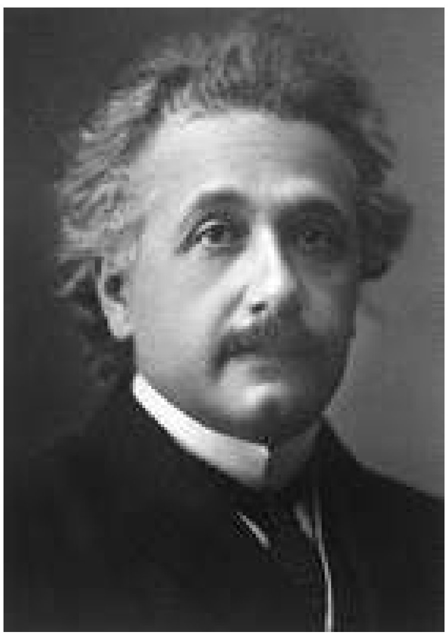
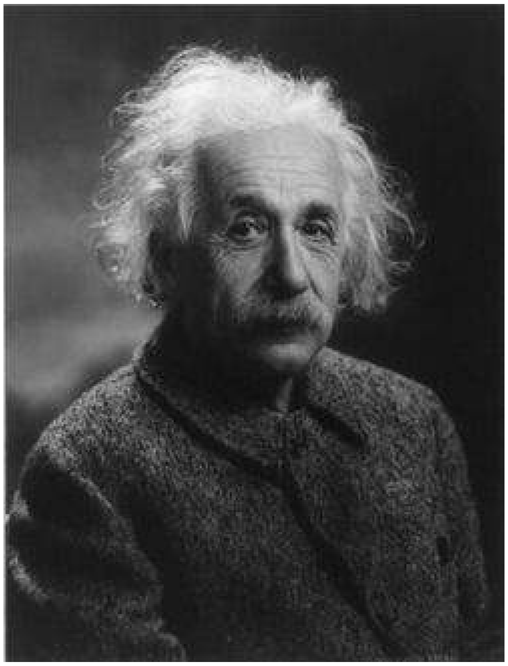
Albert Einstein



Collected & Compiled by Shashank A Sinha/GTS/CSC

[Exclusive for News & Views Readers]



Albert Einstein

Photographed by Oren J. Turner (1947)

Born	**March 14, 1879** **Ulm, Württemberg, Germany**
Died	**April 18, 1955** **Princeton, New Jersey**
Residence	**Germany, Italy, Switzerland, USA**
Nationality	**German (1879-96, 1914-33)** **Swiss (1901-55)** **American (1940-55)**
Field	**Physics**
Institution	**Swiss Patent Office (Berne)** **Univ. of Zürich** **Charles Univ.** **Kaiser Wilhelm Inst.** **Univ. of Leiden** **Inst. for Advanced Study**
Alma Mater	**ETH Zürich**
Known for	**General relativity, Special relativity** **Brownian motion, Photoelectric effect**
Notable Prizes	**Nobel Prize in Physics (1921)** **Copley Medal (1925)** **Max Planck medal (1929)**

Albert Einstein was born at Ulm, in Württemberg, Germany, on March 14, 1879. Six weeks later the family moved to Munich and he began his schooling there at the Luitpold Gymnasium. Later, they moved to Italy and Albert continued his education at Aarau, Switzerland and in 1896 he entered the Swiss Federal Polytechnic School in Zurich to be trained as a teacher in physics and mathematics. In 1901, the year he gained his diploma, he acquired Swiss citizenship and, as he was unable to find a teaching post, he accepted a position as technical assistant in the Swiss Patent Office. In 1905 he obtained his doctor's degree.

During his stay at the Patent Office, and in his spare time, he produced much of his remarkable work and in 1908 he was appointed Privatdozent in Berne. In 1909 he became Professor Extraordinary at Zurich, in 1911 Professor of Theoretical Physics at Prague, returning to Zurich in the following year to fill a similar post. In 1914 he was appointed Director of the Kaiser Wilhelm Physical Institute and Professor in the University of Berlin. He became a German citizen in 1914 and remained in Berlin until 1933 when he renounced his citizenship for political reasons and emigrated to America to take the position of Professor of Theoretical Physics at Princeton*. He became a United States citizen in 1940 and retired from his post in 1945.

After World War II, Einstein was a leading figure in the World Government Movement, he was offered the Presidency of the State of Israel, which he declined, and he collaborated with Dr. Chaim Weizmann in establishing the Hebrew University of Jerusalem.

Einstein always appeared to have a clear view of the problems of physics and the determination to solve them. He had a strategy of his own and was able to visualize the main stages on the way to his goal. He regarded his major achievements as mere stepping-stones for the next advance.

At the start of his scientific work, Einstein realized the inadequacies of Newtonian mechanics and his special theory of relativity stemmed from an attempt to reconcile the laws of mechanics with the laws of the electromagnetic field. He dealt with classical problems of statistical mechanics and problems in which they were merged with quantum theory: this led to an explanation of the Brownian movement of molecules. He investigated the thermal properties of light with a low radiation density and his observations laid the foundation of the photon theory of light.

In his early days in Berlin, Einstein postulated that the correct interpretation of the special theory of relativity must also furnish a theory of gravitation and in 1916 he published his paper on the general theory of relativity. During this time he also contributed to the problems of the theory of radiation and statistical mechanics.

In the 1920's, Einstein embarked on the construction of unified field theories, although he continued to work on the probabilistic interpretation of quantum theory, and he persevered with this work in America. He contributed to statistical mechanics by his development of the quantum theory of a monatomic gas and he has also accomplished valuable work in connection with atomic transition probabilities and relativistic cosmology.

After his retirement he continued to work towards the unification of the basic concepts of physics, taking the opposite approach, geometrisation, to the majority of physicists.

Einstein's researches are, of course, well chronicled and his more important works include *Special Theory of Relativity* (1905), *Relativity* (English translations, 1920 and 1950), *General Theory of Relativity* (1916), *Investigations on Theory of Brownian Movement* (1926), and *The Evolution of Physics* (1938). Among his non-scientific works, *About Zionism* (1930), *Why War?* (1933), *My Philosophy* (1934), and *Out of My Later Years* (1950) are perhaps the most important.

Albert Einstein received honorary doctorate degrees in science, medicine and philosophy from many European and American universities. During the 1920's he lectured in Europe, America and the Far East and he was awarded Fellowships or Memberships of all the leading scientific academies throughout the world. He gained numerous awards in recognition of his work, including the Copley Medal of the Royal Society of London in 1925, and the Franklin Medal of the Franklin Institute in 1935.

Einstein's gifts inevitably resulted in his dwelling much in intellectual solitude and, for relaxation, music played an important part in his life. He married Mileva Maric in 1903 and they had a daughter and two sons; their marriage was dissolved in 1919 and in the same year he married his cousin, Elsa Löwenthal, who died in 1936. He died on April 18, 1955 at Princeton, New Jersey.

Albert Einstein (German pronunciation (help·info)) (March 14, 1879 – April 18, 1955) was a German-born theoretical physicist who is widely considered one of the greatest physicists of all time.[1][2] While best known for the theory of relativity (and specifically mass-energy equivalence, $E=mc^2$), he was awarded the 1921 Nobel Prize in Physics for his 1905 (Annus Mirabilis) explanation of the photoelectric effect and "for his services to Theoretical Physics". In popular culture, the name "Einstein" has become synonymous with great intelligence and genius. Einstein was named Time magazine's "Man of the Century."

He was known for many scientific investigations, among which were: his special theory of relativity which stemmed from an attempt to reconcile the laws of mechanics with the laws of the electromagnetic field, his general theory of relativity which extended the principle of relativity to include gravitation, relativistic cosmology, capillary action, critical opalescence, classical problems of statistical mechanics and problems in which they were merged with quantum theory, leading to an explanation of the Brownian movement of molecules; atomic transition probabilities, the quantum theory of a monatomic gas, the concept of the photon, the theory of radiation, including stimulated emission; the attempt to develop a unified field theory, and the geometrization of physics.

Biography

Youth and college

Young Albert before the Einsteins moved from Germany to Italy.

Einstein was born on March 14, 1879, to a Jewish family, in Ulm, Württemberg, Germany. His father was Hermann Einstein, a salesman who later ran an electrochemical works, and his mother was Pauline *née* Koch. They were married in Stuttgart-Bad Cannstatt.

At his birth, Albert's mother was reputedly frightened that her infant's head was so large and oddly shaped. Though the size of his head appeared to be less remarkable as he grew older, it's evident from photographs of Einstein that his head was disproportionately large for his body throughout his life, a trait regarded as "benign macrocephaly" in large-headed individuals with no related disease or cognitive deficits. His parents also worried about his intellectual development as a child due to his initial language delay (see the Speculation and Controversy section below) and his lack of fluency until the age of nine, though he was one of the top students in his elementary school.

In 1880, shortly after Einstein's birth the family moved to Munich, where his father and his uncle founded a company manufacturing electrical equipment (Elektrotechnische Fabrik J. Einstein & Cie). This company provided the first lighting for the Oktoberfest as well as some cabling in the suburb of Schwabing.

Albert's family members were all non-observant Jews and he attended a Catholic elementary school. At the insistence of his mother, he was given violin lessons. Though he initially disliked the lessons, and eventually discontinued them, he would later take great solace in Mozart's violin sonatas.

When Einstein was five, his father showed him a small pocket compass, and Einstein realized that something in "empty" space acted upon the needle; he would later describe the experience as one of the most revelatory events of his life. He built models and mechanical devices for fun and showed great mathematical ability early on.

In 1889, a medical student named Max Talmud (later: Talmey), who regularly visited the Einsteins,[3] introduced Einstein to key science and philosophy texts, including Kant's *Critique of Pure Reason*.

Einstein attended the Luitpold Gymnasium, where he received a relatively progressive education. In 1891, he taught himself Euclidean geometry from a school booklet and began to study calculus; Einstein realized the power of deductive reasoning from *Euclid's Elements*, which Einstein called the "holy little geometry book"[3] (given by Max Talmud). At school, Einstein clashed with authority and resented the school regimen, believing that the spirit of learning and creative thought were lost in such endeavors as strict rote learning.

From 1894, following the failure of Hermann Einstein's electrochemical business, the Einsteins moved to Milan and proceeded to Pavia after a few months. Einstein's first scientific work, called "*The Investigation of the State of Aether in Magnetic Fields*", was written contemporaneously for one of his uncles. Albert remained in Munich to finish his schooling, but only completed one term before leaving the gymnasium in the spring of 1895 to join his family in Pavia. He quit a year and a half before the final examinations, convincing the school to let him go with a medical note from a friendly doctor, but this meant that he had no secondary-school certificate.[4] That same year, at age 16, he performed a famous thought experiment by trying to visualize what it would be like to ride alongside a light beam. He realized that, according to Maxwell's equations, light waves would obey the principle of relativity: the speed of the light would always be constant, no matter what the velocity of the observer. This conclusion would later become one of the two postulates of special relativity.

Rather than pursuing electrical engineering as his father intended for him, he followed the advice of a family friend and applied at the Federal Polytechnic Institute in Zurich in 1895. Without a school certificate he had to take an admission exam, which he – at the age of 16 being the youngest participant – did not pass. He had preferred travelling in northern Italy over the required preparations for the exam. Still, he easily passed the science part, but failed in general knowledge.

After that he was sent to Aarau, Switzerland to finish secondary school. He lodged with Professor Jost Winteler's family and became enamoured with Sofia Marie-Jeanne Amanda Winteler, commonly referred to as Sofie or Marie, their daughter and his first sweetheart. Einstein's sister, Maja, who was perhaps his closest confidant, was to later marry their son, Paul.[5] While there, he studied Maxwell's electromagnetic theory and received his diploma in September 1896. Einstein subsequently enrolled at the Federal Polytechnic Institute in October and moved to Zurich, while Marie moved to Olsberg, Switzerland for a teaching post. The same year, he renounced his Württemberg citizenship to avoid military service.

In the spring of 1896, Mileva Marić started as a medical student at the University of Zurich, but after a term switched to the Federal Polytechnic Institute. She was the only woman to study in that year for the same diploma as Einstein. Marić's relationship with Einstein developed into romance over the next few years, though his mother objected because she was too old, not Jewish, and physically defective.[6]

In 1900, Einstein was granted a teaching diploma by the Federal Polytechnic Institute. Einstein then submitted his first paper to be published, on the capillary forces of a straw, titled "*Consequences of the observations of capillarity phenomena*" ("*Folgerungen aus den Capillaritätserscheinungen*") [7]. In this paper his quest for a unified physical law becomes apparent, which he followed throughout his life. Through his friend Michele Besso, Einstein was presented with the works of Ernst Mach, and would later consider him "the best sounding board in Europe" for physical ideas. Einstein and Marić had a daughter, Lieserl Einstein, born in January 1902. Her fate is unknown; some believe she died in infancy, while others believe she was given out for adoption.

Works and doctorate

Einstein in 1905, when he wrote the "*Annus Mirabilis Papers*"

Einstein could not find a teaching post upon graduation, mostly because his brashness as a young man had apparently irritated most of his professors. The father of a classmate helped him obtain employment as a technical assistant examiner at the Swiss Patent Office[8] in 1902. His main responsibility was to evaluate patent applications relating to electromagnetic devices.[9] He also learned how to discern the essence of applications despite sometimes poor descriptions, and was taught by the director how "to express [him]self correctly". He occasionally corrected their design errors while evaluating the practicality of their work.

His friend from Zurich, Michele Besso, also moved to Bern and took a job at the patent office, and he became an important sounding board. Einstein also joined with two friends he made in Bern, Maurice Solovine and Conrad Habicht, to create a weekly discussion club on science and philosophy, which they grandly and jokingly named "The Olympia Academy." Their readings included Poincare, Mach, Hume, and others who influenced the development of the special theory of relativity.

Einstein married Mileva Marić on January 6, 1903. Einstein's marriage to Marić, who was a mathematician, was both a personal and intellectual partnership: Einstein referred to Mileva as "a creature who is my equal and who is as strong and independent as I am". Ronald W. Clark, a biographer of Einstein, claimed that Einstein depended on the distance that existed in his marriage to Mileva in order to have the solitude necessary to accomplish his work; he required intellectual isolation. In an obituary of Einstein Abram Joffe wrote: "The author of [the papers of 1905] was… a bureaucrat at the Patent Office in Bern, Einstein-Marić" which has been taken as evidence of a collaborative relationship. However, most probably Joffe referred to Einstein-Marić, because he believed that it was a Swiss custom at the time to append the spouse's surname to the husband's name.[10] The extent of her influence on Einstein's work is a controversial and debated question.

In 1903, Einstein's position at the Swiss Patent Office had been made permanent, though he was passed over for promotion until he had "fully mastered machine technology".[11] He obtained his doctorate under Alfred Kleiner at the University of Zürich after submitting his thesis "*A new determination of molecular dimensions*" ("*Eine neue Bestimmung der Moleküldimensionen*") in 1905.

Annus Mirabilis Papers

During 1905, in his spare time, he wrote four articles that participated in the foundation of modern physics, without much scientific literature he could refer to or many fellow scientists with whom he could discuss the theories. Most physicists agree that three of those papers (on Brownian motion, the photoelectric effect, and special relativity) deserved Nobel Prizes. Only the paper on the photoelectric effect would be mentioned by the Nobel committee in the award; at the time of the award, it had the most unchallenged experimental evidence behind it, although the Nobel committee expressed the opinion that Einstein's other work would be confirmed in due course.

Some might regard the award for the photoelectric effect ironic, not only because Einstein is far better-known for relativity, but also because the photoelectric effect is a quantum phenomenon, and Einstein became somewhat disenchanted with the path quantum theory would take.

Max Planck presents Einstein with the Max-Planck medal, Berlin June 28 1929

Einstein submitted this series of papers to the "*Annalen der Physik*". They are commonly referred to as the "*Annus Mirabilis Papers*" (from *Annus mirabilis*, Latin for 'year of wonders'). The year 2005 has been named the *World Year of Physics* in recognition of the 100th anniversary of this work.

The first paper, named "*On a Heuristic Viewpoint Concerning the Production and Transformation of Light*", ("*Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt*") was specifically cited for his Nobel Prize. In this paper, Einstein extended Planck's hypothesis ($E = h\nu$) of discrete energy elements to his own hypothesis that electromagnetic energy is absorbed or emitted by matter in quanta of $h\nu$ (where h is Planck's constant and ν is the frequency of the light), proposing a new law

$$E_{\max} = h\nu - P$$

to account for the photoelectric effect, as well as other properties of photoluminescence and photoionization. In later papers, Einstein used this law to describe the Volta effect (1906), the production of secondary cathode rays (1909) and the high-frequency limit of Bremsstrahlung (1911). Einstein's key contribution is his assertion that energy quantization is a general, intrinsic property of light, rather than a particular constraint of the interaction between matter and light, as Planck believed. Another result of this paper was Einstein's excellent estimate (6.17×10^{23}) of Avogadro's number (6.02×10^{23}). However, Einstein does *not* propose that light is a particle in this paper; the "photon" concept was not proposed until 1909 (see below).

His second article in 1905, named "*On the Motion—Required by the Molecular Kinetic Theory of Heat—of Small Particles Suspended in a Stationary Liquid*", ("*Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen*") covered his study of Brownian motion, and provided empirical evidence for the existence of atoms. Before this paper, atoms were recognized as a useful concept, but physicists and chemists debated whether atoms were real entities. Einstein's statistical discussion of atomic behavior gave experimentalists a way to count atoms by looking through an ordinary microscope. Wilhelm Ostwald, one of the leaders of the anti-atom school, later told Arnold Sommerfeld that he had been converted to belief in atoms by Einstein's complete explanation of Brownian motion.[12] Brownian motion was also explained by Louis Bachelier in 1900.

Einstein's third paper that year, "*On the Electrodynamics of Moving Bodies*" ("*Zur Elektrodynamik bewegter Körper*"), was published in June 1905. This paper introduced the special theory of relativity, a theory of time, distance, mass and energy which was consistent with electromagnetism, but omitted the force of gravity. While developing this paper, Einstein wrote to Mileva about "our work on relative motion", and this has led some to speculate that Mileva played a part in its development.

A few historians believe that Einstein was aware that Henri Poincaré had already published the equations of relativity, a few weeks before Einstein submitted his paper. Most believe their work was independent and varied in many crucial ways, namely, regarding the "ether" (Einstein denied ether, Poincaré considered it superfluous). Similarly, it is debatable if he knew the 1904 paper of Hendrik Lorentz which contained most of the theory and to which Poincaré referred. Most historians, however, believe that Einsteinian relativity varied in many key ways from other theories of relativity which were circulating at the time, and that many of the questions about priority stem from the misleading trope of portraying Einstein as a genius working in total isolation.[13] Although Einstein discussed physics with Mileva, there is no solid evidence that she made any significant contribution to his work.

In a fourth paper, "*Does the Inertia of a Body Depend Upon Its Energy Content?*", ("*Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?*"), published late in 1905, he showed that from relativity's axioms, it is possible to deduce the famous equation which shows the equivalence between matter and energy. The energy equivalence (E) of some amount of mass (m) is that mass times the speed of light (c) squared: $E = mc^2$. However, it was Poincaré who in 1900 first published the "energy equation" in slightly different form, namely as: $m = E / c^2$ — see also relativity priority dispute.

Middle years

Einstein at the 1911 Solvay Conference.

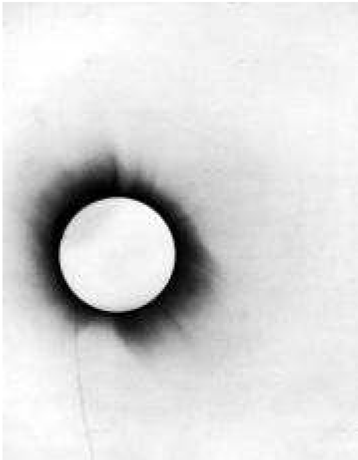
In 1906, Einstein was promoted to technical examiner second class. In 1908, Einstein was licensed in Bern, Switzerland, as a Privatdozent. During this time, Einstein described why the sky is blue in his paper on critical opalescence, which shows the cumulative effect of scattering of light by individual molecules in the atmosphere.[14] In 1911, Einstein became first associate professor at the University of Zurich, and shortly afterwards full professor at the German section of the Charles University of Prague. While at Prague, Einstein published a paper calling on astronomers to test two predictions of his developing theory of relativity: a bending of light in a gravitational field, measurable at a solar eclipse; and a redshift of solar spectral lines relative to spectral lines produced on Earth's surface. A young German astronomer, Erwin Freundlich worked with Einstein and made other astronomers around the world aware of Einstein's astronomical tests.[15] In 1912, Einstein returned to Zurich in order to become full professor at the ETH Zurich. At that time, he worked closely with the mathematician Marcel Grossmann, who introduced him to Riemannian geometry. In 1912, Einstein started to refer to time as the fourth dimension (although H.G. Wells had done this earlier, in 1895 in *The Time Machine*).

In 1914, just before the start of World War I, Einstein settled in Berlin as professor at the University of Berlin and became a member of the Prussian Academy of Sciences. He took German citizenship. From 1914 to 1933, he served as director of the Kaiser Wilhelm Institute for Physics in Berlin. He also held the position of extraordinary professor at the Leiden University from 1920 until 1946, where he regularly gave guest lectures.

In 1917, Einstein published *"On the Quantum Mechanics of Radiation"* (*"Zur Quantentheorie der Strahlung,"* Physkalische Zeitschrift 18, 121–128). This article introduced the concept of stimulated emission, the physical principle that allows light amplification in the laser. He also published a paper that year that used the general theory of relativity to model the behavior of the entire universe, setting the stage for modern cosmology. In this work Einstein created the cosmological constant, which he later considered his "biggest blunder".[16]

On May 14, 1904, Albert and Mileva's first son, Hans Albert Einstein, was born. Their second son, Eduard Einstein, was born on July 28, 1910. Hans Albert became a professor of hydraulic engineering at University of California, Berkeley, having little interaction with his father, but sharing his love for sailing and music. Eduard, the younger brother, intended to practice as a Freudian analyst but was institutionalized for schizophrenia and died in an asylum. Einstein divorced Mileva on February 14, 1919, and married his cousin Elsa Löwenthal (born Einstein: Löwenthal was the surname of her first husband, Max) on June 2, 1919. Elsa was Albert's first cousin (maternally) and his second cousin (paternally). She had nursed him after he had suffered a partial nervous breakdown combined with a severe stomach ailment; there were no children from this marriage.

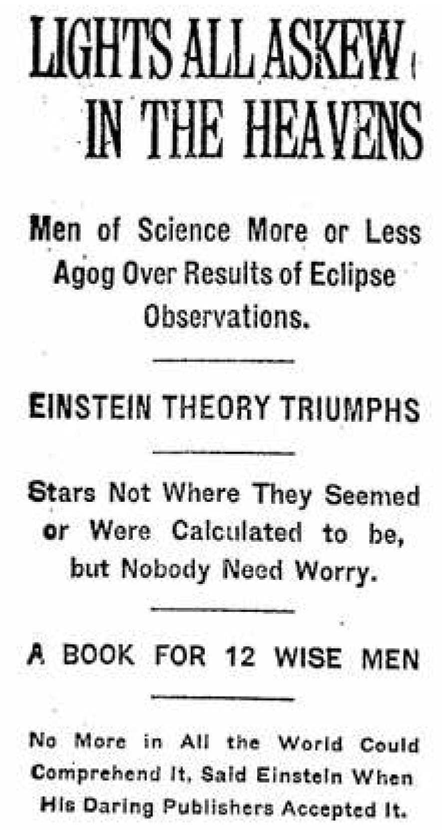
General relativity



1919 solar eclipse

In November 1915, Einstein presented a series of lectures before the Prussian Academy of Sciences on a new theory of gravity, known as general relativity. The final lecture ended with his introduction of an equation that replaced Newton's law of gravity, the Einstein field equation.[17] This theory considered all observers to be equivalent, not only those moving at a uniform speed. In general relativity, gravity is no longer a force (as it is in Newton's law of gravity) but is a consequence of the curvature of space-time.

Einstein's published papers on general relativity were not available outside of Germany due to the war. News of Einstein's theory reached astronomers in England and America via Dutch physicists Hendrik Lorentz, Paul Ehrenfest and Willem de Sitter. Fascinated with the new theory Arthur Stanley Eddington became a leading proponent and popularizer of relativity.[18] Most astronomers did not like Einstein's geometrization of gravity and believed that his light bending and gravitational redshift predictions would not be correct. In 1917, astronomers at Mount Wilson observatory in southern California published results of spectroscopic analysis of the solar spectrum that seemed to indicate that there was no gravitational redshift in the Sun.[19] In 1918, astronomers at Lick Observatory in northern California obtained photographs of a solar eclipse. After the end of the war, they announced results claiming that Einstein's general relativity prediction of light bending was wrong; but they never published their results due to large probable errors.[20]


LIGHTS ALL ASKEW IN THE HEAVENS

Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

A BOOK FOR 12 WISE MEN

No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.

"Einstein theory triumphs," declared the *New York Times* on November 10, 1919.

In May 1919, during British solar eclipse expeditions (carried out in Sobral, Ceará, Brazil and Principe, an island of the west coast of Africa) Arthur Eddington took measurements of the bending of star light as it passed close to the Sun, resulting in star positions appearing farther away from the Sun. This effect is called gravitational lensing and the positions of the stars observed were twice that which would be predicted by Newtonian physics.[21] These observations match the Field Equation of general relativity. Eddington announced that the results confirmed Einstein's prediction and *The Times* reported that confirmation on November 7 of that year, with the headline: "*Revolution in science – New theory of the Universe – Newtonian ideas overthrown*". Nobel laureate Max Born viewed General Relativity as the "greatest feat of human thinking about nature"; fellow laureate Paul Dirac called it "probably the greatest scientific discovery ever made".[22] These comments and resulting publicity cemented Einstein's fame. He became world-famous – an unusual achievement for a scientist.

Many scientists were still unconvinced for various reasons ranging from the scientific (disagreement with Einstein's interpretation of the experiments, belief in the ether or that an absolute frame of reference was necessary) to the psycho-social (conservatism, anti-Semitism). In Einstein's view, most of the objections were from experimentalists with very little understanding of the theory involved.[23] Einstein's public fame which followed the 1919 article created resentment among these scientists, some of which lasted well into the 1930s.[24]

On April 2 1921, Einstein went to New York to give a lecture on his new Theory of Relativity, the same year he was awarded the Nobel Prize. Though he is now most famous for his work on relativity, it was for his earlier work on the photoelectric effect that he was given the Prize, as his work on general relativity was still disputed. The Nobel committee decided that citing his less-contested theory in the Prize would gain more acceptance from the scientific community.

Copenhagen interpretation

Einstein and Niels Bohr sparred over quantum theory during the 1920s. Photo taken by Paul Ehrenfest during their visit to Leiden in December 1925

In 1909, Einstein presented a paper *"The Development of Our Views on the Composition and Essence of Radiation"* (*"Über die Entwicklung unserer Anschauungen über das Wesen und die Konstitution der Strahlung"*) on the history of luminiferous aether and, more importantly, on the quantization of light. In this and an earlier 1909 paper, Einstein showed that the *energy* quanta introduced by Max Planck also carried a well-defined *momentum* and acted in many respects as if they were independent, point-like particles. This paper marks the introduction of the modern "photon" concept (although the term itself was introduced much later, in a 1926 paper by Gilbert N. Lewis). Even more importantly, Einstein showed that light must be *simultaneously* a wave and a particle, a revolutionary idea at the time. However, his own proposal for a solution - that Maxwell's equations for electromagnetic fields be modified to allow wave solutions that are bound to singularities of the field - was never developed, although it may have influenced Louis de Broglie's pilot wave hypothesis for quantum mechanics.

Determinism

Beginning in the mid-1920s, as the original quantum theory was replaced with a new theory of quantum mechanics, Einstein voiced his objections to the Copenhagen interpretation of the new equations. His opposition in this regard would continue all his life. In a 1926 letter to Max Born, Einstein made the following remark:

Quantum mechanics is certainly imposing. But an inner voice tells me it is not yet the real thing. The theory says a lot, but does not really bring us any closer to the secret of the Old One. I, at any rate, am convinced that He does not throw dice.

To this, Bohr, who sparred with Einstein on quantum theory, retorted, "Stop telling God what He must do!" Einstein's deterministic point of view is manifested in the 1935 EPR paradox[25].

There is a case to be made, however, for a quite different view of Einstein's objections to quantum orthodoxy. An emphatic comment on the matter was made by his contemporary Wolfgang Pauli.[26]

…I was unable to recognize Einstein whenever you talked about him in either your letter or your manuscript. It seemed to me as if you had erected some dummy Einstein for yourself, which you then knocked down with great pomp. In particular Einstein does not consider the concept of 'determinism' to be as fundamental as it is frequently held to be (as he told me emphatically many times) …he *disputes* that he uses as a criterion for the admissibility of a theory the question "Is it rigorously deterministic?"… he was not at all annoyed with you, but only said that you were a person who will not listen.

Incompleteness and Realism

The Albert Einstein Memorial, Washington DC at the National Academy of Sciences in Washington, DC.

Many of Einstein's comments indicate his belief that quantum mechanics is 'incomplete'. This was first asserted in the famous 1935 Einstein, Podolsky, Rosen (EPR paradox) paper,[27] and it appears again in the 1949 book *Albert Einstein, Philosopher-Scientist*.[28] The "EPR" paper — entitled "Can Quantum Mechanical Description of Physical Reality Be Considered Complete?" — concluded: "While we have thus shown that the wave function does not provide a complete description of the physical reality, we left open the question of whether or not such a description exists. We believe, however, that such a theory is possible."

Einstein has suggested up a fascinating proposal for an experiment somewhat similar to Schrödinger's cat.[29] He begins by addressing the problem of the radioactive decay of an atom. The following system is used as a means to detect the decay:

Rather than considering a system which comprises only a radioactive atom (and its process of transformation), one considers a system which includes also the means for ascertaining the radioactive transformation — for example, a Geiger-counter with automatic registration mechanism. Let this include a registration-strip, moved by a clockwork, upon which a mark is made by tripping the counter. True, from the point of view of quantum mechanics this total system is very complex and its configuration space is of very high dimension. But there is in principle no objection to treating this entire system from the standpoint of quantum mechanics. Here too the theory determines the probability of each configuration of all coordinates for every time instant. If one considers all configurations of the coordinates, for a time large compared with the average decay time of the radioactive atom, there will be (at most) one such registration-mark on the paper strip. To each co-ordinate- configuration must correspond a definite position of the mark on the paper strip. But, inasmuch as the theory yields only the relative probability of the thinkable coordinate-configurations, it also offers only relative probabilities for the positions of the mark on the paperstrip, but no definite location for this mark.

Einstein continues:

If we attempt [to work with] the interpretation that the quantum-theoretical description is to be understood as a complete description of the individual system, we are forced to the interpretation that the location of the mark on the strip is nothing which belongs to the system *per se*, but that the existence of that location is essentially dependent upon the carrying out of an observation made on the registration-strip. Such an interpretation is certainly by no means absurd from a purely logical point of standpoint; yet there is hardly anyone who would be inclined to consider it seriously. For, in the macroscopic sphere it simply is considered certain that one must adhere to the program of a realistic description in space and time; whereas in the sphere of microscopic situations, one is more readily inclined to give up, or at least to modify, this program." (emphasis due to Einstein)

Einstein never rejected probabilistic techniques and thinking, in and of themselves. Einstein himself was a great statistician,[30] using statistical analysis in his works on Brownian motion and photoelectricity and in papers published before 1905; Einstein had even discovered Gibbs ensembles. According to the majority of physicists, however, he believed that indeterminism constituted a criteria for strong objection to a physical theory. Pauli's testimony contradicts this, and Einstein's own statements indicate a focus on incompleteness, as his major concern.

More recent times have given us another twist to this business. John Stewart Bell discovered further interesting results (Bell's Theorem and Bell's inequality) in his researches on the Einstein, Podolsky, and Rosen paper. There is a divergence in thinking as to the conclusions derivable from this, in conjunction with the EPR analysis. According to Bell, quantum nonlocality has been established, while others see the death of determinism.

Summary

Whatever his inner convictions, Einstein agreed that the quantum theory was the best available,[*citation needed*] but he looked for a more "complete" explanation, i.e., either more deterministic or one that could more fundamentally explain the reason for probabilities in a logical way. He could not abandon the belief that physics described the laws that govern "real things", nor could he abandon the belief that there are no explanations that contain contradictions, which had driven him to his successes explaining photons, relativity, atoms, and gravity.

Bose-Einstein statistics

In 1924, Einstein received a short paper from a young Indian physicist named Satyendra Nath Bose describing light as a gas of photons and asking for Einstein's assistance in publication. Einstein realized that the same statistics could be applied to atoms, and published an article in German (then the lingua franca of physics) which described Bose's model and explained its implications. Bose-Einstein statistics now describe any assembly of these indistinguishable particles known as bosons. The Bose-Einstein condensate phenomenon was predicted in the 1920s by Bose and Einstein, based on Bose's work on the statistical mechanics of photons, which was then formalized and generalized by Einstein. The first such condensate in alkali gases was produced by Eric Cornell and Carl Wieman in 1995 at the University of Colorado at Boulder, though Bose-Einstein Condensation has been observed in superfluid Helium-4 since the 1930s.[*citation needed*] Einstein's original sketches on this theory were recovered in August 2005 in the library of Leiden University.[31]

Einstein also assisted Erwin Schrödinger in the development of the Boltzmann distribution, a mixed classical and quantum mechanical gas model although he realized that this was less significant than the Bose-Einstein model and declined to have his name included on the paper.

Bohr-Einstein debates

From Wikipedia, the free encyclopedia

Niels Bohr with Albert Einstein at Paul Ehrenfest's home in Leiden (December 1925)

The **Bohr-Einstein debates** is a popular name given to what was actually a series of epistemological challenges presented by Albert Einstein against what has come to be called the *standard* or Copenhagen interpretation of quantum mechanics. Since Einstein's closest friend and primary interlocutor in the "school" of Copenhagen was the physicist Niels Bohr, and since it was Bohr who provided answers to most of the challenges presented by Einstein, what was actually a friendly and fruitful series of exchanges of ideas has taken on the label of a "debate".

Einstein's position with respect to quantum mechanics is significantly more subtle and open-minded than it has often been portrayed in technical manuals and popular science articles. Be that as it may, his constant and powerful criticisms of the quantum "orthodoxy" compelled the defenders of that orthodoxy to sharpen and refine their understanding of the philosophical and scientific implications of their own theory.

Einstein's natural reference point, as mentioned above, was always Niels Bohr, as the person who, more than other members of the School of Copenhagen, was animated by a particular interest for the philosophical and epistemological aspects of the theory and drew inspiration from the surprising aspects of the microscopic world in order to present daring hypotheses about reality and about knowledge, such as his idea of complementarity. These two giants of scientific thought nurtured a profound respect for each other and they were both extremely attentive to the acute and penetrating observations of the other. The debate is not only of historical interest: as we will see Einstein's attacks often provoked reactions on the part of Bohr which called into question the crucial elements of the formalization of QM and of its interpretation. This articulated process, in which many other important scientists, from Ehrenfest and Heisenberg to Born and from Schrödinger to John von Neumann, took part, brought more and more detailed attention on certain particularly problematic points of the theory.

First stage

As mentioned above, Einstein's position underwent significant modifications over the course of the years. In the first stage, Einstein refuses to accept quantum indeterminism and seeks to demonstrate that the principle of indeterminacy can be violated, suggesting ingenious *thought experiments* which should permit the accurate determination of incompatible variables, such as position and velocity, or to explicitly reveal simultaneously the wave and the particle aspects of the same process.

The first serious attack by Einstein on the "orthodox" conception took place during the *Fifth Conference of Physics* at the *Solvay Institute* in 1927. Einstein pointed out how it was possible to take advantage of the (universally accepted) laws of conservation of energy and of impulse (momentum) in order to obtain information on the state of a particle in a process of interference which, according to the principle of indeterminacy or that of complementarity, should not be accessible.

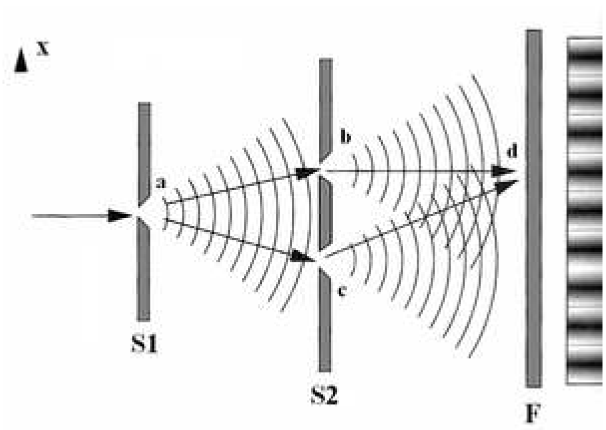


Figure A. A monochromatic beam (one for which all the particles have the same impulse) encounters a first screen, diffracts, and the diffracted wave encounters a second screen with two slits resulting in the formation of an interference figure on the background *F*. As always, it is assumed that only one particle at a time is able to pass the entire mechanism. From the measure of the recoil of the screen *S1*, according to Einstein, one can deduce from which slit the particle has passed without destroying the wave aspects of the process.

In order to follow his argumentation and to evaluate Bohr's response, it is convenient to refer to the experimental apparatus illustrated in figure A. A beam of light perpendicular to the *X* axis which propagates in the direction *z* encounters a screen *S1* which presents a narrow (with respect to the wavelength of the ray) slit. After having passed through the slit, the wave function diffracts with an angular opening that causes it to encounter a second screen *S2* which presents two slits. The successive propagation of the wave results in the formation of the interference figure on the final screen *F*.

At the passage through the two slits of the second screen *S2*, the wave aspects of the process become essential. In fact, it is precisely the interference between the two terms of the superposition corresponding to states in which the particle is localized in one of the two slits which implies that the particle is "guided" preferably into the zones of constructive interference and cannot end up in a point in the zones of destructive interference (in which the wave function is nullified). It is also important to note that any experiment designed to evidence the "corpuscular" aspects of the process at the passage of the screen *S2* (which, in this case, reduces to the determination of which slit the particle has passed through) inevitably destroys the wave aspects, implies the disappearance of the interference figure and the emergence of two concentrated spots of diffraction which confirm our knowledge of the trajectory followed by the particle.

At this point Einstein brings into play the first screen as well and argues as follows: since the incident particles have velocities (practically) perpendicular to the screen *S1*, and since it is only the interaction with this screen that can cause a deflection from the original direction of propagation, by the law of conservation of impulse which implies that the sum of the impulses of two systems which interact is conserved, if the incident particle is deviated toward the top, the screen will recoil toward the bottom and vice-versa. In realistic conditions the mass of the screen is so heavy that it will remain stationary, but, in principle, it is possible to measure even an infinitesimal recoil. If we imagine taking the measurement of the impulse of the screen in the direction *X* after every single particle has passed, we can know, from the fact that the screen will be found recoiled toward the top (bottom), if the particle in question has been deviated toward the bottom (top) and therefore we can know from which slit in *S2* the particle has passed. But since the determination of the direction of the recoil of the screen after the particle has passed cannot influence the successive development of the process, we will still have an interference figure on the screen *F*. The interference takes place precisely because the state of the system is *the superposition* of two states whose wave functions are non-zero only near one of the two slits. On the other hand, if every particle passes through only the slit *b* or the slit *c*, then the set of systems is the statistical mixture of the two states, which means that interference is not possible. If Einstein is correct, then there is a violation of the principle of indeterminacy.

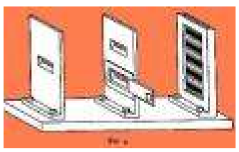


Figure B. Bohr's representation of Einstein's thought experiment described above. The mobile window is evidenced in order to underscore the fact that the attempt to know which slit a particle passes through destroys the interference pattern.

Bohr's response was to illustrate Einstein's idea more clearly via the diagrams in Figures B and C. Bohr observes that extremely precise knowledge of any (potential) vertical motion of the screen is an essential presupposition in Einstein's argument. In fact, if its velocity in the direction X *before* the passage of the particle is not known with a precision substantially greater than that induced by the recoil (that is, if it were already moving vertically with an unknown and greater velocity than that which it derives as a consequence of the contact with the particle), then the determination of its motion after the passage of the particle would not give the information we seek. However, Bohr continues, an extremely precise determination of the velocity of the screen, when one applies the principle of indeterminacy, implies an inevitable imprecision of its position in the direction *X*. Before the process even begins, the screen would therefore occupy an indeterminate position at least to a certain extent (defined by the formalism). Now consider, for example, the point *d* in figure A, where there is destructive interference. It's obvious that any displacement of the first screen would make the lengths of the two paths, *a-b-d* and *a-c-d*, different from those indicated in the figure. If the difference between the two paths varies by half a wavelength, at point *d* there will be constructive rather than destructive interference. The ideal experiment must average over all the possible positions of the screen S1, and, for every position, there corresponds, for a certain fixed point *F*, a different type of interference, from the perfectly destructive to the perfectly constructive. The effect of this averaging is that the pattern of interference on the screen *F* will be uniformly grey. Once more, our attempt to evidence the corpuscular aspects in *S2* has destroyed the possibility of interference in *F* which depends crucially on the wave aspects.

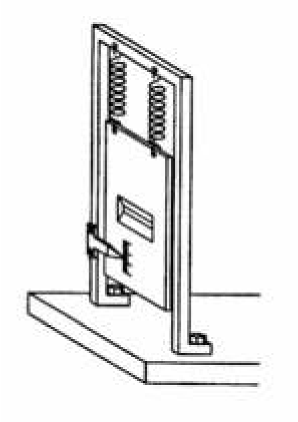


Figure C. In order to realize Einstein's proposal, it is necessary to replace the first screen in Figure 1 (*S1*) with a movable diaphragm which can move vertically such as this proposed by Bohr.

This argument is correct and convincing. Nevertheless it should be noted that, as Bohr recognized, for the understanding of this phenomenon "it is decisive that, contrary to genuine instruments of measurement, these bodies along with the particles would constitute, in the case under examination, the system to which the quantum-mechanical formalism must apply. With respect to the precision of the conditions under which one can correctly apply the formalism, it is essential to include the entire experimental apparatus. In fact, the introduction of any new apparatus, such as a mirror, in the path of a particle could introduce new effects of interference which influence essentially the predictions about the results which will be registered at the end." Further along, Bohr attempts to resolve this ambiguity concerning which parts of the system should be considered macroscopic and which not:

> *In particular, it must be very clear that...the unambiguous use of spatiotemporal concepts in the description of atomic phenomena must be limited to the registration of observations which refer to images on a photographic lens or to analogous practically irreversible effects of amplification such as the formation of a drop of water around an ion in a dark room.*

Bohr's argument about the impossibility of using the apparatus proposed by Einstein to violate the principle of indeterminacy depends crucially on the fact that a macroscopic system (the screen *S1*) obeys quantum laws. On the other hand, Bohr consistently asserted that, in order to illustrate the microscopic aspects of reality it is necessary to set off a process of amplification which involves macroscopic apparatuses, whose fundamental characteristic is that of obeying classical laws and which can be described in classical terms. This ambiguity would later come back in the form of what is still called today the measurement problem.

The principle of indeterminacy applied to time and energy

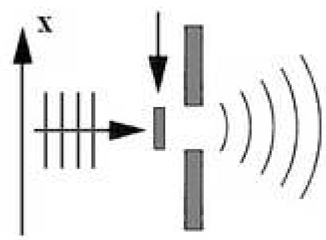


Figure D. A wave extended longitudinally passes through a slit which remains open only for a brief interval of time. Beyond the slit, there is a spatially limited wave in the direction of propagation.

In many textbook examples and popular discussions of quantum mechanics, the principle of indeterminacy is explained by reference to the pair of variables position and velocity (or angular momentum). It is important to note that the wave nature of physical processes implies that there must exist another relation of indeterminacy: that between time and energy. In order to comprehend this relation, it is convenient to refer to the experiment illustrated in Figure D, which results in the preparation of a wave which is limited in spatial extension. Assume that, as illustrated in the figure, a ray which is extremely extended longitudinally is propagated toward a screen with a slit furnished with a shutter which remains open only for a very brief interval of time Δt. Beyond the slit, there will be a wave of limited spatial extension which continues to propagate toward the right.

A perfectly monochromatic wave (such as a note which cannot be divided into harmonics) is infinitely spatially extended. In order to have a wave which is limited in spatial extension (which is technically called a wave packet), several waves of different frequencies must be superimposed and distributed continuously within a certain interval of frequencies around an average value, such as v_0;. It then happens that at a certain instant, there exists a spatial region (which translates with time) in which the contributions of the various fields of the superposition add up constructively. Nonetheless, according to a precise mathematical theorem, as we move far away from this region, the phases of the various fields, in any specified point, are distributed casually and destructive interference is produced. The region in which the wave is non-zero is therefore spatially limited. It is easy to demonstrate that if the wave has a spatial extension equal to Δx (which means, in our example, that the shutter has remained open for a time $\Delta t = \Delta x / v$ where v is the velocity of the wave), then the wave contains (or is a superposition of) various monochromatic waves whose frequencies cover an interval Δv which satisfies the relation:

$$\Delta\nu \geq 1/\Delta t$$

Remembering that in the universal relation of Planck, frequency and energy are proportional:

$$E = h\nu$$

it follows immediately from the preceding inequality that the particle associated with the wave should possess an energy which is not perfectly defined (since different frequencies are involved in the superposition) and consequently there is indeterminacy in energy:

$$\Delta E = h\Delta\nu \geq h/\Delta t$$

From this it follows immediately that:

$$\Delta E \Delta t \geq h$$

which is the relation of indeterminacy between time and energy.

Einstein's second attack

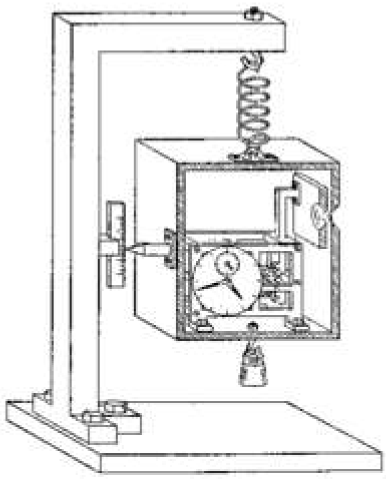


Figure E. Einstein's thought experiment of 1930 as designed by Bohr. It was supposed to prove the violation of the indeterminacy relation between time and energy.

At the sixth Congress of Solvay in 1930, the indeterminacy relation just discussed was Einstein's target of attack. His idea contemplates the existence of an experimental apparatus which was subsequently designed by Bohr in such a way as to emphasize the essential elements and the key points which he would use in his response.

Einstein considers a box (figure E) containing electromagnetic radiation and a clock which controls the opening of a shutter which covers a hole made in one of the walls of the box. The shutter uncovers the hole for a time Δ*t* which can be chosen arbitrarily. During the opening, we are to suppose that a photon, from among those inside the box, escapes through the hole. In this way a wave of limited spatial extension has been created, following the explanation given above. In order to challenge the indeterminacy relation between time and energy, it is necessary to find a way to determine with an adequate precision the energy that the photon has brought with it. At this point, Einstein turns to his celebrated relation between mass and energy of special relativity: $E = mc^2$. From this it follows that knowledge of the mass of an object provides a precise indication about its energy. The argument is therefore very simple: if one weighs the box before and after the opening of the shutter and if a certain amount of energy has escaped from the box, the box will be lighter. The variation in mass multiplied by c^2 will provide precise knowledge of the energy emitted. Moreover, the clock will indicate the precise time at which the event of the particle's emission took place. Since, in principle, the mass of the box can be determined to an arbitrary degree of accuracy, the energy emitted can be determined with a precision Δ*E* as accurate as one desires. Therefore, the product Δ*E*Δ*t* can be rendered less than what is implied by the principle of indeterminacy.

The idea, like all of those advanced by Einstein, is particularly acute and the argument seemed unassailable. It's important to consider the impact of all of these exchanges on the people involved at the time. Leon Rosenfeld, a scientist who had participated in the Congress, described the event several years later:

> *It was a real shock for Bohr...who, at first, could not think of a solution. For the entire evening he was extremely agitated, and he continued passing from one scientist to another, seeking to persuade them that it could not be the case, that it would have been the end of physics if Einstein were right,; but he couldn't come up with any way to resolve the paradox. I will never forget the image of the two antagonists as they left the club: Einstein, with his tall and commanding figure, who walked tranquilly, with a mildly ironic smile, and Bohr who trotted along beside him, full of excitement...The morning after saw the triumph of Bohr.*

The "triumph of Bohr" consisted in his demonstrating, once again, that Einstein's subtle argument was not conclusive, but even more so in the way that he arrived at this conclusion by appealing precisely to one of the great ideas of Einstein: the principle of equivalence between gravitational mass and inertial mass. Bohr showed that, in order for Einstein's experiment to function, the box would have to be suspended on a spring in the middle of a gravitational field. In order to obtain a measurement of weight, a pointer would have to be attached to the box which corresponded with the index on a scale. After the release of a photon, weights could be added to the box to restore it to its original position and this would allow us to determine the weight. But in order to return the box to its original position, the box itself would have to be measured. The inevitable uncertainty of the position of the box translates into an uncertainty in the position of the pointer and of the determination of weight and therefore of energy. On the other hand, since the system is immersed in a gravitational field which varies with the position, according to the principle of equivalence the uncertainty in the position of the clock implies an uncertainty with respect to its measurement of time and therefore of the value of the interval Δ*t*. A precise evaluation of this effect leads to the conclusion that the relation $\Delta E \Delta t \geq h,$, cannot be violated.

Second stage

The second phase of Einstein's "debate" with Bohr and the orthodox interpretation is characterized by an acceptance of the fact that it is, as a practical matter, impossible to simultaneously determine the values of certain incompatible quantities, but the rejection that this implies that these quantities do not actually have precise values. He rejects the probabilistic interpretation of Born and insists that quantum probabilities are epistemic and not ontological in nature. As a consequence, the theory must be incomplete in some way. He recognizes the great value of the theory, but suggests that it "does not tell the whole story," and, while providing an appropriate description at a certain level, it gives no information on the more fundamental underlying level:

> *I have the greatest consideration for the goals which are pursued by the physicists of the latest generation which go under the name of quantum mechanics, and I believe that this theory represents a profound level of truth, but I also believe that the restriction to laws of a statistical nature will turn out to be transitory....Without doubt quantum mechanics has grasped an important fragment of the truth and will be a paragon for all future fundamental theories, for the fact that it must be deducible as a limiting case from such foundations, just as electrostatics is deducible from Maxwell's equations of the electromagnetic field or as thermodynamics is deducible from statistical mechanics.*

These thoughts of Einstein's would set off a line of research into so-called hidden variable theories, such as the Bohm interpretation, in an attempt to complete the edifice of quantum theory. If quantum mechanics can be made *complete* in Einstein's sense, it cannot be done locally; this fact was demonstrated by John Stewart Bell with the formulation of Bell's inequality in 1964.

Third stage

The argument of EPR

In 1935 Einstein, Boris Podolsky and Nathan Rosen developed an argument, published in the magazine *Physics Review* with the title *Is the quantum description of physical reality complete?*, based on an entangled state of two particles. Before coming to this argument, it is necessary to formulate another hypothesis that comes out of Einstein's work in relativity: the idea of locality. *The elements of physical reality which are objectively possessed cannot be influenced instantaneously at a distance.*

The argument of EPR can be summarized as follows:

1) Consider a system of two photons which at time *t* are located, respectively, in the spatially distant regions *A* and *B* and which are also in the entangled state of polarization $|\Psi\rangle$ described above:

$$|\Psi, t\rangle = 1/\sqrt{2}\,|1, V\rangle\,|2, V\rangle + 1/\sqrt{2}\,|1, H\rangle\,|2, H\rangle$$

2) At time *t* the photon in region A is tested for vertical polarization. Suppose that the result of the measurement is that the photon passes through the filter. According to the reduction of the wave packet, the result is that, at time *t+dt*, the system becomes:

$$|\Psi, t + dt\rangle = |1, V\rangle\,|2, V\rangle$$

3) At this point, the observer in A who carried out the first measurement on photon *1*, without doing anything else that could disturb the system or the other photon, can predict with certainty that photon *2* will pass a test of vertical polarization. From assumption (R), it follows that photon *2* possesses an element of physical reality: that of having a vertical polarization.

4) According to the assumption of locality, it cannot have been the action carried out in A which created this element of reality for photon *2*. Therefore, we must conclude that the photon possessed the property of being able to pass the vertical polarization test *before* and *independently* of the measurement of photon *1*.

5) At time *t*, the observer in *A* could have decided to carry out a test of polarization at 45°, obtaining a certain result, for example, that the photon passes the test. In that case, he could have concluded that photon *2* turned out to be polarized at 45°. Alternatively, if the photon did not pass the test, he could have concluded that photon *2* turned out to be polarized at 135°. Combining one of these alternatives with the conclusion reached in 4, it seems that photon *2*, before the measurement took place, possessed both the property of being able to pass with certainty a test of vertical polarization and the property of being able to pass with certainty a test of polarization at either 45° or 135°. These properties are incompatible according to the formalism.

6) Since natural and obvious requirements have forced the conclusion that photon *2* simultaneously possesses incompatible properties, this means that, even if it is not possible to determine these properties simultaneously and with arbitrary precision, they are nevertheless possessed objectively by the system. But quantum mechanics denies this possibility and it is therefore an incomplete theory.

Bohr's response

Bohr's response to this fascinating and elegant argument was published, five months later than the original publication of EPR, in the same magazine *Physical Review* and with the exact same title as the original. The crucial point of Bohr's answer is distilled in a passage which he later had republished in Paul Arthur Schilpp's book *Albert Einstein, scientist-philosopher* in honor of the seventieth birthday of Einstein. Bohr attacks assumption (R) of EPR by stating:

> *the statement of the criterion in question is ambiguous with regard to the expression "without disturbing the system in any way". Naturally, in this case no mechanical disturbance of the system under examination can take place in the crucial stage of the process of measurement. But even in this stage there arises the essential problem of an influence on the precise conditions which define the possible types of prediction which regard the subsequent behaviour of the system...their arguments do not justify their conclusion that the quantum description turns out to be essentially incomplete...This description can be characterized as a rational use of the possibilities of an unambiguous interpretation of the process of measurement compatible with the finite and uncontrollable interaction between the object and the instrument of measurement in the context of quantum theory*.

As John Bell later pointed out, this passage is almost unintelligible. What does Bohr mean, Bell asks, by the specification "mechanical" that is used to refer to the "disturbances" that Bohr maintains should not be taken into consideration? What is meant by the expression "an influence on the precise conditions" if not that different measurements in A provide different information on the system in B? This fact is not only admitted but is an essential part of the argument of EPR. Lastly, what could Bohr have meant by the expression "uncontrollable interaction between the object and the measuring apparatus", considering that the central point of the argument of EPR is the hypothesis that, if one accepts locality, only the part of the system in A can be disturbed by the process of measurement and that, notwithstanding this fact, this process provides precise information on the part of the system in B? Is Bohr already contemplating the possibility of "spooky action at a distance?" If so, why not declare it explicitly? If one abandons the assumption of locality, the argument of EPR obviously collapses immediately.

In any case, very few among the illustrious protagonists of the debate on the foundations of quantum theory were able to grasp the true sense of the profound analysis of Einstein. Pauli dismissed it with a few words and Born completely misinterpreted it. But Einstein's defeat (and it really was a defeat) represents one of the highest points of scientific research in the first half of the twentieth century because it called attention to an element of quantum theory, quantum non-locality, which is absolutely central to our modern understanding of the physical world.

Fourth stage

In his last writing on the topic, Einstein further refined his position, making it completely clear that what really disturbed him about the quantum theory was the problem of the total renunciation of all minimal standards of realism, even at the macroscopic level, that the acceptance of the completeness of the theory implied. Although the majority of experts in the field seem to accept the Copenhagen interpretation, there are a growing number of critics who, like Einstein, believe that it has failed to provide a sensible and acceptable representation of reality (see Interpretation of quantum mechanics).

See also

- Afshar's experiment
- Complementarity
- Copenhagen interpretation
- Double-slit experiment

- EPR paradox
- Quantum eraser
- Schrödinger's cat
- Uncertainty principle
- Wheeler's delayed choice experiment

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Einstein refrigerator

In 1926, Einstein and former student Leó Szilárd co-invented the Einstein refrigerator.[32]. The patent covered a thermodynamic refrigeration cycle providing cooling with no moving parts, at a constant pressure, with only heat as an input.

World War II

When Adolf Hitler came to power in January 1933, Einstein was a guest professor at Princeton University, a position which he took in December 1932, after an invitation from the American educator, Abraham Flexner. In 1933, the Nazis passed "The Law of the Restoration of the Civil Service," which forced all Jewish university professors out of their jobs. Throughout the 1930s, a campaign to label Einstein's work as "Jewish physics"-in contrast with "German" or "Aryan physics"-was led by Nobel laureates Philipp Lenard and Johannes Stark. With the assistance of the SS, the *Deutsche Physik* supporters worked to publish pamphlets and textbooks denigrating Einstein's theories and attempted to politically blacklist German physicists who taught them, notably Werner Heisenberg. Einstein renounced his German citizenship and stayed in the United States, where he was given permanent residency. He accepted a position at the newly founded Institute for Advanced Study in Princeton, New Jersey, where he concentrated on developing a *unified field theory* (see below). Einstein became an American citizen in 1940, though he still retained Swiss citizenship.

In 1939, under the encouragement of Szilárd, Einstein sent a letter to President Franklin Delano Roosevelt urging the study of nuclear fission for military purposes, under fears that the Nazi government would be first to develop nuclear weapons. Roosevelt started a small investigation into the matter which eventually became the massive Manhattan Project. Einstein did not work on the bomb project, and, according to Linus Pauling, he later regretted having signed this letter.[33]

The International Rescue Committee was founded in 1933 at the request of Albert Einstein to assist opponents of Adolf Hitler.

For more information, see the section below on Einstein's Political views.

Unified field theory

Einstein's research efforts after developing the theory of general relativity consisted primarily of a long series of attempts to generalize his theory of gravitation in order to unify and simplify the fundamental laws of physics, particularly gravitation and electromagnetism. In 1950, he described this work, which he referred to as the *Unified Field Theory*, in a *Scientific American* article. Einstein was guided by a belief in a single origin for the entire set of physical laws.

Einstein's two-story house, white frame with front porch in Greek revival style, in Princeton (112 Mercer Street).

Einstein became increasingly isolated in his research on a generalized theory of gravitation and his attempts were ultimately unsuccessful. In particular, his pursuit of a unification of the fundamental forces ignored work in the physics community at large (and vice versa), most notably the discovery of the strong and weak nuclear forces, which were not understood independently until around 1970, fifteen years after Einstein's death. Einstein's goal of unifying the laws of physics under a single model survives in the current drive for the grand unification theory.

Einstein's Geometric Approaches

When the equivalent of Maxwell's equations for electromagnetism is formulated within the framework of Einstein's theory of general relativity, the electromagnetic field energy (being equivalent to mass as one would expect from Einstein's famous equation $E=mc^2$) contributes to the stress tensor and thus to the curvature of space-time, which is the general-relativistic representation of the gravitational field; or putting it another way, certain configurations of curved space-time *incorporate* effects of an electromagnetic field. This suggests that a purely geometric theory ought to treat these two fields as different aspects of the same basic phenomenon. However, ordinary Riemannian geometry is unable to describe the properties of the electromagnetic field as a purely geometric phenomenon.

Einstein tried to form a generalized theory of gravitation that would unify the gravitational and electromagnetic forces (and perhaps others), guided by a belief in a single origin for the entire set of physical laws. These attempts initially concentrated on additional geometric notions such as vierbeins and "distant parallelism", but eventually centered around treating both the metric tensor and the affine connection as fundamental fields. (Because they are not independent, the metric-affine theory was somewhat complicated.) In general relativity, these fields are symmetric (in the matrix sense), but since antisymmetry seemed essential for electromagnetism, the symmetry requirement was relaxed for one or both fields. Einstein's proposed unified-field equations (fundamental laws of physics) were generally derived from a variational principle expressed in terms of the Riemann curvature tensor for the presumed space-time manifold.

In field theories of this kind, particles appear as limited regions in space-time in which the field strength or the energy density are particularly high. Einstein and coworker Leopold Infeld managed to demonstrate that, in Einstein's ultimate theory of the unified field, true singularities of the field did have trajectories resembling point particles. However, singularities are places where the equations break down, and Einstein believed that in an ultimate theory the laws should apply *everywhere*, with particles being soliton-like solutions to the (highly nonlinear) field equations. Further, the large-scale topology of the universe should impose restrictions on the solutions, such as quantization or discrete symmetries.

The degree of abstraction, combined with a relative lack of good mathematical tools for analyzing nonlinear equation systems, make it hard to connect such theories with the physical phenomena that they might describe. For example, it has been suggested that the torsion (antisymmetric part of the affine connection) might be related to isospin rather than electromagnetism; this is related to a discrete (or *"internal"*) symmetry known to Einstein as "displacement field duality".

Einstein became increasingly isolated in his research on a generalized theory of gravitation, and most physicists consider his attempts ultimately unsuccessful. In particular, his pursuit of a unification of the fundamental forces ignored developments in quantum physics (and vice versa), most notably the discovery of the strong nuclear force and weak nuclear force.

Final years

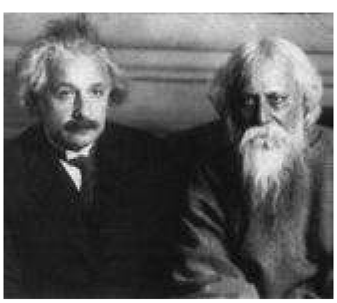
In 1948, Einstein served on the original committee which resulted in the founding of Brandeis University. In 1952, the Israeli government proposed to Einstein that he take the post of second president. He declined the offer, and is believed to be the only United States citizen ever to have been offered a position as a foreign head of state.

He died at 1:15 AM[34] in Princeton hospital[35] in Princeton, New Jersey, on April 18, 1955 at the age of 76 from internal bleeding, which was caused by the rupture of an aortic aneurism, leaving the Generalized Theory of Gravitation unsolved. He was cremated without ceremony on the same day he died at Trenton, New Jersey, in accordance with his wishes. His ashes were scattered at an undisclosed location.

An autopsy was performed on Einstein by Dr. Thomas Stoltz Harvey, who removed and preserved his brain. Harvey found nothing unusual with his brain, but in 1999 further analysis by a team at McMaster University revealed that his parietal operculum region was missing and, to compensate, his inferior parietal lobe was 15% wider than normal.[36] The inferior parietal region is responsible for mathematical thought, visuospatial cognition, and imagery of movement. Einstein's brain also contained 73% more glial cells than the average brain.

Beliefs

Religious views



Rabindranath Tagore sits with Einstein during their widely-publicized July 14, 1930 conversation.

Einstein was an Honorary Associate of the Rationalist Press Association beginning in 1934, and was an admirer of Ethical Culture.[37] He served on the advisory board of the First Humanist Society of New York.[38][39]

Nature Paper

He published a paper in Nature in 1940 entitled *Science and Religion* which gave his considered views on the subject.[40]

In this he says that: "a person who is religiously enlightened appears to me to be one who has, to the best of his ability, liberated himself from the fetters of his selfish desires and is preoccupied with thoughts, feelings and aspirations to which he clings because of their super-personal value ... regardless of whether any attempt is made to unite this content with a Divine Being, for otherwise it would not be possible to count Buddha and Spinoza as religious personalities. Accordingly a religious person is devout in the sense that he has no doubt of the significance of those super-personal objects and goals which neither require nor are capable of rational foundation...In this sense religion is the age-old endeavour of mankind to become clearly and completely conscious of these values and goals, and constantly to strengthen their effects."

He argues that conflicts between science and religion "have all sprung from fatal errors." However "even though the realms of religion and science in themselves are clearly marked off from each other" there are "strong reciprocal relationships and dependencies"... "science without religion is lame, religion without science is blind ...a legitimate conflict between science and religion cannot exist." However he makes it clear that he does not believe in a personal God, and suggests that "neither the rule of human nor Divine Will exists as an independent cause of natural events. To be sure, the doctrine of a personal God interfering with natural events could never be *refuted*...by science, for [it] can always take refuge in those domains in which scientific knowledge has not yet been able to set foot."

Other Quotations on religion and God

> *I came — though the child of entirely irreligious (Jewish) parents — to a deep religiousness, which, however, reached an abrupt end at the age of twelve.*[41]
> *I do not think that it is necessarily the case that science and religion are natural opposites. In fact, I think that there is a very close connection between the two. Further, I think that science without religion is lame and, conversely, that religion without science is blind. Both are important and should work hand-in-hand.*[42]
> *A Jew who sheds his faith along the way, or who even picks up a different one, is still a Jew.*[43]
> *It was, of course, a lie what you read about my religious convictions, a lie which is being systematically repeated. I do not believe in a personal God and I have never denied this but have expressed it clearly. If something is in me which can be called religious then it is the unbounded admiration for the structure of the world so far as our science can reveal it.*[44]

As an adult, he called his religion a "cosmic religious sense".[45]

In *The World As I See It* he wrote:

> *You will hardly find one among the profounder sort of scientific minds without a peculiar religious feeling of his own. But it is different from the religion of the naive man.*

> *For the latter God is a being from whose care one hopes to benefit and whose punishment one fears; a sublimation of a feeling similar to that of a child for its father, a being to whom one stands to some extent in a personal relation, however deeply it may be tinged with awe.*
> *But the scientist is possessed by the sense of universal causation. The future, to him, is every whit as necessary and determined as the past. There is nothing divine about morality, it is a purely human affair. His religious feeling takes the form of a rapturous amazement at the harmony of natural law, which reveals an intelligence of such superiority that, compared with it, all the systematic thinking and acting of human beings is an utterly insignificant reflection.*[46]

In response to the telegrammed question of New York's Rabbi Herbert S. Goldstein in 1929: "Do you believe in God? Stop. Answer paid 50 words." Einstein replied in only 25 (German) words: "I believe in Spinoza's God, Who reveals Himself in the lawful harmony of the world, not in a God Who concerns Himself with the fate and the doings of mankind."

Scientific philosophy

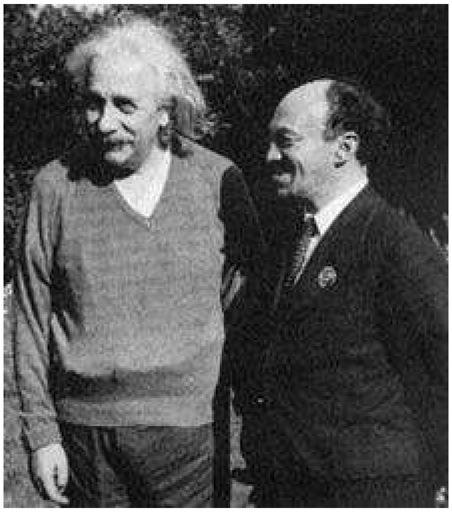
In the "Copenhagen Interpretation" above, reference was made to the disagreement regarding Einstein's actual position regarding the quantum theory. The famous quotation *"God does not play dice"* is often used to support the majority view that he disliked the theory due to its indeterminism.

Others make the case for a different view. They note that the 1926 "Dice" quotation occurred when the quantum theory was just in its first year of discovery and in the subsequent 30 years of his life, one would be hard pressed to find a similar comment from the man. Instead Einstein focused on the conceptually independent subject of 'incompleteness'. This attention is shown both in his 1935 "EPR" paper, and in his 1949 Geiger counter registration strip thought-experiment. Further evidence against the "Einstein-determinist" view is W. Pauli's quotation: "he (Einstein) *disputes* that he uses as a criterion for the admissibility of a theory the question 'Is it rigorously deterministic?'".

The following general assessment was given by his colleague Nathan Rosen:

> *I think that the things which impressed me most were the simplicity of his thinking and his faith in the ability of the human mind to understand the workings of nature. Throughout his life, Einstein believed the human reason was capable of leading to theories that would provide correct descriptions of physical phenomena. In building a theory, his approach had something in common with that of an artist; he would aim for simplicity and beauty (and beauty for him was, after all, essentially simplicity). The crucial question that he would ask, when weighing an element of a theory was: "Is it reasonable?" No matter how successful a theory appeared to be, if it seemed to him not to be reasonable (the German word that he used was* "vernünftig"*), he was convinced that the theory could not provide a really fundamental understanding of nature.*[47]

Political views



Einstein and Solomon Mikhoels, the chairman of the Soviet Jewish Anti-Fascist Committee, in 1943.

Einstein considered himself a pacifist[48] and humanitarian,[49] and in later years, a committed democratic socialist. He once said, *"I believe Gandhi's views were the most enlightened of all the political men of our time. We should strive to do things in his spirit: not to use violence for fighting for our cause, but by non-participation of anything you believe is evil."* Deeply influenced by Gandhi, Einstein once said of Gandhi, "Generations to come will scarce believe that such a one as this ever in flesh and blood walked upon this earth." Einstein's views were sometimes controversial. In a 1949 article entitled "Why Socialism?",[50] Albert Einstein described the "predatory phase of human development", exemplified by a chaotic capitalist society, as a source of evil to be overcome. He disapproved of the totalitarian regimes in the Soviet Union and elsewhere, and argued in favor of a democratic socialist system which would combine a planned economy with a deep respect for human rights. Einstein was a co-founder of the liberal German Democratic Party and a member of the AFL-CIO-affiliated union the American Federation of Teachers.

Einstein was very much involved in the Civil Rights movement. He was a close friend of Paul Robeson for over 20 years. Einstein was a member of several civil rights groups (including the Princeton chapter of the NAACP) many of which were headed by Paul Robeson. He served as co-chair with Paul Robeson of the *American Crusade to End Lynching*. When W.E.B. DuBois was frivolously charged with being a communist spy during the McCarthy era while he was in his 80s, Einstein volunteered as a character witness in the case. The case was dismissed shortly after it was announced that he was to appear in that capacity. Einstein was quoted as saying that "racism is America's greatest disease".

The U.S. FBI kept a 1,427 page file on his activities and recommended that he be barred from immigrating to the United States under the Alien Exclusion Act, alleging that Einstein *"believes in, advises, advocates, or teaches a doctrine which, in a legal sense, as held by the courts in other cases, 'would allow anarchy to stalk in unmolested' and result in 'government in name only'"*, among other charges. They also alleged that Einstein *"was a member, sponsor, or affiliated with thirty-four communist fronts between 1937 and 1954"* and *"also served as honorary chairman for three communist organizations"*.[51] Many of the documents in the file were submitted to the FBI, mainly by civilian political groups, and not written by the FBI.

In 1939, Einstein and Leó Szilárd writing a letter to President Roosevelt.[52]

Einstein opposed tyrannical forms of government, and for this reason (and his Jewish background), opposed the Nazi regime and fled Germany shortly after it came to power. Einstein initially favored construction of the atomic bomb, in order to ensure that Hitler did not do so first, and even sent a letter to President Roosevelt (dated August 2, 1939, before World War II broke out, written in collaboration with Leó Szilárd) encouraging him to initiate a program to create a nuclear weapon. Roosevelt responded to this by setting up a committee for the investigation of using uranium as a weapon, which in a few years was superseded by the Manhattan Project.

After the war, though, Einstein lobbied for nuclear disarmament and a world government: "I do not know how the Third World War will be fought, but World War IV will be fought with sticks and stones."[53]

A 5 Israeli pound note from 1968 with the portrait of Einstein.

While Einstein was a supporter of Zionism in the cultural sense, he often expressed reservations regarding its application in terms of nationalism. During a speech at the Commodore Hotel in New York, he told the crowd "My awareness of the essential nature of Judaism resists the idea of a Jewish state with borders, an army, and a measure of temporal power, no matter how modest. I am afraid of the inner damage Judaism will sustain. - especially from the development of a narrow nationalism within our own ranks, against which we have already had to fight strongly, even without a Jewish state."[54] He also signed an open letter published in the New York Times condemning Menachem Begin and his nationalistic Herut party, especially for the treatment of the indigenous Arabs at Deir Yassin by Herut's predecessor Irgun.

Despite these reservations, he was active in the establishment of the Hebrew University in Jerusalem, which published (1930) a volume titled *About Zionism: Speeches and Lectures by Professor Albert Einstein*, and to which Einstein bequeathed his papers. In later life, in 1952, he was offered the post of second president of the newly created state of Israel, but declined the offer, saying that he lacked the necessary skills. However, Einstein was deeply committed to the welfare of Israel and the Jewish people for the rest of his life.

Albert Einstein was closely associated with plans for what the press called "a Jewish-sponsored non-quota university," from August 19, 1946, with the announcement of the formation of the Albert Einstein Foundation for Higher Learning, Inc. until June 22, 1947, when he withdrew support and barred the use of his name by the foundation. The university opened in 1948 as Brandeis University.

Einstein, along with Albert Schweitzer and Bertrand Russell, fought against nuclear tests and bombs. As his last public act, and just days before his death, he signed the Russell-Einstein Manifesto, which led to the Pugwash Conferences on Science and World Affairs.

Citizenship

Albert Einstein receiving from Judge Phillip Forman his certificate of American citizenship.

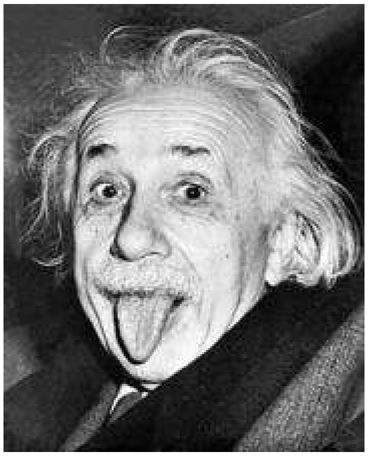
Einstein was born a German citizen. At the age of 17, on January 28, 1896, he was released from his German citizenship by his own request and with the approval of his father. He remained stateless for five years. On February 21, 1901, he gained Swiss citizenship, which he never revoked. Einstein obtained German citizenship in April 1914 when he entered the German civil service, but due to the political situation and the persecution of Jewish people in Nazi Germany, he left civil service in March 1933 and thus also lost the German citizenship. On October 1, 1940, Einstein became an American citizen. He remained both an American and a Swiss citizen until his death on April 18, 1955.[55]

Popularity and cultural impact

According to "A Ranking of the Most Influential Persons in History", Einstein is "the greatest scientist of the twentieth century and one of the supreme intellects of all time".[56] His popularity has also led to widespread use of Einstein's image in advertising and merchandising, including the registration of "Albert Einstein" as a trademark.

Einstein is commonly credited with supporting causes or making claims for which there is no evidence of his having done so, such as the claim that compound interest was the greatest discovery of the 20th Century, which first appeared in a New York Times article some 28 years after his death.

Entertainment



Albert Einstein sticks his tongue out for UPI photographer Arthur Sasse

Albert Einstein has been the subject of and inspiration for a number of novels, films and plays, including Jean-Claude Carrier's 2005 French novel, *Einstein S'il Vous Plait* (Please Mr Einstein), Nicolas Roeg's film *Insignificance*, Fred Schepisi's film *I.Q.* (where he was portrayed by Walter Matthau), Alan Lightman's collection of short stories *Einstein's Dreams*, and Steve Martin's comedic play *Picasso at the Lapin Agile*. He was the subject of Philip Glass's groundbreaking 1976 opera *Einstein on the Beach*. His humorous side is also the subject of Ed Metzger's one-man play *Albert Einstein: The Practical Bohemian*.

He is often used as a model for depictions of mad scientists and absent-minded professors in works of fiction; his own character and distinctive hairstyle suggest eccentricity, or even lunacy, and are widely copied or exaggerated. TIME magazine writer Frederic Golden referred to Einstein as "a cartoonist's dream come true."[57]

On Einstein's 72nd birthday in 1951, the UPI photographer Arthur Sasse was trying to persuade him to smile for the camera. Having done this for the photographer many times that day, Einstein stuck out his tongue instead.[58] The image has become a pop icon for its contrast of the genius scientist displaying a moment of levity. Yahoo Serious, an Australian film maker, used the photo as an inspiration for the intentionally anachronistic movie *Young Einstein*. The image is also used in a poster used in the UK as part of dyslexia education, which has a string of posters showing great scientists, thinkers and artists and talks about the unfounded (not specified within the posters) claims that they had/have dyslexia.

Speculation and controversy

A remarkable aspect of Einstein's childhood is the fact that he spoke much later than the average child. Einstein claimed that he did not begin speaking until the age of three and only did so hesitantly, even beyond the age of nine. Because of Einstein's late speech development and his later childhood tendency to ignore any subject in school that bored him - focusing intensely on things he was interested in - some observers at the time suggested that he might be "retarded", such as one of the Einstein family's housekeepers. This latter observation was not the only time in his life that controversial labels and pathology would be applied to Einstein.

There is speculation that Einstein was a poor student, a slow learner, or had a form of autism, dyslexia, and/or ADHD. According to the biography by Pais (page 36, among others), such speculations are unfounded. Some researchers have periodically claimed otherwise,[59] but most historians and doctors are skeptical of retrospective medical diagnoses, especially for complex and, in the case of ADHD, diagnostically-controversial conditions.

Einstein's matura, obtained in 1896. 6 is the best possible mark.

The recurring rumor that Einstein failed in mathematics during his education is untrue. On the contrary, Einstein always showed great talent at mathematics; when he obtained his matura, he got the best mark (6/6) in algebra, geometry, physics and history, among all of the classes that he took.[60] The grading system of Switzerland, where *6* is the best mark, may have been confused with the German system, in which *1* is the best mark. As can be seen from his Matura grades, indicated in the graphic to the right (also found in "Einstein: A Hundred Years of Relativity" by W. Andrew Robinson, p.27), Albert Einstein failed French (3/6) and received poor grades (4/6) in drawing, (both artistic- and technical) and geography. His performance (5/6) in all other subjects studied in high school, namely Natural history, German literature and Italian literature as well as chemistry, was significantly above average. Furthermore, Robinson states on pages 33 through to 35 that Einstein's interests mainly spanned in science and mathematics and that he disliked "games and physical training". Einstein also had problems with the heavy emphasis on the humanities; that is on classical studies and to a "lesser extent German history and literature, to the detriment of modern foreign languages." Robinson states that this explains Einstein's lack of competence in French literature and English studies, for instance. In 1920 Einstein told a Berlin interviewer that the school of matriculation exam should be abolished. "Let us return to Nature, which upholds the principle of getting the maximum amount of effect from the minimum effort, whereas the matriculation test does exactly the opposite."

As for Einstein's childhood trait of delayed speech development, a few have speculated that Einstein had elective mutism and may have refused to speak until he could do so in complete sentences. Though this concept fits with a profile of a sensitive perfectionist (when Einstein did begin to speak, he would often softly "rehearse" what he meant to say before uttering the statement outright), it is somewhat dated insofar as selective mutism- as it is now known- is no longer considered to be a matter of willful silence: it presently refers to individuals with verbal ability who cannot speak in certain social circumstances.[61] This would not apply to Einstein, who could not speak at all until the time that he did.

According to neuroscientist Steven Pinker, the autopsy of Einstein's brain exhibited a more likely possibility that Einstein, as a child, had been displaying a lesser known type of language delay relating to extraordinary and rapid prenatal development of areas of the brain responsible for spatial and analytical reasoning which, in competing for "brain real estate", had temporarily robbed resources from functions of the brain responsible for speech development.[62][63] Pinker

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and others have extended this speculation to explain the asynchronous development of other famously gifted late-talkers, such as mathematician Julia Robinson, pianists Arthur Rubinstein and Clara Schumann, and physicists Richard Feynman and Edward Teller, who were also said to have shared several of Einstein's other childhood peculiarities, such as monumental tantrums, rugged individualism and highly selective interests. A syndrome — the "Einstein syndrome" — was even coined by journalist and economist Thomas Sowell as a non-pathologizing means to describe this series of traits seen in a small percentage (though how small is debatable) of late-talking children who go on to develop into analytically advanced and socially conscious adults without (or in spite of) intense therapeutic intervention.[64]

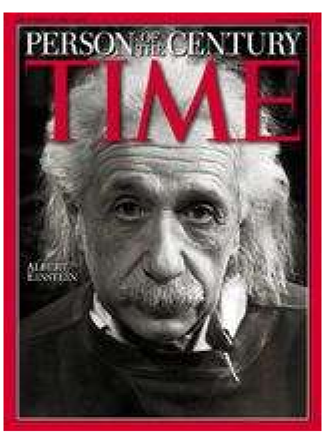
Personal relations

Letters written by Einstein to his relatives and kept at the Hebrew University of Jerusalem, have revealed that during the course of his life, he had a dozen lovers, two of whom he married.[65] Barbara Wolff of the Hebrew University's Albert Einstein Archives has made public about 3,500 pages of correspondence including letters to his first and second wives and children between the years 1912–1955. In letters to his second wife Elsa and her daughter Margot he claimed that he had been showered with unwanted attention from women. One of his lovers, a Berlin socialite Ethel Michanowski, "followed me [to England], and her chasing me is getting out of control." His son Eduard's schizophrenia troubled Einstein greatly, and he often expressed the idea that it would have been better if Eduard had not been born. He adored his stepdaughter and in a letter to Elsa in 1924, he writes: "I love her [Margot] as much as if she were my own daughter, perhaps even more so, since who knows what kind of brat she would have become [had I fathered her]." The letters have been claimed as evidence to dispel myths that Einstein was cold toward his family.

Licensing

Einstein bequeathed his estate, as well as the use of his image (see personality rights), to the Hebrew University of Jerusalem.[66] Einstein actively supported the university during his life and this support continues with the royalties received from licensing activities. The Roger Richman Agency licences the commercial use of the name "Albert Einstein" and associated imagery and likenesses of Einstein, as agent for the Hebrew University of Jerusalem. As head licensee the agency can control commercial usage of Einstein's name which does not comply with certain standards (e.g., when Einstein's name is used as a trademark, the ™ symbol must be used).[67] As of May, 2005, the Roger Richman Agency was acquired by Corbis.

Honors



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Einstein on the cover of *TIME* as Person of the Century.

Einstein has received a number of posthumous honors. For example:

- In 1999, he was named *Person of the Century* by TIME magazine.
- Also in 1999, Gallup Poll recorded him as the fourth most admired person of the 20th century.
- The year 2005 was designated as the "World Year of Physics" by UNESCO for its coinciding with the centennial of the "Annus Mirabilis" papers.
- The National Academy of Sciences commissioned the "Albert Einstein Memorial", a monumental bronze sculpture by Robert Berks, at its Washington, D.C. campus, adjacent to the National Mall.

Among Einstein's many namesakes are:

- a unit used in photochemistry, the *einstein*.
- the chemical element 99, einsteinium.
- the asteroid 2001 Einstein.
- the Albert Einstein Award.
- the Albert Einstein Peace Prize.
- the Albert Einstein College of Medicine of Yeshiva University[68] opened in 1955.
- the Albert Einstein Medical Center[69] in Philadelphia, Pennsylvania.

Works by Einstein

Einstein published over fifty scientific papers during his lifetime. He also published several non-scientific works, including *About Zionism* (1930), *Why War?* (1933, co-authored by Sigmund Freud), *The World As I See It* (1934), and *Out of My Later Years* (1950).

The following is a chronological bibliography of Albert Einstein's publications.

- "Folgerungen aus den Capillaritätserscheinungen" ("Consequences of the phenomena of capillarity") Annalen der Physik. 1901.
- "Über die thermodynamische Theorie der Potentialdifferenz zwischen Metallen und vollständig dissociirten Lösungen ihrer Salze und über eine electrische Methode zur Erforschung der Molecularkräfte" ("On the thermodynamic Theory of the potential Difference between Metals and fully dissociated Solutions of their salts, and on an electric Method for Probing molecular Forces") Annalen der Physik. 1902.
- "Kinetische Theorie des Wärmegleichgewichtes und des zweiten Hauptsatzes der Thermodynamik" ("Kinetic Theory of the Equilibrium of Heat and the second Law of Thermodynamics") Annalen der Physik. 1902.
- "Eine Theorie der Grundlagen der Thermodynamik" ("A Theory over the Foundations of Thermodynamics") Annalen der Physik. 1903.
- "Zur allgemeinen molekularen Theorie der Wärme" ("On the general molecular Theory of Heat") Annalen der Physik. 1904.
- "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt" ("On a Heuristic Viewpoint Concerning the Production and Transformation of Light") Annalen der Physik. 1905.
- "Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen" ("On the Motion—Required by the Molecular Kinetic Theory of Heat—of Small Particles Suspended in a Stationary Liquid") Annalen der Physik. 1905.

- "Zur Elektrodynamik bewegter Körper" ("On the Electrodynamics of Moving Bodies") Annalen der Physik. 1905.
- "Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?" ("Does the Inertia of a Body Depend Upon Its Energy Content?") Annalen der Physik. 1905.
- "Eine neue Bestimmung der Moleküldimensionen" ("A new determination of molecular dimensions") Annalen der Physik. 1906.
- "Zur Theorie der Brownschen Bewegung" ("On the Theory of Brownian Motion") Annalen der Physik. 1906.
- "Zur Theorie der Lichterzeugung und Lichtabsorption" ("On the Theory of generation and absorption of light") Annalen der Physik. 1906.
- "Das Prinzip von der Erhaltung der Schwerpunktsbewegung und die Trägheit der Energie" ("The principle of conservation of the centre of mass motion and the inertia of energy") Annalen der Physik. 1906.
- "Über eine Methode zur Bestimmung des Verhältnisses der transversalen und longitudinalen Masse des Elektrons" ("On a method to determine the ratio of the transversal and longitudinal mass of the electron") Annalen der Physik. 1906.
- "Die Plancksche Theorie der Strahlung und die Theorie der spezifischen Wärme" ("Planck's Theory of Radiation and the Theory of specific Heat") Annalen der Physik. 1907.
- "Über die Gültigkeitsgrenze des Satzes vom thermodynamischen Gleichgewicht und über die Möglichkeit einer neuen Bestimmung der Elementarquanta" ("On the limit of applicability of the law of thermodynamic equilibrium and on a new possibility of determining the elementary quanta") Annalen der Physik. 1907.
- "Berichtigung zu meiner Arbeit: Die Plancksche Theorie der Strahlung etc." ("Correction to my work: Planck's Theory of Radiation etc") Annalen der Physik. 1907.
- "Über die Möglichkeit einer neuen Prüfung des Relativitätsprinzips" ("On the possibility of a reexamination of the principle of relativity") Annalen der Physik. 1907.
- "Bemerkungen zu der Notiz von Hrn. Paul Ehrenfest: Die Translation deformierbarer Elektronen und der Flächensatz" ("Reply to the note by Mr Paul Ehrenfest: The translation of deformable electrons and the area law") Annalen der Physik. 1907.
- "Über die vom Relativitätsprinzip geforderte Trägheit der Energie" ("On the Inertia of Energy as required by the Principle of Relativity") Annalen der Physik. 1907.
- "Über die elektromagnetischen Grundgleichungen für bewegte Körper" Annalen der Physik. 1908 (with J. Laub).
- "Über die im elektromagnetischen Felde auf ruhende Körper ausgeübten ponderomotorischen Kräfte" Annalen der Physik. 1908 (with J. Laub).
- "Berichtigung zur Abhandlung: Über die elektromagnetischen Grundgleichungen für bewegte Körper" Annalen der Physik. 1908 (with J. Laub).
- "Bemerkungen zu unserer Arbeit: Über die elektromagnetischen Grundgleichungen für bewegte Körper" Annalen der Physik. 1909 (with J. Laub).
- "Bemerkung zu der Arbeit von D. Mirimanoff: 'Über die Grundgleichungen ...'" Annalen der Physik. 1909.
- "Über einen Satz der Wahrscheinlichkeitsrechnung und seine Anwendung in der Strahlungstheorie" Annalen der Physik. 1910 (with L. Hopf).
- "Statistische Untersuchung der Bewegung eines Resonators in einem Strahlungsfeld" Annalen der Physik. 1910 (with L. Hopf).
- "Theorie der Opaleszenz von homogenen Flüssigkeiten und Flüssigkeitsgemischen in der Nähe des kritischen Zustandes" Annalen der Physik. 1910.
- "Bemerkungen zu dem Gesetz von Eötvös" Annalen der Physik. 1911.
- "Eine Beziehung zwischen dem elastischen Verhalten und der spezifischen Wärme bei festen Körpern mit einatomigem Molekül" Annalen der Physik. 1911.
- "Bemerkungen zu den P. Hertzschen Arbeiten: 'Über die mechanischen Grundlagen der Thermodynamik'" Annalen der Physik. 1911.

- "Bemerkung zu meiner Arbeit: 'Eine Beziehung zwischen dem elastischen Verhalten ...'" Annalen der Physik. 1911.
- "Berichtigung zu meiner Arbeit: 'Eine neue Bestimmung der Moleküldimensionen'" Annalen der Physik. 1911.
- "Elementare Betrachtungen über die thermische Molekularbewegung in festen Körpern" Annalen der Physik. 1911.
- "Über den Einfluß der Schwerkraft auf die Ausbreitung des Lichtes" ("On the Influence of Gravity on the Propagation of Light") Annalen der Physik. 1911.
- "Thermodynamische Begründung des photochemischen Äquivalentgesetzes" Annalen der Physik. 1912.
- "Lichtgeschwindigkeit und Statik des Gravitationsfeldes" Annalen der Physik. 1912.
- "Zur Theorie des statischen Gravitationsfeldes" ("On the Theory of the static gravitational Field") Annalen der Physik. 1912.
- "Nachtrag zu meiner Arbeit: 'Thermodynamische Begründung des photochemischen Äquivalentgesetzes'" Annalen der Physik. 1912.
- "Antwort auf eine Bemerkung von J. Stark: 'Über eine Anwendung des Planckschen Elementargesetzes ...'" Annalen der Physik. 1912.
- "Relativität und Gravitation. Erwiderung auf eine Bemerkung von M. Abraham" ("Relativity and Gravitation. Reply to a Comment by M. Abraham") Annalen der Physik. 1912.
- "Bemerkung zu Abrahams vorangehender Auseinandersetzung 'Nochmals Relativität und Gravitation'" Annalen der Physik. 1912.
- "Einige Argumente für die Annahme einer molekularen Agitation beim absoluten Nullpunkt" Annalen der Physik. 1913 (with O. Stern).
- "Die Nordströmsche Gravitationstheorie vom Standpunkt des absoluten Differentialkalküls" Annalen der Physik. 1914 (with A. D. Fokker).
- "Antwort auf eine Abhandlung M. v. Laues 'Ein Satz der Wahrscheinlichkeitsrechnung und seine Anwendung auf die Strahlungstheorie'" Annalen der Physik. 1915.
- "Die Grundlage der allgemeinen Relativitätstheorie" Annalen der Physik. 1916.
- "Über Friedrich Kottlers Abhandlung 'Über Einsteins Äquivalenzhypothese und die Gravitation'" Annalen der Physik. 1916.
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See also

- Theory of Everything
- History of special relativity
- History of general relativity
- Relativity priority dispute
- List of things named after Einstein
- Photoelectric effect
- EPR paradox
- Lambdavacuum solution
- Sticky bead argument
- Annus Mirabilis Papers

Notes

1. ^ "Einstein the greatest", *BBC*, November 29, 1999.
2. ^ Einstein tops physicist pop chart. Institute Of Physics. Retrieved on 2006-09-28.
3. ^ [a] [b] Dudley Herschbach, "Einstein as a Student," Department of Chemistry and Chemical Biology, Harvard University, Cambridge, MA, USA, page 3, web: HarvardChem-Einstein-PDF: about Max Talmud visited on Thursdays for 6 years.
4. ^ Highfield.
5. ^ Ibid.
6. ^ Einstein's wife. Retrieved on 8 October, 2006.
7. ^ *Annalen der Physik*" volume 4, page 513
8. ^ Officially named "Federal Office for Intellectual Property" at the time, and now the Swiss Federal Institute of Intellectual Property. Retrieved on 16 October, 2006. See also their FAQ about Einstein and the Institute. Retrieved on 16 October, 2006.
9. ^ Peter Galison, "Einstein's Clocks: The Question of Time" *Critical Inquiry* 26, no. 2 (Winter 2000): 355–389, on 368.
10. ^ Arguing about Einstein's wife (April 2004) - Physics World - PhysicsWeb (See above). Retrieved on 21 November, 2005.
11. ^ Peter Galison, "Einstein's Clocks: The Question of Time" *Critical Inquiry* 26, no. 2 (Winter 2000): 355–389, on 370.
12. ^ Smoluchowski worked on Brownian motion at the same time as Einstein. He published in 1906 the same formula as Einstein (arrived at by a different method), except for a mistaken factor Paul Langevin's 1908 paper ''On the Theory of Brownian Motion''. Retrieved on 17 March, 2006. for details.
13. ^ See, for example, Helge Kragh, "Einstein's Relativity, and Others'" in *Quantum Generations: A History of Physics in the Twentieth Century* (Princeton, NJ: Princeton University Press, 1999): 87-104. On Einstein's lack of total isolation, and differences between his an Poincaré's relativity theories, see Peter Galison, *Einstein's clocks, Poincarés maps: empires of time* (New York: W.W. Norton, 2003).
14. ^ PBS - NOVA - Einstein's Big Idea - "Genius Among Geniuses", by Thomas Levenson
15. ^ Crelinsten, Jeffrey, "Einstein's Jury: The Race to Test Relativity", Princeton University Press, 2006
16. ^ History of Physics: Einstein and the Cosmological Constant
17. ^ David Hilbert actually published the field equation in an article that was dated five days before Einstein's lecture. But according to Thorne (pp. 117–118), Hilbert had discovered the correct derivation after "mulling over things he had learned" on a recent visit by

Einstein to Gottingen. Thorne goes on to say "Quite naturally, and in accord with Hilbert's view of things, the resulting law of warpage was quickly given the name the *Einstein field equation* rather than being named after Hilbert. In fact without Einstein, the general relativistic laws of gravity might not have been discovered until several decades later." See Relativity priority disputes for more details.

18. ^ Crelinsten, *Einstein's Jury*, pp. 94–98.
19. ^ Crelinsten, pp. 103–108.
20. ^ Crelinsten, pp. 114–119, 126–140.
21. ^ It is ironic that later examinations of the photographs taken on that expedition showed their measurement error to be comparable to the effect they were trying to measure. The light deflection has, however, been accurately confirmed by a number of later observations.
22. ^ ALBERT EINSTEIN (1879 - 1955) and the "Greatest Scientific Discovery Ever" by J. Schmidhuber:. Retrieved on 4 October, 2006.
23. ^ See esp. Albert Einstein, "My Reply. On the Anti-Relativity Theoretical Co., Ltd. [August 27, 1920," in Klaus Hentschel, ed. *Physics and National Socialism: An anthology of primary sources* (Basel: Birkhaeuser, 1996), pp.1-5.
24. ^ There is a good discussion of resentment towards Einstein's fame, especially among those German physicists who would later start the *Deutsche Physik* anti-Einsteinian movement, in the Introduction to Klaus Hentschel, ed. *Physics and National Socialism: An anthology of primary sources* (Basel: Birkhaeuser, 1996), on p.lxxi. For a discussion of astronomers' attitudes and debates about relativity, see Jeffrey Crelinsten, Einstein's Jury: The Race to Test Relativity (Princeton University Press, 2006), esp. chapters 6, 9, 10 and 11.
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