Albert Einstein as a Philosopher of Science

Einstein's philosophical habit of mind, cultivated by undergraduate training and lifelong dialogue, had a profound effect on the way he did physics.

Don A. Howard

Nowadays, explicit engagement with the philosophy of science plays almost no role in the training of physicists or in physics research. What little the student learns about philosophical issues is typically learned casually, by a kind of intellectual osmosis. One picks up ideas and opinions in the lecture hall, in the laboratory, and in collaboration with one's supervisor. Careful reflection on philosophical ideas is rare. Even rarer is systematic instruction. Worse still, publicly indulging an interest in philosophy of science is often treated as a social blunder. To be fair, more than a few physicists do think philosophically. Still, explicitly philosophical approaches to physics are the exception. Things were not always so.

"Independence of judgment"

In December 1944 Robert A. Thornton had a new job teaching physics at the University of Puerto Rico. He was fresh from the University of Minnesota, where he had written his PhD thesis on "Measurement, Concept Formation, and Principles of Simplicity: A Study in the Logic and Methodology of Physics" under Herbert Feigl, a noted philosopher of science. Wanting to incorporate the philosophy of science into his teaching of introductory physics, Thornton wrote to Albert Einstein for help in persuading his colleagues to accept that innovation. Einstein replied:

> 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 someone 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.[1]

Einstein was not just being polite; he really meant this. He had been saying the same thing for nearly 30 years. He knew from his experience at the forefront of the revolutions in early 20th-century physics that having cultivated a philosophical habit of mind had made him a better physicist.

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A few years after his letter to Thornton, Einstein wrote in a contribution to *Albert Einstein: Philosopher-Scientist*, "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."[2]

In a 1936 article entitled "Physics and Reality," he explained why the physicist cannot simply defer to the philosopher but must be a philosopher himself:

> 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 to do 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't reach them; but it cannot 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 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.[3]

Already in 1916, just after completing his general theory of relativity, Einstein had discussed philosophy's relation to physics in an obituary for the physicist and philosopher Ernst Mach:

> How does it happen that a properly endowed natural scientist comes to concern himself with epistemology? Is there not some more valuable work to be done in his specialty? That's what I hear many of my colleagues ask, and I sense it from many more. But I cannot share this sentiment. When I think about the ablest students whom I have encountered in my teaching—that

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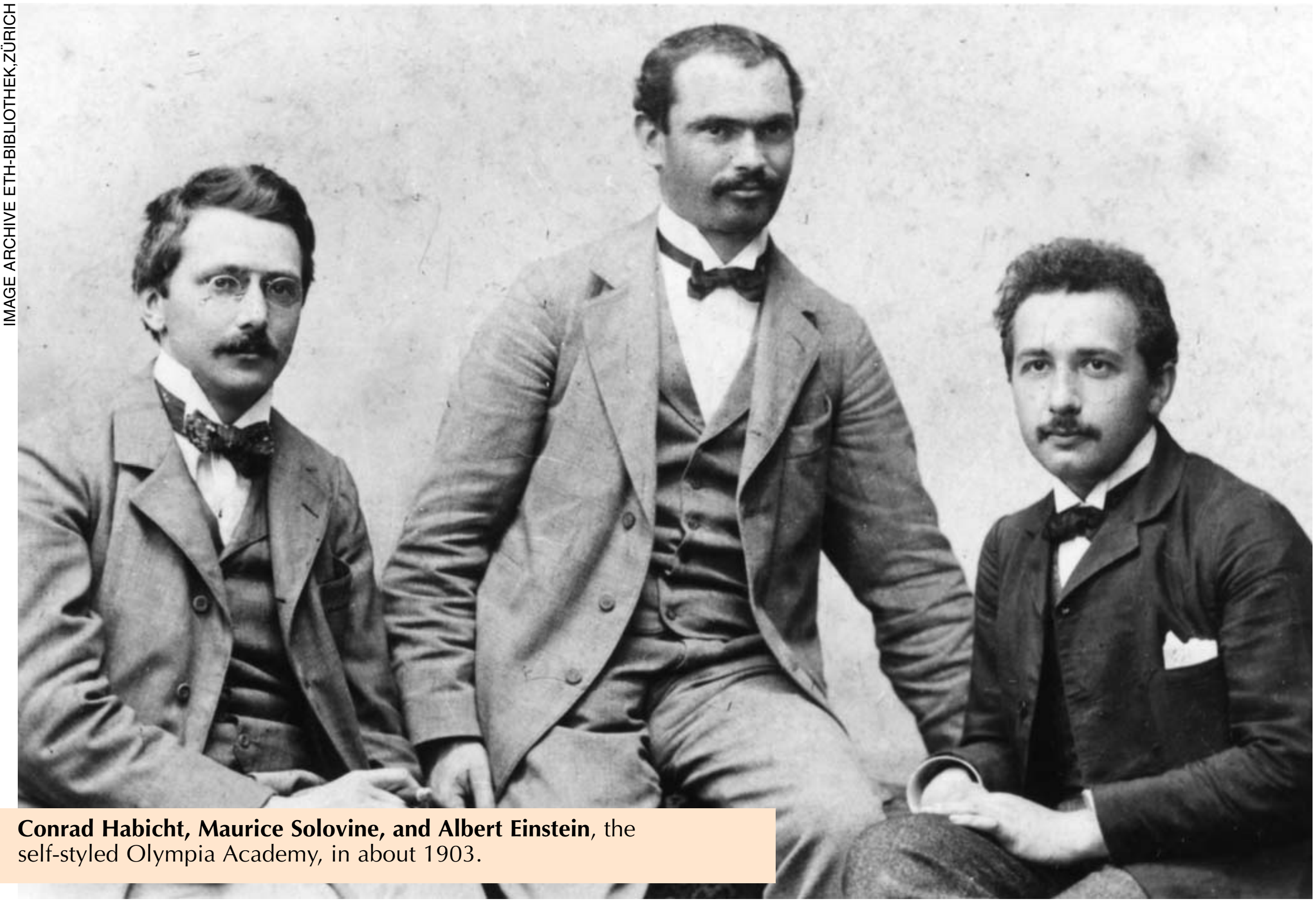

Conrad Habicht, Maurice Solovine, and Albert Einstein, the self-styled Olympia Academy, in about 1903.

> is, those who distinguish themselves by their independence of judgment and not just 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 tenacious defense of their views, that the subject seemed important to them.[4]

Notice that philosophy's benefit to physics is not some specific bit of philosophical doctrine such as the antimetaphysical empiricism championed by Mach. It is, instead, "independence of judgment." The philosophical habit of mind, Einstein argued, encourages a critical attitude toward received ideas:

> Concepts that have proven useful in ordering things easily achieve such authority over us that we forget their earthly origins and accept them as unalterable givens. Thus they come to be stamped as "necessities of thought," "a priori givens," etc. The path of scientific progress is often made impassable for a long time by such errors. Therefore it is by no means an idle game if we become practiced in analyzing long-held commonplace concepts and showing the circumstances on which their justification and usefulness depend, and how they have grown up, individually, out of the givens of experience. Thus their excessive authority will be broken. They will be removed if they cannot be properly legitimated, corrected if their correlation with given things be far too superfluous, or replaced if a new system can be established that we prefer for whatever reason.[4]

Here Einstein is describing the kind of historical–critical conceptual analysis for which Mach was famous. This mode of analysis is at the heart of the arguments for the special and general theories of relativity, and of many of Einstein's other revolutionary works.[5] How did he become this kind of philosophical physicist? Reading Mach was one way, but not the only way.

Early acquaintance with philosophy

Einstein was typical of his generation of physicists in the seriousness and extent of his early and lasting engagement with philosophy. By the age of 16, he had already read all three of Immanuel Kant's major works, the *Critique of Pure Reason*, the *Critique of Practical Reason*, and the *Critique of Judgment*.[6] Einstein was to read Kant again while studying at the Swiss Federal Polytechnic Institute in Zürich, where he attended August Stadler's lectures on Kant in the summer semester of 1897. Stadler belonged to the Marburg neo-Kantian movement, which was distinguished by its efforts to make sense of foundational and methodological aspects of current science within the Kantian framework.[7]

It was also at university that Einstein first read Mach's *Mechanics* (1883) and his *Principles of the Theory of Heat* (1896), along with Arthur Schopenhauer's *Parerga and Paralipomena* (1851). It was probably also there that he first read Friedrich Albert Lange's *History of Materialism* (1873), Eugen Dühring's *Critical History of the Principles of Mechanics* (1887), and Ferdinand Rosenberger's *Isaac Newton and His Physical Principles* (1895). All those

Ernst Mach (1838–1916)

books were, at the end of the century, well known to intellectually ambitious young physics students.

A telling fact about Einstein's acquaintance with philosophy at university was his enrollment in Stadler's course on the "Theory of Scientific Thought" in the winter semester of 1897. The course was in fact required for all students in Einstein's division at the Polytechnic. Think about that: Every physics student at the Polytechnic, one of the leading technical universities in Europe, was required to take a course in the philosophy of science. Such an explicit requirement was not found at every good university, although in 1896 Mach was named to the newly created chair for the "Philosophy of the Inductive Sciences" at the University of Vienna, and students learning physics under Hermann von Helmholtz in Berlin got a heavy dose of philosophy as well. Even if not every university had a specific requirement in the philosophy of science, the Zürich curriculum tells us that good young physicists were expected to know more than just a smattering of philosophy.

Einstein's interest in philosophy continued after graduation. At about the time he started his job in the patent office in Bern in 1902, Einstein and some newfound friends, Maurice Solovine and Conrad Habicht, formed an informal weekly discussion group to which they gave the grandiloquent name "Olympia Academy." Thanks to Solovine, we know what they read.[8] Here is a partial list:

- Richard Avenarius, *Critique of Pure Experience* (1888).
- Richard Dedekind, *What Are and What Should Be the Numbers?* (2nd ed., 1893).
- David Hume, *A Treatise of Human Nature* (1739; German translation 1895).
- Ernst Mach, *The Analysis of Sensations and the Relation of the Physical to the Psychical* (2nd ed., 1900).
- John Stuart Mill, *A System of Logic* (1872; German translation 1887).
- Karl Pearson, *The Grammar of Science* (1900).
- Henri Poincaré, *Science and Hypothesis* (1902; German translation 1904).

Those are titles one would have found on the bookshelf of many bright young physicists at the time. That Einstein and friends read them for pleasure or self-improvement shows how common it was in the scientific culture of the day to know such books and the ideas they held.

The philosophical seeds sown at the Polytechnic and the Olympia Academy were soon to bear fruit in Einstein's 1905 paper on the special theory of relativity and in many other places in his scientific work. But they would bear additional fruit in Einstein, himself, becoming an important philosopher of science.

Relations with philosophers

Einstein's philosophical education made a profound difference in the way he did physics. But his interest in the philosophy of science went further. By the 1930s he had become an active participant in the development of the freestanding discipline of the philosophy of science. His role evolved largely through his personal and professional relations with many of the era's most important philosophers, mainly the founders of the tradition known as logical empiricism.

Einstein's personal acquaintance with prominent philosophers of science began early and somewhat by accident. Friedrich Adler was also a physics student in Zürich in the late 1890s.[9] Although Adler studied at the University of Zürich, not the Polytechnic, he and Einstein became friends. The friendship was renewed in 1909 when Einstein moved back from Bern to Zürich to take up his first academic appointment, at the University of Zürich, a position for which Adler had been the other finalist.

By then, Adler had become a well-known defender of Mach's empiricism, especially after the searing criticism that Max Planck leveled at Mach in a 1908 lecture on "The Unity of the Physical World Picture." The close relationship with Mach led Adler to publish, in 1908, a German translation of Pierre Duhem's influential 1906 book, *Aim and Structure of Physical Theory*.

From Duhem Einstein learned a version of what is known as conventionalism. Henri Poincaré, another well-known conventionalist, famously argued that the geometer's conventional definition of "straight line segment" as "the path of a light ray" made Euclidean geometry safe from straightforward empirical refutation, say by line-of-sight triangulation of three mountain peaks, because anyone impressed by the simplicity of Euclidean geometry could save it by simply changing the definition of straight line.

Duhem's conventionalism differed somewhat from Poincaré's. He argued that what was conventional was not the choice of individual definitions, but rather one's choice of a whole theory. According to Duhem, it is always whole theories and never individual scientific claims that one tests. Duhem's "holistic" conventionalism was to become deeply woven into Einstein's mature picture of the structure of theories and the way they are tested.

It was also in 1909 that Einstein's fame made possible his first meeting with Mach. There was mutual respect on both sides. When Einstein left the German University of Prague in 1912, he nominated Philipp Frank as his successor. Frank was a Mach disciple who was to become an

Immanuel Kant (1724–1804)

important member of the so-called Vienna Circle of logical empiricists. Frank's 1947 Einstein biography is well known.[10]

Einstein's move to Berlin in 1914 further expanded his circle of philosophical colleagues. It included a few neo-Kantians like Ernst Cassirer, whose 1921 book, *Einstein's Theory of Relativity*, was a technically sophisticated and philosophically subtle attempt to fit relativity within the Kantian framework. General relativity presented an obvious challenge to Kant's famous assertion that Euclidean geometry was true a priori, the necessary form under which we organize our experience of external objects.

Hans Reichenbach, a student socialist leader in Berlin at the end of World War I, went on to anchor the Vienna Circle's Berlin outpost and become logical empiricism's most important interpreter of the philosophical foundations of relativity with books like his 1928 *Philosophy of Space and Time*. He had been Einstein's student in Berlin, and Einstein was so impressed by his abilities as a philosopher of physics that when the conservative Berlin philosophy department refused Reichenbach a faculty post in the mid-1920s, Einstein contrived to have a chair in the philosophy of science created for him in the university's more liberal physics department.

Without question, the most important new philosophical friend Einstein made during his Berlin years was Moritz Schlick. He was originally a physicist who did his PhD under Planck in 1904. Schlick's move to Vienna in 1922 to take up the chair in philosophy of science earlier occupied by Mach and Ludwig Boltzmann marks the birth of the Vienna Circle and the emergence of logical empiricism as an important philosophical movement. Prior to the work of Reichenbach, Schlick's 1917 monograph *Space and Time in Contemporary Physics* was the most widely read philosophical introduction to relativity, and Schlick's 1918 *General Theory of Knowledge* had a comparable influence on the broader field of the philosophy of science.[11]

Einstein and Schlick first got to know one another by correspondence in 1915, after Schlick published an astute essay on the philosophical significance of relativity. For the first six years of their acquaintance, Einstein showed high regard for Schlick's work, but by 1922 the relationship had started to cool. Einstein was dismayed by the Vienna Circle's ever more stridently antimetaphysical doctrine. The group dismissed as metaphysical any element of theory whose connection to experience could not be demonstrated clearly enough. But Einstein's disagreement with the Vienna Circle went deeper. It involved fundamental questions about the empirical interpretation and testing of theories.

Schlick, Reichenbach, and Einstein agreed that the challenge facing empiricist philosophers of physics was to formulate a new empiricism capable of defending the integrity of general relativity against attacks from the neo-Kantians. General relativity's introduction of a hybrid spacetime with varying curvature was a major challenge to Kantianism. Some of Kant's defenders argued that general relativity, being non-Euclidean, was false a priori. More subtle and sophisticated thinkers like Cassirer argued that Kant was wrong to claim a priori status for Euclidean geometry but right to maintain that there is some mathematically weaker a priori spatial form, perhaps just a topological form.

Mach's philosophy was not up to the task. It could not acknowledge an independent cognitive role for the knower. Schlick, Reichenbach, and Einstein, on the other hand, agreed that the Kantians were right to insist that the mind is not a blank slate upon which experience writes; that cognition involves some structuring provided by the knower. But how could they assert such an active role for the knower without conceding too much to Kant? They were, after all, empiricists, believing that the reasons for upholding general relativity were ultimately empirical. But in what sense is our reasoning empirical if our knowing has an a priori structure?

Schlick and Reichenbach's eventual answer was based mainly on Poincaré's version of conventionalism. They argued that what the knower contributes are the definitions linking fundamental theoretical terms like "straight line segment" with empirical or physical notions like "path of a ray of light." But, they contended, once such definitions are stipulated by convention, the empirical truth or falsity of all other assertions is uniquely fixed by experience. Moreover, since we freely choose only definitions, the differences resulting from those choices can be no more significant than expressing measurement results in English or metric units.

Einstein also sought an empiricist response to the Kantians, but he deeply disagreed with Schlick and Reichenbach. For one thing, he, like Duhem, thought it impossible to distinguish different kinds of scientific propositions just on principle. Some propositions function like definitions, but there was no clear philosophical reason why any one such proposition *had* to be so regarded. One theorist's definition could be another's synthetic, empirical claim.

As used by philosophers, "synthetic," as distinguished from analytic, means an assertion that goes beyond what is already implied by the meanings of the terms being used. An analytic assertion, by contrast, is a claim whose truth depends solely on meaning or definitions. A central empiricist tenet is that there are no synthetic a priori truths.

A deeper reason for Einstein's dissent from Schlick and Reichenbach was his worry that the new logical empiricist philosophy made science too much like engineering. Missing from the empiricists' picture was what Einstein thought most important in creative theoretical physics, namely, "free inventions" by the human intellect. Not that the theorist was free to make up any picture whatsoever. Theorizing was constrained by the requirement of fit with experience. But Einstein's own experience had taught him that creative theorizing could not be replaced by an algorithm for building and testing theories.

How would Einstein reply to Kant? He deployed Duhem's holism in a novel way. When a theory is tested, something must be held fixed so that we can say clearly what the theory tells us about the world. But Einstein argued that precisely because theories are tested as wholes, not piecemeal, what we choose to hold fixed is arbitrary. One might think, like Kant, that one fixes Euclidean geometry and then tests a physics thus structured. But we really test physics and geometry together. Therefore, one could just as well hold the physics fixed and test the geometry. Better just to say that we are testing both and that we choose among the possible ways of interpreting the results by asking which interpretation yields the simplest theory. Einstein chose general relativity over rivals equally consistent with the evidence because its physics plus non-Euclidean spacetime geometry was, as a whole, simpler than the alternatives.

Such questions might seem overly subtle and arcane philosophical issues better left alone. But they cut to the heart of what it means to respect evidence in the doing of science, and they are questions about which we still argue. As theoretical physics moves ever deeper into realms less firmly anchored to empirical test, as experimental physics becomes ever more difficult and abstruse, the same questions over which Schlick, Reichenbach, and Einstein argued become more and more acute.

When theory confronts experience, how do we apportion credit or blame for success or failure? Can philosophical analysis supply reasons for focusing a test on an individual postulate, or should judgment and taste decide what nature is telling us? The logical empiricists were seeking an algorithm for choosing the right theory. But Einstein likened crucial aspects of the choosing to the "weighing of incommensurable qualities."[12] In one sense, Einstein lost the argument with Schlick and Reichenbach. By midcentury, their logical empiricism had become orthodoxy. But Einstein's dissent did not go unnoticed, and today it lives again as a challenge to another Kant revival.[13]

Philosophy in Einstein's physics

How did Einstein's philosophical habit of mind lead to his doing physics differently? Did it, as he believed, make him a better physicist?

Most readers of Einstein's 1905 special-relativity paper note its strikingly philosophical tone. The paper begins with a philosophical question about an asymmetry in the conventional explanation of electromagnetic induction: A fixed magnet produces a current in the moving coil by an induced electromotive force in the coil. A moving magnet, on the other hand, is said to produce a current in a fixed coil through the electromagnetic field created by the magnet's motion. But if motion is relative, why should

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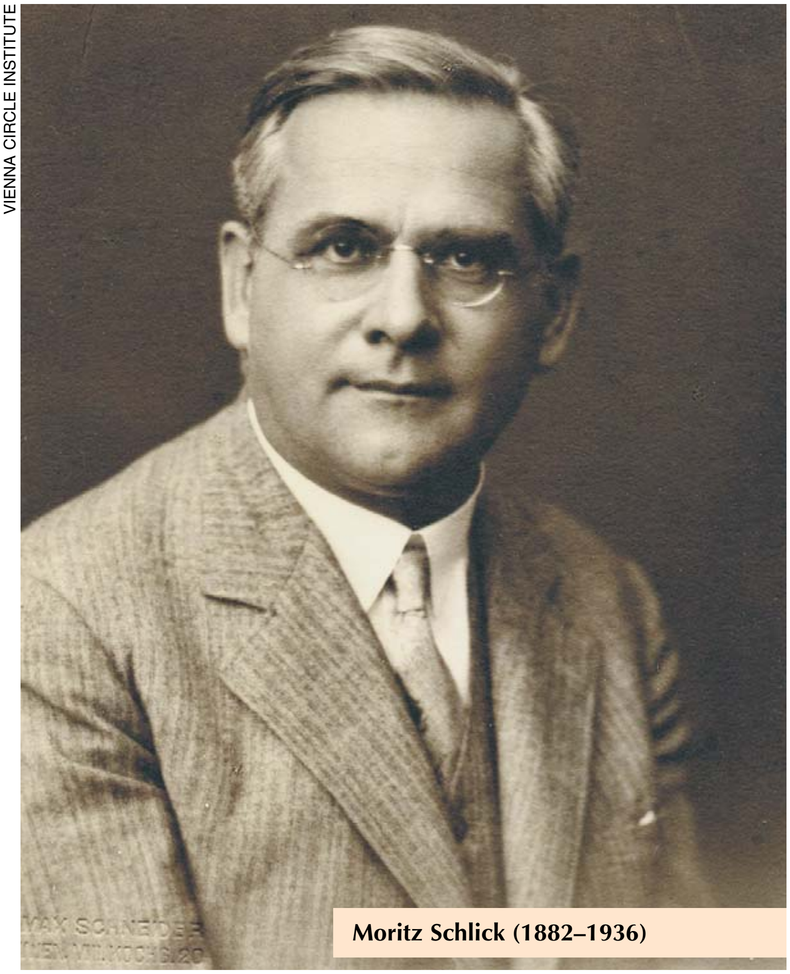


Moritz Schlick (1882–1936)

there be any difference? The paper goes on to fault the idea of objective determination of simultaneity between distant events for similarly philosophical reasons; nothing other than the simultaneity of immediately adjacent events is directly observable. One must therefore stipulate which distant events are deemed simultaneous for a given observer. But that stipulation must rest on a conventional assumption about, say, the equal speeds of outbound and inbound light signals.

There is dispute among historians and philosophers of physics about exactly what philosophical perspective is involved here. Some explicitly conventionalist language in the paper suggests Poincaré as a source. Einstein himself credited principally Hume and secondarily Mach (see Einstein's 1915 letter to Schlick on page 17 of this issue). In any case, the strikingly philosophical tenor of the 1905 relativity paper is unmistakable.

Einstein's philosophical sources are less obscure with regard to his lifelong commitment to the principle of spatial separability in the face of quantum mechanical nonlocality. We know that Einstein read Schopenhauer while a student at the Zürich Polytechnic and regularly thereafter. He knew well one of Schopenhauer's central doctrines, a modification of Kant's doctrine of space and time as necessary a priori forms of intuition. Schopenhauer stressed the essential structuring role of space and time in individuating physical systems and their evolving states. Space and time, for him, constituted the *principium individuationis*, the ground of individuation. In more explicitly physical language, this view implies that difference of location suffices to make two systems different in the sense that each has its own real physical state, independent of the state of the other. For Schopenhauer, the mutual independence of spatially separated systems was a necessary a priori truth.

Did that way of thinking make a difference in Einstein's physics?[14] Consider another famous paper from his annus mirabilis, the 1905 paper on the photon hypothesis, which explained the photoelectric effect by quantizing the way electromagnetic energy lives in free space. A photoelectron is emitted when one quantum of electromagnetic energy is absorbed at an illuminated metal surface, the electron's energy gain being proportional to the frequency of the incident radiation. What most struck Einstein about the behavior of these energy quanta was that in the so-called Wien regime near the high-energy end of the blackbody spectrum, they behave like mutually independent corpuscles by virtue of their occupying different parts of space.

Einstein argued that assuming the validity of Boltzmann's entropy principle ($S = k \log W$) for radiation fields in the Wien regime implies a granular structure to such radiation. Thanks to the Boltzmann principle's logarithmic form, the additivity of the entropy S is equivalent to the factorizability of the joint probability W for two spatially separated constituents of the radiation field to occupy given cells of phase space. The factorizability of a joint probability is one classical expression for the mutual independence of events.

But there was a problem: The same reasoning that implied a quantal structure for radiation in the Wien regime also implied that, outside that regime, the assumed mutual independence of photons must fail. The assumption of mutually independent photons does not yield a derivation of the full Planck formula for the energy density of blackbody radiation. Einstein realized that fact, and for nearly 20 years he sought to understand how it could be.

As early as 1909, Einstein toyed with assigning a wave field to each particlelike photon to account for interference, an obvious failure of mutual independence. That's where the idea of wave–particle duality began. Only late in 1924, when Einstein first read Satyendra Bose's new derivation of the Planck radiation formula, did he grasp that what was implied was a new quantum statistics, in which particles fail to be independent not because of some exotic interaction but because their identity makes them indistinguishable.[15]

Thanks to Bose, Einstein realized that failure of the mutual independence of spatially separated light quanta would be an enduring feature of the emerging quantum theory. But from Schopenhauer he had learned to regard the independence of spatially separated systems as, virtually, a necessary a priori assumption. As the new quantum formalism appeared in the mid-1920s, Einstein sought either to interpret it in a manner compatible with spatial separability or to show that if quantum mechanics could not be so interpreted, it was fatally flawed. In 1927, Einstein produced a hidden-variables interpretation of Erwin Schrödinger's wave mechanics. But he abandoned the effort prior to publication when he found that even his own hidden-variables interpretation involved the kind of failure of spatial separability that Schrödinger later dubbed "entanglement."

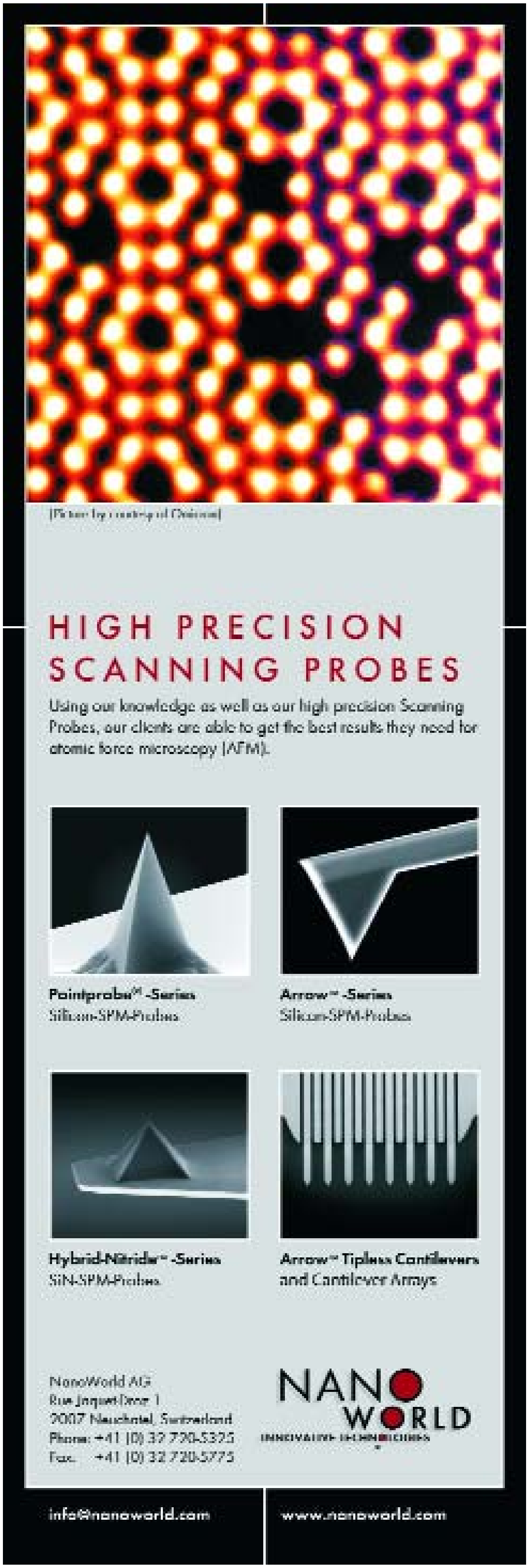
Einstein's most famous assault on the quantum theory was his 1935 "EPR" paper with Boris Podolsky and Nathan Rosen, which sought to demonstrate that quantum mechanics was an incomplete theory. Many readers find the EPR argument convoluted. Few are aware that Einstein repudiated the paper soon after publication, writing to Schrödinger in June of 1935 that the paper was actually written by Podolsky "for reasons of language," and that he was unhappy with the result because "the main point was buried by excessive formalism."

The argument Einstein intended starts from an assumption that he called "the separation principle." Spatially separated systems have independent realities, and relativistic locality precludes superluminal influences between spacelike separated measurement events. Therefore quantum mechanics must be incomplete, because it assigns different wavefunctions, hence different states, to one of two previously interacting systems, depending on what parameter one chooses to measure on the other system. Surely a theory cannot assign two or more different states to one and the same physical reality unless those theoretical states are incomplete descriptions of that reality.[16]

The important point here is that Einstein regarded his separation principle, descended from Schopenhauer's *principium individuationis*, as virtually an axiom for any future fundamental physics. In later writings he explained that field theory, as he understood it—after the model of general relativity, *not* quantum field theory—was the most radical possible expression of separability. In effect, such classical field theories treat all point events in the spacetime manifold as mutually independent, separable systems endowed with their own separate, real physical states.

Einstein's deep philosophical commitment to separability and his consequent lifelong disquiet about quantum mechanics is nowhere more clearly expressed than in a long note he wrote to Max Born in 1949. Einstein asks, "What must be an essential feature of any future fundamental physics?" His answer surprises many who expect him to say "causality."

> I just want to explain what I mean when I say that we should try to hold on to physical reality.
>
> We are . . . all 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 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 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 don't see at all what physics is supposed to be describing. For what is thought to be a "system" is, after all, just conventional, and I do not see



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> how one is supposed to divide up the world objectively so that one can make statements about the parts.[17]

That is how a philosopher–physicist thinks and writes.

Too much philosophizing?

One might respond to Einstein's argument by saying that it proves what's wrong with importing too much philosophy into physics. Einstein was probably wrong to doubt the completeness of quantum mechanics. The entanglement that so bothered him has emerged in recent decades as the chief novelty of the quantum realm.

But such a reaction would reflect a serious misunderstanding of the history. Einstein was wrong, but not because he was a philosophical dogmatist. His reasons were scientific as well as philosophical, the empirical success of general relativity being one among those scientific reasons. What the philosophical habit of mind made possible was Einstein's seeing more deeply into the foundations of quantum mechanics than many of its most ardent defenders. And the kind of philosophically motivated critical questions he asked but could not yet answer were to bear fruit barely 10 years after his death when they were taken up again by another great philosopher–physicist, John Bell.

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