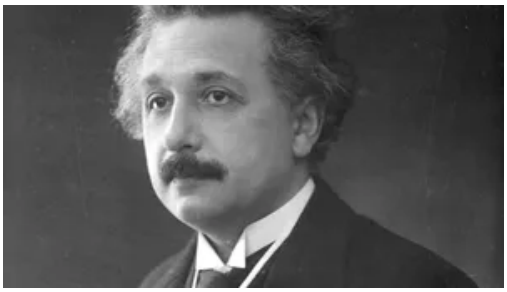
Albert Einstein



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Einstein, (born March 14, 1879, Ulm, Württemberg, Germany—died April 18, 1955, Princeton, New Jersey, U.S.), German-born physicist who developed the special and general theories of relativity and won the Nobel Prize for Physics in 1921 for his explanation of the photoelectric effect. Einstein is generally considered the most influential physicist of the 20th century.

(Read Einstein's 1926 Britannica essay on space-time.)

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Childhood and education

Einstein's parents were secular, middle-class Jews. His father, Hermann Einstein, was originally a featherbed salesman and later ran an electrochemical factory with moderate success. His mother, the former Pauline Koch, ran the family household. He had one sister, Maria (who went by the name Maja), born two years after Albert.

Einstein would write that two "wonders" deeply affected his early years. The first was his encounter with a compass at age five. He was mystified that invisible forces could deflect the needle. This would lead to a lifelong fascination with invisible forces. The second wonder came at age 12 when he discovered a book of geometry, which he devoured, calling it his "sacred little geometry book."

Einstein became deeply religious at age 12, even composing several songs in praise of God and chanting religious songs on the way to school. This began to change, however, after he read science books that contradicted his religious beliefs. This challenge to established authority left a deep and lasting impression. At the Luitpold Gymnasium, Einstein often felt

out of place and victimized by a Prussian-style educational system that seemed to stifle originality and creativity. One teacher even told him that he would never amount to anything.

Yet another important influence on Einstein was a young medical student, Max Talmud (later Max Talmey), who often had dinner at the Einstein home. Talmud became an informal tutor, introducing Einstein to higher mathematics and philosophy. A pivotal turning point occurred when Einstein was 16 years old. Talmud had earlier introduced him to a children's science series by Aaron Bernstein, *Naturwissenschaftliche Volksbucher* (1867–68; *Popular Books on Physical Science*), in which the author imagined riding alongside electricity that was traveling inside a telegraph wire. Einstein then asked himself the question that would dominate his thinking for the next 10 years: What would a light beam look like if you could run alongside it? If light were a wave, then the light beam should appear stationary, like a frozen wave. Even as a child, though, he knew that stationary light waves had never been seen, so there was a paradox. Einstein also wrote his first "scientific paper" at that time ("The Investigation of the State of Aether in Magnetic Fields").

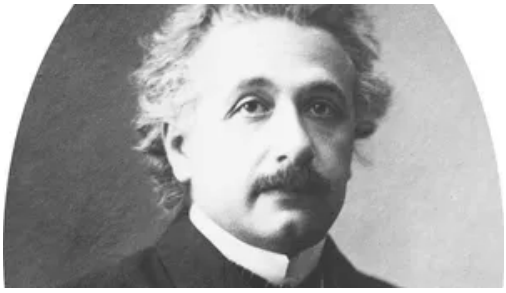
Einstein's education was disrupted by his father's repeated failures at business. In 1894, after his company failed to get an important contract to electrify the city of Munich, Hermann Einstein moved to Milan to work with a relative. Einstein was left at a boardinghouse in Munich and expected to finish his education. Alone, miserable, and repelled by the looming prospect of military duty when he turned 16, Einstein ran away six months later and landed on the doorstep of his surprised parents. His parents realized the enormous problems that he faced as a school dropout and draft dodger with no employable skills. His prospects did not look promising.

Fortunately, Einstein could apply directly to the Eidgenössische Polytechnische Schule ("Swiss Federal Polytechnic School"; in 1911, following expansion in 1909 to full university status, it was renamed the Eidgenössische Technische Hochschule, or "Swiss Federal Institute of Technology") in Zürich without the equivalent of a high school diploma if he passed its stiff entrance examinations. His marks showed that he excelled in mathematics and physics, but he failed at French, chemistry, and biology. Because of his exceptional math scores, he was allowed into the polytechnic on the condition that he first finish his formal schooling. He went to a special high school run by Jost Winteler in Aarau, Switzerland, and graduated in 1896. He also renounced his German citizenship at that time. (He was stateless until 1901, when he was granted Swiss citizenship.) He became lifelong

friends with the Winteler family, with whom he had been boarding. (Winteler's daughter, Marie, was Einstein's first love; Einstein's sister, Maja, would eventually marry Winteler's son Paul; and his close friend Michele Besso would marry their eldest daughter, Anna.)

Einstein would recall that his years in Zürich were some of the happiest years of his life. He met many students who would become loyal friends, such as Marcel Grossmann, a mathematician, and Besso, with whom he enjoyed lengthy conversations about space and time. He also met his future wife, Mileva Maric, a fellow physics student from Serbia.

From graduation to the "miracle year" of scientific theories



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After graduation in 1900, Einstein faced one of the greatest crises in his life. Because he studied advanced subjects on his own, he often cut classes; this earned him the animosity of some professors, especially Heinrich Weber. Unfortunately, Einstein asked Weber for a letter of recommendation. Einstein was subsequently turned down for every academic position that he applied to. He later wrote,

> I would have found [a job] long ago if Weber had not played a dishonest game with me.

Meanwhile, Einstein's relationship with Maric deepened, but his parents vehemently opposed the relationship. His mother especially objected to her Serbian background (Maric's family was Eastern Orthodox Christian). Einstein defied his parents, however, and in January 1902 he and Maric even had a child, Lieserl, whose fate is unknown. (It is commonly thought that she died of scarlet fever or was given up for adoption.)

In 1902 Einstein reached perhaps the lowest point in his life. He could not marry Maric and support a family without a job, and his father's business went bankrupt. Desperate and unemployed, Einstein took lowly jobs tutoring children, but he was fired from even these jobs.

The turning point came later that year, when the father of his lifelong friend Marcel Grossmann was able to recommend him for a position as a clerk in the Swiss patent office in Bern. About then, Einstein's father became seriously ill and, just before he died, gave his blessing for his son to marry Maric. For years, Einstein would experience enormous sadness remembering that his father had died thinking him a failure.

With a small but steady income for the first time, Einstein felt confident enough to marry Maric, which he did on January 6, 1903. Their children, Hans Albert and Eduard, were born in Bern in 1904 and 1910, respectively. In hindsight, Einstein's job at the patent office was a blessing. He would quickly finish analyzing patent applications, leaving him time to daydream about the vision that had obsessed him since he was 16: What would happen if you raced alongside a light beam? While at the polytechnic school he had studied Maxwell's equations, which describe the nature of light, and discovered a fact unknown to James Clerk Maxwell himself—namely, that the speed of light remains the same no matter how fast one moves. This violates Newton's laws of motion, however, because there is no absolute velocity in Isaac Newton's theory. This insight led Einstein to formulate the principle of relativity: "the speed of light is a constant in any inertial frame (constantly moving frame)."

During 1905, often called Einstein's "miracle year," he published four papers in the *Annalen der Physik*, each of which would alter the course of modern physics:

1. "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt" ("On a Heuristic Viewpoint Concerning the Production and Transformation of Light"), in which Einstein applied the quantum theory to light in order to explain the photoelectric effect. If light occurs in tiny packets (later called photons), then it should knock out electrons in a metal in a precise way.
2. "Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen" ("On the Movement of Small Particles Suspended in Stationary Liquids Required by the Molecular-Kinetic Theory of Heat"), in which Einstein offered the first experimental proof of the existence of atoms. By analyzing the motion of tiny particles suspended in still water, called Brownian motion, he could calculate the size of the jostling atoms and Avogadro's number (*see* Avogadro's law).
3. "Zur Elektrodynamik bewegter Körper" ("On the Electrodynamics of Moving Bodies"), in which Einstein laid out the mathematical theory of special relativity.
4. "Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?" ("Does the Inertia of a Body Depend Upon Its Energy Content?"), submitted almost as an afterthought, which showed that relativity theory led to the equation $E = mc^2$. This provided the first mechanism to explain the energy source of the Sun and other stars.

Einstein also submitted a paper in 1905 for his doctorate.

Other scientists, especially Henri Poincaré and Hendrik Lorentz, had pieces of the theory of special relativity, but Einstein was the first to assemble the whole theory together and to realize that it was a universal law of nature, not a curious figment of motion in the ether, as Poincaré and Lorentz had thought. (In one private letter to Mileva, Einstein referred to "our

theory," which has led some to speculate that she was a cofounder of relativity theory. However, Mileva had abandoned physics after twice failing her graduate exams, and there is no record of her involvement in developing relativity. In fact, in his 1905 paper, Einstein only credits his conversations with Besso in developing relativity.)

In the 19th century there were two pillars of physics: Newton's laws of motion and Maxwell's theory of light. Einstein was alone in realizing that they were in contradiction and that one of them must fall.

General relativity and teaching career

At first Einstein's 1905 papers were ignored by the physics community. This began to change after he received the attention of just one physicist, perhaps the most influential physicist of his generation, Max Planck, the founder of the quantum theory.

Soon, owing to Planck's laudatory comments and to experiments that gradually confirmed his theories, Einstein was invited to lecture at international meetings, such as the Solvay Conferences, and he rose rapidly in the academic world. He was offered a series of positions at increasingly prestigious institutions, including the University of Zürich, the University of Prague, the Swiss Federal Institute of Technology, and finally the University of Berlin, where he served as director of the Kaiser Wilhelm Institute for Physics from 1913 to 1933 (although the opening of the institute was delayed until 1917).

Even as his fame spread, Einstein's marriage was falling apart. He was constantly on the road, speaking at international conferences, and lost in contemplation of relativity. The couple argued frequently about their children and their meager finances. Convinced that his marriage was doomed, Einstein began an affair with a cousin, Elsa Löwenthal, whom he later married. (Elsa was a first cousin on his mother's side and a second cousin on his father's side.) When he finally divorced Mileva in 1919, he agreed to give her the money he might receive if he ever won a Nobel Prize.

One of the deep thoughts that consumed Einstein from 1905 to 1915 was a crucial flaw in his own theory: it made no mention of gravitation or acceleration. His friend Paul Ehrenfest had noticed a curious fact. If a disk is spinning, its rim travels faster than its centre, and hence (by special relativity) metre sticks placed on its circumference should shrink. This meant that Euclidean plane geometry must fail for the disk. For the next 10 years, Einstein would be absorbed with formulating a theory of gravity in terms of the curvature of space-time. To Einstein, Newton's gravitational force was actually a by-product of a deeper reality: the bending of the fabric of space and time.

In November 1915 Einstein finally completed the general theory of relativity, which he considered to be his masterpiece. In the summer of 1915, Einstein had given six two-hour lectures at the University of Göttingen that thoroughly explained an incomplete version of general relativity that lacked a few necessary mathematical details. Much to Einstein's consternation, the mathematician David Hilbert, who had organized the lectures at his university and had been corresponding with Einstein, then completed these details and submitted a paper in November on general relativity just five days before Einstein, as if the theory were his own. Later they patched up their differences and remained friends. Einstein would write to Hilbert,

> I struggled against a resulting sense of bitterness, and I did so with complete success. I once more think of you in unclouded friendship, and would ask you to try to do likewise toward me.

Today physicists refer to the action from which the equations are derived as the Einstein-Hilbert action, but the theory itself is attributed solely to Einstein.

Einstein was convinced that general relativity was correct because of its mathematical beauty and because it accurately predicted the precession of the perihelion of Mercury's orbit around the Sun (*see* Mercury: Mercury in tests of relativity). His theory also predicted a measurable deflection of light around the Sun. As a consequence, he even offered to help fund an expedition to measure the deflection of starlight during an eclipse of the Sun.

World renown and Nobel Prize

Einstein's work was interrupted by World War I. A lifelong pacifist, he was only one of four intellectuals in Germany to sign a manifesto opposing Germany's entry into war. Disgusted, he called nationalism "the measles of mankind." He would write, "At such a time as this, one realizes what a sorry species of animal one belongs to."

In the chaos unleashed after the war, in November 1918, radical students seized control of the University of Berlin and held the rector of the college and several professors hostage. Many feared that calling in the police to release the officials would result in a tragic confrontation. Einstein, because he was respected by both students and faculty, was the logical candidate to mediate this crisis. Together with Max Born, Einstein brokered a compromise that resolved it.

After the war, two expeditions were sent to test Einstein's prediction of deflected starlight near the Sun. One set sail for the island of Principe, off the coast of West Africa, and the other to Sobral in northern Brazil in order to observe the solar eclipse of May 29, 1919. On

November 6 the results were announced in London at a joint meeting of the Royal Society and the Royal Astronomical Society.

Nobel laureate J.J. Thomson, president of the Royal Society, stated:

> This result is not an isolated one, it is a whole continent of scientific ideas.…This is the most important result obtained in connection with the theory of gravitation since Newton's day, and it is fitting that it should be announced at a meeting of the Society so closely connected with him.

The headline of *The Times* of London read, "Revolution in Science—New Theory of the Universe—Newton's Ideas Overthrown—Momentous Pronouncement—Space 'Warped.'" Almost immediately, Einstein became a world-renowned physicist, the successor to Isaac Newton.

Invitations came pouring in for him to speak around the world. In 1921 Einstein began the first of several world tours, visiting the United States, England, Japan, and France. Everywhere he went, the crowds numbered in the thousands. En route from Japan, he received word that he had received the Nobel Prize for Physics, but for the photoelectric effect rather than for his relativity theories. During his acceptance speech, Einstein startled the audience by speaking about relativity instead of the photoelectric effect.

Einstein also launched the new science of cosmology. His equations predicted that the universe is dynamic—expanding or contracting. This contradicted the prevailing view that the universe was static, so he reluctantly introduced a "cosmological term" to stabilize his model of the universe. In 1929 astronomer Edwin Hubble found that the universe was indeed expanding, thereby confirming Einstein's earlier work. In 1930, in a visit to the Mount Wilson Observatory near Los Angeles, Einstein met with Hubble and declared the cosmological constant to be his "greatest blunder." Recent satellite data, however, have shown that the cosmological constant is probably not zero but actually dominates the matter-energy content of the entire universe. Einstein's "blunder" apparently determines the ultimate fate of the universe.

During that same visit to California, Einstein was asked to appear alongside the comic actor Charlie Chaplin during the Hollywood debut of the film *City Lights*. When they were mobbed by thousands, Chaplin remarked, "The people applaud me because everybody understands me, and they applaud you because no one understands you." Einstein asked Chaplin, "What does it all mean?" Chaplin replied, "Nothing."

Einstein also began correspondences with other influential thinkers during this period. He corresponded with Sigmund Freud (both of them had sons with mental problems) on whether war was intrinsic to humanity. He discussed with the Indian mystic Rabindranath Tagore the question of whether consciousness can affect existence. One journalist remarked,

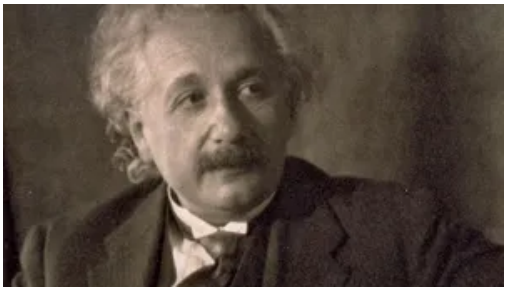
> It was interesting to see them together—Tagore, the poet with the head of a thinker, and Einstein, the thinker with the head of a poet. It seemed to an observer as though two planets were engaged in a chat.

Einstein also clarified his religious views, stating that he believed there was an "old one" who was the ultimate lawgiver. He wrote that he did not believe in a personal God that intervened in human affairs but instead believed in the God of the 17th-century Dutch Jewish philosopher Benedict de Spinoza—the God of harmony and beauty. His task, he believed, was to formulate a master theory that would allow him to "read the mind of God." He would write,

> I'm not an atheist and I don't think I can call myself a pantheist. We are in the position of a little child entering a huge library filled with books in many different languages.…The child dimly suspects a mysterious order in the arrangement of the books but doesn't know what it is. That, it seems to me, is the attitude of even the most intelligent human being toward God.

Nazi backlash and coming to America

Inevitably, Einstein's fame and the great success of his theories created a backlash. The rising Nazi movement found a convenient target in relativity, branding it "Jewish physics" and sponsoring conferences and book burnings to denounce Einstein and his theories. The Nazis enlisted other physicists, including Nobel laureates Philipp Lenard and Johannes Stark, to denounce Einstein. *One Hundred Authors Against Einstein* was published in 1931. When asked to comment on this denunciation of relativity by so many scientists, Einstein replied that to defeat relativity one did not need the word of 100 scientists, just one fact.



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In December 1932 Einstein decided to leave Germany forever (he would never go back). It became obvious to Einstein that his life was in danger. A Nazi organization published a magazine with Einstein's picture and the caption "Not Yet Hanged" on the cover. There was even a price on his head. So great was the threat that Einstein split with his pacifist friends and said that it was justified to defend yourself with arms against Nazi aggression.

To Einstein, pacifism was not an absolute concept but one that had to be re-examined depending on the magnitude of the threat.

Einstein settled at the newly formed Institute for Advanced Study at Princeton, New Jersey, which soon became a mecca for physicists from around the world. Newspaper articles declared that the “pope of physics” had left Germany and that Princeton had become the new Vatican.

Personal sorrow, World War II, and the atomic bomb

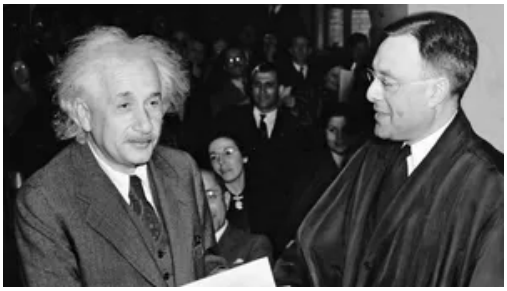
Albert Einstein

The 1930s were hard years for Einstein. His son Eduard was diagnosed with schizophrenia and suffered a mental breakdown in 1930. (Eduard would be institutionalized for the rest of his life.) Einstein’s close friend, physicist Paul Ehrenfest, who helped in the development of general relativity, committed suicide in 1933. And Einstein’s beloved wife, Elsa, died in 1936.

To his horror, during the late 1930s, physicists began seriously to consider whether his equation $E = mc^2$ might make an atomic bomb possible. In 1920 Einstein himself had considered but eventually dismissed the possibility. However, he left it open if a method could be found to magnify the power of the atom. Then in 1938–39 Otto Hahn, Fritz Strassmann, Lise Meitner, and Otto Frisch showed that vast amounts of energy could be unleashed by the splitting of the uranium atom. The news electrified the physics community.

In July 1939 physicist Leo Szilard convinced Einstein that he should send a letter to U.S. President Franklin D. Roosevelt urging him to develop an atomic bomb. With Einstein’s guidance, Szilard drafted a letter on August 2 that Einstein signed, and the document was delivered to Roosevelt by one of his economic advisers, Alexander Sachs, on October 11. Roosevelt wrote back on October 19, informing Einstein that he had organized the Uranium Committee to study the issue. (*See* primary source document: Einstein’s letter to President Roosevelt, 1939.)

Einstein was granted permanent residency in the United States in 1935 and became an American citizen in 1940, although he chose to retain his Swiss citizenship. During the war Einstein’s colleagues were asked to journey to the desert town of Los Alamos, New Mexico, to develop the first atomic bomb for the Manhattan Project. Einstein, the man



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whose equation had set the whole effort into motion, was never asked to participate. Voluminous declassified Federal Bureau of Investigation (FBI) files, numbering several thousand, reveal the reason: the U.S. government feared Einstein's lifelong association with peace and socialist organizations. (FBI director J. Edgar Hoover went so far as to recommend that Einstein be kept out of America by the Alien Exclusion Act, but he was overruled by the U.S. State Department.) Instead, during the war Einstein was asked to help the U.S. Navy evaluate designs for future weapons systems. Einstein also helped the war effort by auctioning off priceless personal manuscripts. In particular, a handwritten copy of his 1905 paper on special relativity was sold for $6.5 million. It is now located in the Library of Congress.

Einstein was on vacation when he heard the news that an atomic bomb had been dropped on Japan. Almost immediately he was part of an international effort to try to bring the atomic bomb under control, forming the Emergency Committee of Atomic Scientists.

Albert Einstein with children from the Reception Shelter of United Service for New Americans

The physics community split on the question of whether to build a hydrogen bomb. J. Robert Oppenheimer, the director of the atomic bomb project, was stripped of his security clearance for having suspected leftist associations. Einstein backed Oppenheimer and opposed the development of the hydrogen bomb, instead calling for international controls on the spread of nuclear technology. Einstein also was increasingly drawn to antiwar activities and to advancing the civil rights of African Americans.

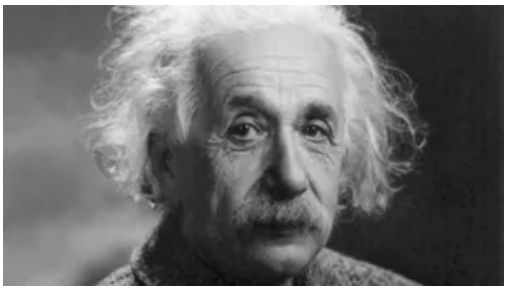
In 1952 David Ben-Gurion, Israel's premier, offered Einstein the post of president of Israel. Einstein, a prominent figure in the Zionist movement, respectfully declined.

Increasing professional isolation and death

Although Einstein continued to pioneer many key developments in the theory of general relativity—such as wormholes, higher dimensions, the possibility of time travel, the existence of black holes, and the creation of the universe—he was increasingly isolated from the rest of the physics community. Because of the huge strides made by quantum

theory in unraveling the secrets of atoms and molecules, the majority of physicists were working on the quantum theory, not relativity. In fact, Einstein would engage in a series of historic private debates with Niels Bohr, originator of the Bohr atomic model. Through a series of sophisticated “thought experiments,” Einstein tried to find logical inconsistencies in the quantum theory, particularly its lack of a deterministic mechanism. Einstein would often say that “God does not play dice with the universe.”

In 1935 Einstein’s most celebrated attack on the quantum theory led to the EPR (Einstein-Podolsky-Rosen) thought experiment. According to quantum theory, under certain circumstances two electrons separated by huge distances would have their properties linked, as if by an umbilical cord. Under these circumstances, if the properties of the first electron were measured, the state of the second electron would be known instantly—faster than the speed of light. This conclusion, Einstein claimed, clearly violated relativity. (Experiments conducted since then have confirmed that the quantum theory, rather than Einstein, was correct about the EPR experiment. In essence, what Einstein had actually shown was that quantum mechanics is nonlocal—i.e., random information can travel faster than light. This does not violate relativity, because the information is random and therefore useless.)



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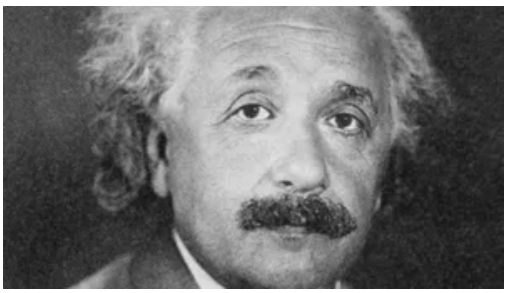
The other reason for Einstein’s increasing detachment from his colleagues was his obsession, beginning in 1925, with discovering a unified field theory—an all-embracing theory that would unify the forces of the universe, and thereby the laws of physics, into one framework. In his later years he stopped opposing the quantum theory and tried to incorporate it, along with light and gravity, into a larger unified field theory. Gradually Einstein became set in his ways. He rarely traveled far, confining himself to long walks around Princeton with close associates, whom he engaged in deep conversations about politics, religion, physics, and his unified field theory. In 1950 he published an article on his theory in *Scientific American*, but because it neglected the still-mysterious strong force, it was necessarily incomplete. When he died five years later of an aortic aneurysm, it was still unfinished.

Legacy

In some sense, Einstein, instead of being a relic, may have been too far ahead of his time. The strong force, a major piece of any unified field theory, was still a total mystery in Einstein’s lifetime. Only in the 1970s and ’80s did physicists begin to unravel the secret of



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the strong force with the quark model. Nevertheless, Einstein's work continues to win Nobel Prizes for succeeding physicists. In 1993 a Nobel Prize was awarded to the discoverers of gravitation waves, predicted by Einstein. In 1995 a Nobel Prize was awarded to the discoverers of Bose-Einstein condensates (a new form of matter that can occur at extremely low temperatures). Known black holes now number in the thousands. New generations of space satellites have continued to verify the cosmology of Einstein. And many leading physicists are trying to finish Einstein's ultimate dream of a "theory of everything."

Michio Kaku

Einstein wrote the space-time entry for the 13th edition of the *Encyclopædia Britannica*. (*See* the Britannica Classic: Space-Time.)

Michio Kaku

Citation Information
Article Title: Albert Einstein
Website Name: Encyclopaedia Britannica
Publisher: Encyclopaedia Britannica, Inc.
Date Published: 17 July 2023
URL: https://www.britannica.comhttps://www.britannica.com/biography/Albert-Einstein
Access Date: September 05, 2023