system comes to be univocally coordinated with sensory experience. On my view, Kant has influenced the development of our thinking in an unfavorable way, in that he has ascribed a special status to spatio-temporal concepts and their relations in contrast to other concepts.

Albert Einstein. Review of Alfred Elsbach. *Kant und Einstein. Untersuchungen über das Verhältnis der modernen Erkenntnistheorie zur Relativitätstheorie*. Berlin and Leipzig: Walter de Gruyter. 1924. *Deutsche Literaturzeitung* 45 (1924), 1685-1692. (Continued)

Viewed from standpoint B, the choice of geometrical concepts and relations is, indeed, determined only on the grounds of simplicity and instrumental utility. . . . Concerning the metrical determination of space, nothing can then be made out empirically, but not "because it is not real," but because, on this choice of a standpoint, geometry is not a complete physical conceptual system, but only a part of one such.



Physikalisches Institut, Berlin, ca. 1924

Einstein’s Methodological Critique of Weyl’s Unified Field Theory

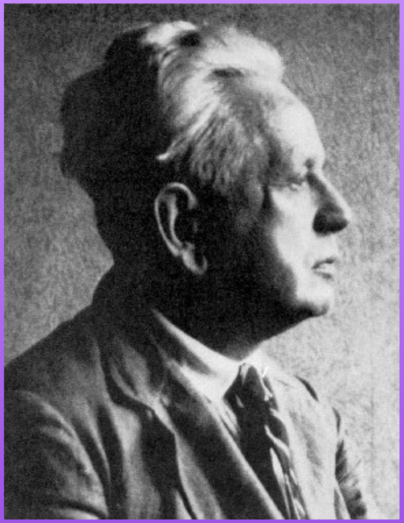
Ernst Cassirer. *Zur Einsteinschen Relativitätstheorie. Erkenntnistheoretische Betrachtungen*. Berlin: Bruno Cassirer, 1921.

Hans Reichenbach. *Relativitätstheorie und Erkenntnis Apriori*. Berlin: Julius Springer, 1920.

Hans Reichenbach. *Axiomatik der relativistischen Raum-Zeit-Lehre.* Braunschweig: Friedrich Vieweg und Sohn, 1924.

Hans Reichenbach. *Philosophie der Raum-Zeit-Lehre*. Berlin and Leipzig: Walter de Gruyter, 1928.

Moritz Schlick. “Kritizistische oder empiristische Deutung der neuen Physik.” *Kant-Studien* 26 (1921), 96-111.



Ernst Cassirer (1879-1945)

Hans Reichenbach (1891-1953)

Einstein's Methodological Critique of Weyl's Unified Field Theory

The issue:

a. Do physical theories possess empirical content only as a whole (Duhem, Einstein, Weyl)?

Or

b. Do individual concepts and propositions (e.g., ascriptions of local metrical structure) possess empirical content, meaning that they can be subjected to a directed empirical test (Schlick, Reichenbach)?

If b.

Then what is the status not of the empirical statements themselves but of the statements asserting connections between individual concepts and either experience or some physical objects or circumstances (e.g., "segment of a straight line" $=_{df}$ "path of a ray of light")?

i. Arbitrary conventions (Schlick, Reichenbach).
ii. A priori (Cassirer, Elsbach, et al.).

Einstein's Critique of the Quantum Theory

Don Howard. "Einstein on Locality and Separability." *Studies in History and Philosophy of Science* 16 (1985), 171-201.

Don Howard. "Holism, Separability, and the Metaphysical Implications of the Bell Experiments." In *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*. James T. Cushing and Ernan McMullin, eds. Notre Dame, Indiana: University of Notre Dame Press, 1989, pp. 224-253.

Don Howard. "'Nicht sein kann was nicht sein darf,' or the Prehistory of EPR, 1909-1935: Einstein's Early Worries about the Quantum Mechanics of Composite Systems." In *Sixty-Two Years of Uncertainty: Historical, Philosophical, and Physical Inquiries into the Foundations of Quantum Mechanics*. Proceedings of the 1989 Conference, "Ettore Majorana" Centre for Scientific Culture, International School of History of Science, Erice, Italy, 5-14 August. Arthur Miller, ed. New York: Plenum, 1990, pp. 61-111.

Niels Bohr (1885-1962)

Einstein's Critique of the Quantum Theory

Albert Einstein, Boris Podolsky, and Nathan Rosen. "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 47 (1935), 777-780.

Niels Bohr. "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 48 (1935), 696-702.

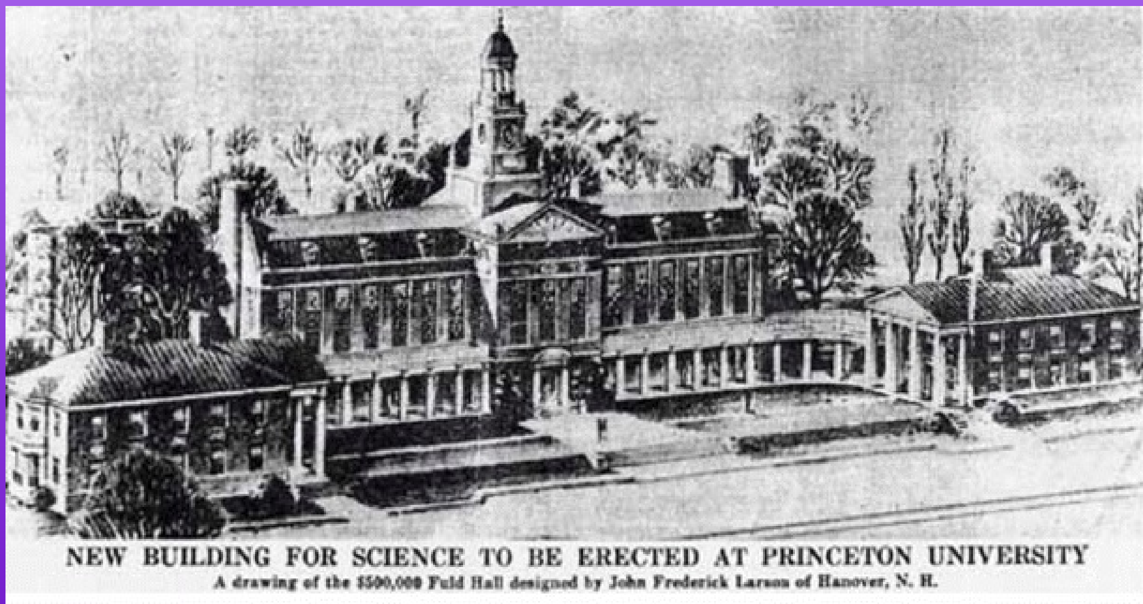
Albert Einstein. "Quanten-Mechanik und Wirklichkeit." *Dialectica* 2 (1948), 320-324.

Niels Bohr. "Discussion with Einstein on Epistemological Problems in Atomic Physics." In *Albert Einstein: Philosopher-Scientist*. Paul Arthur Schilpp, ed. Evanston, Illinois: The Library of Living Philosophers, 201-241.

Einstein and Bohr ca. 1927

Einstein to Erwin Schrödinger, 19 June 1935

I was very pleased with your detailed letter, which speaks about the little essay. For reasons of language, this was written by Podolsky after many discussions. But still it has not come out as well as I really wanted; on the contrary, the main point was, so to speak, buried by the erudition [die Hauptsache ist sozusagen durch Gelehrsamkeit verschüttet].



Institute for Advanced Study, Princeton

Einstein's Critique of the Quantum Theory

The argument that Einstein intended to give:

Separability + Locality ⇒ Incompleteness

(No assumption of Heisenberg indeterminacy)

Separability: Independent real states of affairs in spatially (spatio-temporally?) separated regions.

Locality: No causal influences between spacelike separated regions.

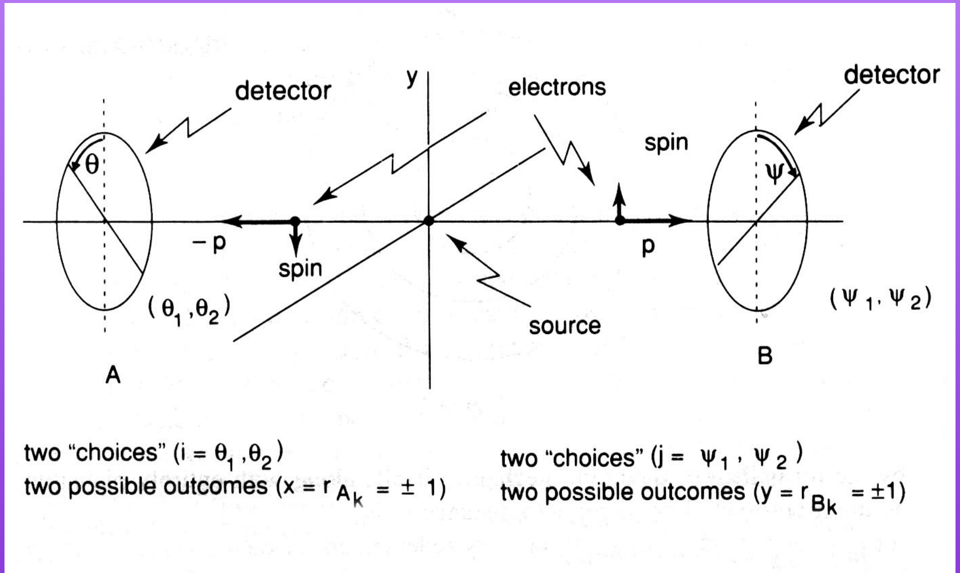


Figure 3.

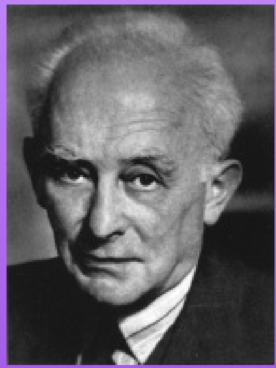
From: James T. Cushing. "A Background Essay." In James T. Cushing and Ernan McMullin, eds. *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*. Notre Dame, IN: University of Notre Dame Press, 1989.

Einstein to Max Born, 18 March 1948

I just want to explain what I mean when I say that we should try to hold on to physical reality.
We are, to be sure, all of us aware of the situation regarding what will turn out to be the basic foundational concepts in physics: the point-mass or the particle is surely not among them; the field, in the Faraday-Maxwell sense, might be, but not with certainty. But that which we conceive as existing ("real") should somehow be localized in time and space. That is, the real in one part of space, A, should (in theory) somehow "exist" independently of that which is thought of as real in another part of space, B. If a physical system stretches over the parts of space A and B, then what is present in B should somehow have an existence independent of what is present in A. What is actually present in B should thus not depend upon the type of measurement carried out in the part of space, A; it should also be independent of whether or not, after all, a measurement is made in A.

If one adheres to this program, then one can hardly view the quantum-theoretical description as a complete representation of the physically real. If one attempts, nevertheless, so to view it, then one must assume that the physically real in B undergoes a sudden change because of a measurement in A. My physical instincts bristle at that suggestion.

However, if one renounces the assumption that what is present in different parts of space has an independent, real existence, then I do not at all see what physics is supposed to describe. For what is thought to be a "system" is, after all, just conventional, and I do not see how one is supposed to divide up the world objectively so that one can make statements about the parts.



Max Born
(1882-1970)