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Schrodinger

Schrodinger is probably the most important scientist for our Scientific Spiritualism discussed in The Blink of An I and in Saltafide..Schrödinger coined the term *Verschränkung* (entanglement). More importantly Schrodinger discovered the universal connection of consciousness. It is important to note that John A. Ciampa discovered Schrodinger's connected consciousness long after writing about it on his own. At the close of his book, *What Is Life? (discussed below)* Schrodinger reasons that consciousness is only a manifestation of a unitary consciousness pervading the universe. He mentions tat tvam asi, stating "you can throw yourself flat on the ground, stretched out upon Mother Earth, with the certain conviction that you are one with her and she with you".[25]. Schrödinger concludes this chapter and the book with philosophical speculations on determinism, free will, and the mystery of human consciousness. He attempts to "see whether we cannot draw the correct non-contradictory conclusion from the following two premises: (1) My body functions as a pure mechanism according to Laws of Nature; and (2) Yet I know, by incontrovertible direct experience, that I am directing its motions, of which I foresee the effects, that may be fateful and all-important, in which case I feel and take full responsibility for them. The only possible inference from these two facts is, I think, that I – I in the widest meaning of the word, that is to say, every conscious mind that has ever said or felt 'I' – am the person, if any, who controls the 'motion of the atoms' according to the Laws of Nature". Schrödinger then states that this insight is not new and that Upanishads considered this insight of "ATHMAN = BRAHMAN" to "represent quintessence of deepest insights into the happenings of the world. Schrödinger rejects the idea that the source of consciousness should perish with the body because he finds the idea "distasteful". He also rejects the idea that there are multiple immortal souls that can exist without the body because he believes that consciousness is nevertheless highly dependent on the body. Schrödinger writes that, to reconcile the two premises,

The only possible alternative is simply to keep to the immediate experience that consciousness is a singular of which the plural is unknown; that there is only one thing and that what seems to be a plurality is merely a series of different aspects of this one thing…

Any intuitions that consciousness is plural, he says, are illusions. Schrödinger is sympathetic to the Hindu concept of Brahman, by which each individual's consciousness is only a manifestation of a unitary consciousness pervading the universe — which corresponds to the Hindu concept of God. Schrödinger concludes that "...'I' am the person, if any, who controls the 'motion of the atoms' according to the Laws of Nature." However, he also qualifies the conclusion as "necessarily subjective" in its "philosophical implications". In the final paragraph, he points out that what is meant by "I" is not the collection of experienced events but "namely the canvas upon which they are collected." If a hypnotist succeeds in blotting out all earlier reminiscences, he writes, there would be no loss of personal existence — "Nor will there ever be."[8]

This coincidental "consciousness entanglement" between these two minds provides evidence of the seamlessness of consciousness.

What Is Life?, was written in In 1944. It contains a discussion of negentropy and the concept of a complex molecule with the genetic code for living organisms. According to James D. Watson's memoir, *DNA, the Secret of Life*, Schrödinger's book gave Watson the inspiration to research the gene, which led to the discovery of the DNA double helix structure in 1953. Similarly, Francis Crick, in his autobiographical book *What Mad Pursuit*, described how he was influenced by Schrödinger's speculations about how genetic information might be stored in molecules.

Schrödinger was not entirely comfortable with the implications of quantum theory. He wrote about the probability interpretation of quantum mechanics, saying: "I don't like it, and I'm sorry I ever had anything to do with it." (Just in order to ridicule the Copenhagen interpretation of quantum mechanics he contrived the famous thought-experiment called Schrödinger's cat paradox.)[40]

A hypothetical cat that may be simultaneously both alive and dead, as a result of being linked to a random subatomic event that may or may not occur. The idea involves a state of reality he calls quantum superposition. A cat, a flask of poison, and a radioactive source are placed in a sealed box. If an internal monitor detects radioactivity (i.e. a single atom decaying), the flask is shattered, releasing the poison, which kills the cat. The Copenhagen interpretation of quantum mechanics implies that after a while, the cat is *simultaneously* alive *and* dead. Yet, when one looks in the box, one sees the cat *either* alive *or* dead, not both alive *and* dead. This poses the question of when exactly quantum superposition ends and reality collapses into one possibility or the other.The thought experiment is also often featured in theoretical discussions of the interpretations of quantum mechanics, particularly in situations involving the measurement problem.

Early in his life, Schrödinger experimented in the fields of electrical engineering, atmospheric electricity, and atmospheric radioactivity, but he usually worked with his former teacher Franz Exner. He also studied vibrational theory, the theory of Brownian movement, and mathematical statistics. In 1912, at the request of the editors of the *Handbook of Electricity and Magnetism*, Schrödinger wrote an article titled *Dieelectrism*. That same year, Schrödinger gave a theoretical estimate of the probable height distribution of radioactive substances, which is required to explain the observed radioactivity of the atmosphere Schrödinger performed his last physical experiment on coherent light and subsequently focused on theoretical studies.

In the first years of his career Schrödinger became acquainted with the ideas of quantum theory, developed in the works of Max Planck, Albert Einstein, Niels Bohr, Arnold Sommerfeld, and others. The first publications of Schrödinger about atomic theory and the theory of spectra began to emerge only from the beginning of the 1920s, after his personal acquaintance with Sommerfeld and Wolfgang Pauli and his move to Germany. In January 1921, Schrödinger finished his first article on this subject, about the framework of the Bohr-Sommerfeld effect of the interaction of electrons on some features of the spectra of the alkali metals. In autumn 1922 he analyzed the electron orbits in an atom from a geometric point of view, using methods developed by the mathematician Hermann Weyl (1885–1955). This work, in which it was shown that quantum orbits are associated with certain geometric properties, was an important step in predicting some of the features of wave mechanics. Earlier in the same year he created the Schrödinger equation of the relativistic Doppler effect for spectral lines, based on the hypothesis of light quanta and considerations of energy and momentum.

In January of 1926, Schrödinger published in *Annalen der Physik* the paper "*Quantisierung als Eigenwertproblem*" (Quantization as an Eigenvalue Problem)[38] on wave mechanics and presented what is now known as the Schrödinger equation. In this paper, he gave a "derivation" of the wave equation for time-independent systems and showed that it gave the correct energy eigenvalues for a hydrogen-like atom. This paper has been universally celebrated as one of the most important achievements of the twentieth century and created a revolution in most areas of quantum mechanics and indeed of all physics and chemistry. A second paper was submitted just four weeks later that solved the quantum harmonic oscillator, rigid rotor, and diatomic molecule problems and gave a new derivation of the Schrödinger equation. A third paper, published in May, showed the equivalence of his approach to that of Heisenberg and gave the treatment of the Stark effect. A fourth paper in this series showed how to treat problems in which the system changes with time, as in scattering problems. In this paper he introduced a complex solution to the Wave equation in order to prevent the occurrence of fourth and sixth order differential equations. (This was arguably the moment when quantum mechanics switched from real to complex numbers.) When he introduced complex numbers in order to lower the order of the differential equations, something magical happened, and all of wave mechanics was at his feet. (He eventually reduced the order to one.)[39] These papers were his central achievement and were at once recognized as having great significance by the physics community.

Following his work on quantum mechanics, Schrödinger devoted considerable effort to working on a unified field theory that would unite gravity, electromagnetism, and nuclear forces within the basic framework of General Relativity, doing the work with an extended correspondence with Albert Einstein.[41] In 1947, he announced a result, "Affine Field Theory,"[42] in a talk at the Royal Irish Academy, but the announcement was criticized by Einstein as "preliminary" and failed to lead to the desired unified theory.[41] Following the failure of his attempt at unification, Schrödinger gave up his work on unification and turned to other topics.

Colour[edit]

Schrödinger had a strong interest in psychology, in particular colour perception and colorimetry (German: *Farbenmetrik*). He spent quite a few years of his life working on these questions and published a series of papers in this area:

- "Theorie der Pigmente von größter Leuchtkraft", *Annalen der Physik*, (4), 62, (1920), 603–22 (Theory of Pigments with Highest Luminosity)
- "Grundlinien einer Theorie der Farbenmetrik im Tagessehen", *Annalen der Physik*, (4), 63, (1920), 397–456; 481–520 (Outline of a theory of colour measurement for daylight vision)
- "Farbenmetrik", *Zeitschrift für Physik*, 1, (1920), 459–66 (Colour measurement).
- "Über das Verhältnis der Vierfarben- zur Dreifarben-theorie", *Mathematisch-Naturwissenschaftliche Klasse*,[*clarification needed Which academy?*] 134, 471, (On The Relationship of Four-Color Theory to Three-Color Theory).
- "Lehre von der strahlenden Energie", *Müller-Pouillets Lehrbuch der Physik und Meteorologie*, Vol 2, Part 1 (1926) (Thresholds of Color Differences).

His work on the psychology of color perception follows the step of Newton, Maxwell and von Helmholtz in the same area. Some of these papers have been translated into English and can be found in: *Sources of Colour Science*, Ed. David L. MacAdam, MIT Press (1970) and in *Erwin Schrödinger's Color Theory, Translated with Modern Commentary*, Ed. Keith K. Niall, Springer (2017). ISBN 978-3-319-64619-0 doi:10.1007/978-3-319-64621-3.

Schrödinger's 126th birthday anniversary in 2013 was celebrated with a Google Doodle.[45][46]

Erwin Rudolf Josef Alexander Schrödinger 12 August 1887 – 4 January 1961), sometimes written as **Erwin Schrodinger** was a Nobel Prize-winning Austrian-Irish physicist who developed a number of fundamental results in quantum theory: the Schrödinger equation provides a way to calculate the wave function of a system and how it changes dynamically in time. In addition, he was the author of many works on various aspects of physics: statistical mechanics and thermodynamics, physics of dielectrics, colour theory, electrodynamics, general relativity, and cosmology, and he made several attempts to construct a unified field theory. The philosophical issues raised by Schrödinger's cat are still debated today and remain his most enduring legacy in popular science, while Schrödinger's equation is his most enduring legacy at a more technical level. Schrödinger is one of several individuals who have been called "the father of quantum mechanics". The large crater Schrödinger, on the far side of the Moon, is named after him. The Erwin Schrödinger International Institute for Mathematical Physics was established in Vienna in 1993.

Schrödinger's portrait was the main feature of the design of the 1983–97 Austrian 1000-schilling banknote, the second-highest denomination.
A building is named after him at the University of Limerick, in Limerick, Ireland,[43] as is the 'Erwin Schrödinger Zentrum' at Adlershof in Berlin.[44]

Heisenberg

The importance of Heisenberg to Scientific Spiritualism and Saltafide is his challenge to the absolute truth sought after by science. Heisenberg creates a separation between consciousness where knowledge resides and the world of objects. The observer is a subject and the observed is an object, between which lies a mysterious chasm of uncertainty. This is justifies the separation of the object and subject domains discussed in Castle of Consciousness .

Heisenberg was an anti-realist, arguing that direct knowledge of what is "real" was beyond the scope of science.[49] Writing in his book *The Physicist's Conception of Nature,*[50] Heisenberg argued that ultimately we only can speak of the *knowledge* (numbers in tables) which describe something about particles but we can never have any "true" access to the particles themselves:[49]

We can no longer speak of the behavior of the particle independently of the process of observation. As a final consequence, the natural laws formulated mathematically in quantum theory no longer deal with the elementary particles themselves but with our knowledge of them. Nor is it any longer possible to ask whether or not these particles exist in space and time objectively ... When we speak of the picture of nature in the exact science of our age, we do not mean a picture of nature so much as a *picture of our relationships with nature*. ...Science no longer confronts nature as an objective observer, but sees itself as an actor in this interplay between man [*sic*] and nature. The scientific method of analysing, explaining and classifying has become conscious of its limitations, which arise out of the fact that by its intervention science alters and refashions the object of investigation. In other words, method and object can no longer be separated.[49][50]

Werner Karl Heisenberg 5 December 1901 – 1 February 1976)[3] was a German theoretical physicist and one of the key pioneers of quantum mechanics. He published his work in 1925 in a breakthrough paper. In the subsequent series of papers with Max Born and Pascual Jordan, during the same year, this matrix formulation of quantum mechanics was substantially elaborated. He is known for the Heisenberg uncertainty principle, which he published in 1927. Heisenberg was awarded the 1932 Nobel Prize in Physics "for the creation of quantum mechanics".[4]

He also made important contributions to the theories of the hydrodynamics of turbulent flows, the atomic nucleus, ferromagnetism, cosmic rays, and subatomic particles, and he was instrumental in planning the first West German nuclear reactor at Karlsruhe, together with a research reactor in Munich, in 1957. He was a principal scientist in the German nuclear weapons program during World War II. He travelled to occupied Copenhagen where he met and discussed the German project with Niels Bohr.

Following World War II, he was appointed director of the Kaiser Wilhelm Institute for Physics, which soon thereafter was renamed the Max Planck Institute for Physics. He was director of the institute until it was moved to Munich in 1958, when it was expanded and renamed the Max Planck Institute for Physics and Astrophysics.

Heisenberg was also president of the German Research Council, chairman of the Commission for Atomic Physics, chairman of the Nuclear Physics Working Group, and president of the Alexander von Humboldt Foundation.[1]

Heisenberg's paper establishing quantum mechanics[37] has puzzled physicists and historians. His methods assume that the reader is familiar with Kramers-Heisenberg transition probability calculations. The main new idea, non-commuting matrices, is justified only by a rejection of unobservable quantities. It introduces the non-commutative multiplication of matrices by physical reasoning, based on the correspondence principle, despite the fact that Heisenberg was not then familiar with the mathematical theory of matrices. The path leading to these results has been reconstructed in MacKinnon, 1977,[38] and the detailed calculations are worked out in Aitchison et al.[39]

In Copenhagen, Heisenberg and Hans Kramers collaborated on a paper on dispersion, or the scattering from atoms of radiation whose wavelength is larger than the atoms. They showed that the successful formula Kramers had developed earlier could not be based on Bohr orbits, because the transition frequencies are based on level spacings which are not constant. The frequencies which occur in the Fourier transform of sharp classical orbits, by contrast, are equally spaced. But these results could be explained by a semi-classical virtual state model: the incoming radiation excites the valence, or outer, electron to a virtual state from which it decays. In a subsequent paper Heisenberg showed that this virtual oscillator model could also explain the polarization of fluorescent radiation.
These two successes, and the continuing failure of the Bohr–Sommerfeld model to explain the outstanding problem of the anomalous Zeeman effect, led Heisenberg to use the virtual oscillator model to try to calculate spectral frequencies. The method proved too difficult to immediately apply to realistic problems, so Heisenberg turned to a simpler example, the anharmonic oscillator.

The dipole oscillator consists of a simple harmonic oscillator, which is thought of as a charged particle on a spring, perturbed by an external force, like an external charge. The motion of the oscillating charge can be expressed as a Fourier series in the frequency of the oscillator. Heisenberg solved for the quantum behavior by two different methods. First, he treated the system with the virtual oscillator method, calculating the transitions between the levels that would be produced by the external source.
He then solved the same problem by treating the anharmonic potential term as a perturbation to the harmonic oscillator and using the perturbation methods that he and Born had developed. Both methods led to the same results for the first and the very complicated second order correction terms. This suggested that behind the very complicated calculations lay a consistent scheme.

So Heisenberg set out to formulate these results without any explicit dependence on the virtual oscillator model. To do this, he replaced the Fourier expansions for the spatial coordinates by matrices, matrices which corresponded to the transition coefficients in the virtual oscillator method. He justified this replacement by an appeal to Bohr's correspondence principle and the Pauli doctrine that quantum mechanics must be limited to observables.

On 9 July, Heisenberg gave Born this paper to review and submit for publication. When Born read the paper, he recognized the formulation as one which could be transcribed and extended to the systematic language of matrices,[40] which he had learned from his study under Jakob Rosanes[41] at Breslau University. Born, with the help of his assistant and former student Pascual Jordan, began immediately to make the transcription and extension, and they submitted their results for publication; the paper was received for publication just 60 days after Heisenberg's paper.[42] A follow-on paper was submitted for publication before the end of the year by all three authors.[43]
Up until this time, matrices were seldom used by physicists; they were considered to belong to the realm of pure mathematics. Gustav Mie had used them in a paper on electrodynamics in 1912 and Born had used them in his work on the lattice theory of crystals in 1921. While

matrices were used in these cases, the algebra of matrices with their multiplication did not enter the picture as they did in the matrix formulation of quantum mechanics.[44]
In 1928, Albert Einstein nominated Heisenberg, Born, and Jordan for the Nobel Prize in Physics,[45] The announcement of the Nobel Prize in Physics for 1932 was delayed until November 1933.[46] It was at that time that it was announced Heisenberg had won the Prize for 1932 "for the creation of quantum mechanics, the application of which has, inter alia, led to the discovery of the allotropic forms of hydrogen".[47][48]

Interpretation of Quantum Theory[edit]
The development of quantum mechanics, and the apparent contradictory implications in regard to what is "real" had profound philosophical implications, including what scientific observations truly mean. In contrast to Albert Einstein and Louis de Broglie, who were realists who believed that particles had an objectively true momentum and position at all times (even if both could not be measured),

Shortly after the discovery of the neutron by James Chadwick in 1932, Heisenberg submitted the first of three papers[51] on his neutron-proton model of the nucleus.[27][52] After Adolf Hitler came to power in 1933, Heisenberg was attacked in the press as a "White Jew".[53] Supporters of *Deutsche Physik*, or Aryan Physics, launched vicious attacks against leading theoretical physicists, including Arnold Sommerfeld and Heisenberg.[27] From the early 1930s onward, the anti-Semitic and anti-theoretical physics movement *Deutsche Physik* had concerned itself with quantum mechanics and the theory of relativity. As applied in the university environment, political factors took priority over scholarly ability,[54] even though its two most prominent supporters were the Nobel Laureates in Physics Philipp Lenard[55] and Johannes Stark.[56][57]
There had been many failed attempts to have Heisenberg appointed as professor at a number of German universities. His attempt to be appointed as successor to Arnold Sommerfeld failed because of opposition by the *Deutsche Physik* movement.[58] On 1 April 1935, the eminent theoretical physicist Sommerfeld, Heisenberg's doctoral advisor at the Ludwig-Maximilians-Universität München, achieved emeritus status. However, Sommerfeld stayed in his chair during the selection process for his successor, which took until 1 December 1939. The process was lengthy due to academic and political differences between the Munich Faculty's selection and that of the Reichserziehungsministerium (Reich Education Ministry) and the supporters of *Deutsche Physik*.
In 1935, the Munich Faculty drew up a list of candidates to replace Sommerfeld as ordinarius professor of theoretical physics and head of the Institute for Theoretical Physics at the University of Munich. The three candidates had all been former students of Sommerfeld: Heisenberg, who had received the Nobel Prize in Physics; Peter Debye, who had received the Nobel Prize in Chemistry in 1936; and Richard Becker. The Munich Faculty was firmly behind these candidates, with Heisenberg as their first choice. However, supporters of *Deutsche Physik* and elements in the REM had their own list of candidates, and the battle dragged on for over four years. During this time, Heisenberg came under vicious attack by the *Deutsche Physik* supporters. One attack was published in *Das Schwarze Korps*, the newspaper of the Schutzstaffel (SS), headed by Heinrich Himmler. In this, Heisenberg was called a "White Jew" (i.e. an Aryan who acts like a Jew) who should be made to "disappear".[59] These attacks were taken seriously, as Jews were violently attacked and incarcerated. Heisenberg fought back with an editorial and a letter to Himmler, in an attempt to resolve the matter and regain his honor.
At one point, Heisenberg's mother visited Himmler's mother. The two women knew each other, as Heisenberg's maternal grandfather and Himmler's father were rectors and members of a Bavarian hiking club. Eventually, Himmler settled the Heisenberg affair by sending two letters, one to SS Gruppenführer Reinhard Heydrich and one to Heisenberg, both on 21 July 1938. In the letter to Heydrich, Himmler said Germany could not afford to lose or silence Heisenberg, as he would be useful for teaching a generation of scientists. To Heisenberg, Himmler said the

letter came on recommendation of his family and he cautioned Heisenberg to make a distinction between professional physics research results and the personal and political attitudes of the involved scientists.[60]

Wilhelm Müller replaced Sommerfeld at the Ludwig Maximilian University of Munich. Müller was not a theoretical physicist, had not published in a physics journal, and was not a member of the Deutsche Physikalische Gesellschaft; his appointment was considered a travesty and detrimental to educating theoretical physicists.[60][61][62][63][64]

The three investigators who led the SS investigation of Heisenberg had training in physics—Heisenberg had participated in the doctoral examination of one of them at the Universität Leipzig. The most influential of the three was Johannes Juilfs. During their investigation, they became supporters of Heisenberg as well as his position against the ideological policies of the *Deutsche Physik* movement in theoretical physics and academia.[65]

On 29 June 1936, a Nazi Party newspaper published a column attacking Heisenberg. On 15 July 1937, he was attacked in a journal of the SS.[27] In mid-1936, Heisenberg presented his theory of cosmic-ray showers in two papers.[66] Four more papers[67][68][69][70] appeared in the next two years.[27][71]

Heisenberg enjoyed classical music and was an accomplished pianist.[3] His interest in music led to meeting his future wife. In January 1937, Heisenberg met Elisabeth Schumacher (1914–1998) at a private music recital. Elisabeth was the daughter of a well-known Berlin economics professor, and her brother was the economist E. F. Schumacher, author of *Small Is Beautiful*. Heisenberg married her on 29 April. Fraternal twins Maria and Wolfgang were born in January 1938, whereupon Wolfgang Pauli congratulated Heisenberg on his "pair creation"—a word play on a process from elementary particle physics, pair production. They had five more children over the next 12 years: Barbara, Christine, Jochen, Martin and Verena.[72][73]

In December 1938, the German chemists Otto Hahn and Fritz Strassmann sent a manuscript to *Naturwissenschaften* reporting they had detected the element barium after bombarding uranium with neutrons and Otto Hahn concluded a *bursting* of the uranium nucleus;[74] simultaneously, Hahn communicated these results to his friend Lise Meitner, who had in July of that year fled to the Netherlands and then went to Sweden.[75] Meitner, and her nephew Otto Robert Frisch, correctly interpreted Hahn's and Strassmann's results as being nuclear fission.[76] Frisch confirmed this experimentally on 13 January 1939.[77]

In June 1939, Heisenberg bought a summer home for his family in Urfeld am Walchensee, in southern Germany. He also traveled to the United States in June and July, visiting Samuel Abraham Goudsmit at the University of Michigan in Ann Arbor. However, Heisenberg refused an invitation to emigrate to the United States. He did not see Goudsmit again until six years later, when Goudsmit was the chief scientific advisor to the American Operation Alsos at the close of World War II.[27][78][79]

The German nuclear weapons program, known as *Uranverein*, was formed on 1 September 1939, the day World War II began. The *Heereswaffenamt* (HWA, Army Ordnance Office) had squeezed the *Reichsforschungsrat* (RFR, Reich Research Council) out of the *Reichserziehungsministerium* (REM, Reich Ministry of Education) and started the formal German nuclear energy project under military auspices. The project had its first meeting on 16 September 1939. The meeting was organized by Kurt Diebner, advisor to the HWA, and held in Berlin. The invitees included Walther Bothe, Siegfried Flügge, Hans Geiger, Otto Hahn, Paul Harteck, Gerhard Hoffmann, Josef Mattauch and Georg Stetter. A second meeting was held soon thereafter and included Heisenberg, Klaus Clusius, Robert Döpel and Carl Friedrich von Weizsäcker. The *Kaiser-Wilhelm Institut für Physik* (KWIP, Kaiser Wilhelm Institute for Physics) in Berlin-Dahlem, was placed under HWA authority, with Diebner as the administrative director, and the military control of the nuclear research commenced.[80][81][82] During the period when Diebner administered the KWIP under the HWA program, considerable personal and professional animosity developed between Diebner and Heisenberg's inner circle, which included Karl Wirtz and Carl Friedrich von Weizsäcker.[27][83

At a scientific conference on 26–28 February 1942 at the Kaiser Wilhelm Institute for Physics, called by the Army Weapons Office, Heisenberg presented a lecture to Reichs officials on energy acquisition from nuclear fission.[84] The lecture, entitled "Die theoretischen Grundlagen für die Energiegewinnung aus der Uranspaltung" ("The theoretical basis for energy generation from uranium fission") was, as Heisenberg confessed after the Second World War in a letter to Samuel Goudsmit, "adapted to the intellectual level of a Reichs Minister".[85] Heisenberg lectured on the enormous energy potential of nuclear fission, stating that 250 million electron volts could be released through the fission of an atomic nucleus. Heisenberg stressed that pure U-235 had to be obtained to achieve a chain reaction. He explored various ways of obtaining isotope $^{235}_{92}U$ in its pure form, including uranium enrichment and an alternative layered method of normal uranium and a moderator in a machine. This machine, he noted, could be used in practical ways to fuel vehicles, ships and submarines. Heisenberg stressed the importance of the Army Weapons Office's financial and material support for this scientific endeavour. A second scientific conference followed. Lectures were heard on problems of modern physics with decisive importance for the national defense and economy. The conference was attended by Bernhard Rust, the Reichs Minister of Science, Education and National Culture. At the conference Reichs Minister Rust decided to take the nuclear project away from the Kaiser Wilhelm Society. The Reichs Research Council was to take on the project.[86] In April 1942 the army returned the Physics Institute to the Kaiser Wilhelm Society, naming Heisenberg as Director at the Institute. With this appointment at the KWIP, Heisenberg obtained his first professorship.[58] Peter Debye was still director of the institute, but had gone on leave to the United States after he had refused to become a German citizen when the HWA took administrative control of the KWIP. Heisenberg still also had his department of physics at the University of Leipzig where work had been done for the *Uranverein* by Robert Döpel and his wife Klara Döpel.[27][83]

On 4 June 1942, Heisenberg was summoned to report to Albert Speer, Germany's Minister of Armaments, on the prospects for converting the Uranverein's research toward developing nuclear weapons. During the meeting, Heisenberg told Speer that a bomb could not be built before 1945, because it would require significant monetary resources and number of personnel.[87][88]

After the Uranverein project was placed under the leadership of the Reichs Research Council, it focused on nuclear power production and thus maintained its *kriegswichtig* (importance for the war) status; funding therefore continued from the military. The nuclear power project was broken down into the following main areas: uranium and heavy water production, uranium isotope separation and the *Uranmaschine* (uranium machine, i.e., nuclear reactor). The project was then essentially split up between a number of institutes, where the directors dominated the research and set their own research agendas.[80][89][90] The point in 1942, when the army relinquished its control of the German nuclear weapons program, was the zenith of the project relative to the number of personnel. About 70 scientists worked for the program, with about 40 devoting more than half their time to nuclear fission research. After 1942, the number of scientists working on applied nuclear fission diminished dramatically. Many of the scientists not working with the main institutes stopped working on nuclear fission and devoted their efforts to more pressing war related work.[91]

In September 1942, Heisenberg submitted his first paper of a three-part series on the scattering matrix, or S-matrix, in elementary particle physics. The first two papers were published in 1943[92][93] and the third in 1944.[94] The S-matrix described only the states of incident particles in a collision process, the states of those emerging from the collision, and stable bound states; there would be no reference to the intervening states. This was the same precedent as he followed in 1925 in what turned out to be the foundation of the matrix formulation of quantum mechanics through only the use of observables.[27][71]

In February 1943, Heisenberg was appointed to the Chair for Theoretical Physics at the *Friedrich-Wilhelms-Universität* (today, the Humboldt-Universität zu Berlin). In April, his election to the *Preußische Akademie der Wissenschaften* (Prussian Academy of Sciences) was approved. That same month, he moved his family to their retreat in Urfeld as Allied bombing increased in Berlin. In the summer, he dispatched the first of his staff at the *Kaiser-Wilhelm Institut für Physik* to Hechingen and its neighboring town of Haigerloch, on the edge of the Black Forest, for the same reasons. From 18–26 October, he travelled to German-occupied Netherlands. In December 1943, Heisenberg visited German-occupied Poland.[27][95]

From 24 January to 4 February 1944, Heisenberg travelled to occupied Copenhagen, after the German army confiscated Bohr's Institute of Theoretical Physics. He made a short return trip in April. In December, Heisenberg lectured in neutral Switzerland.[27] The United States Office of Strategic Services sent agent Moe Berg to attend the lecture carrying a pistol, with orders to shoot Heisenberg if his lecture indicated that Germany was close to completing an atomic bomb.[96]

In January 1945, Heisenberg, with most of the rest of his staff, moved from the *Kaiser-Wilhelm Institut für Physik* to the facilities in the Black Forest.[27]

Alsos Mission

The Alsos Mission was an Allied effort to determine if the Germans had an atomic bomb program and to exploit German atomic related facilities, research, material resources, and scientific personnel for the benefit of the US. Personnel on this operation generally swept into areas which had just come under control of the Allied military forces, but sometimes they operated in areas still under control by German forces.[97][98][99] Berlin had been a location of many German scientific research facilities. To limit casualties and loss of equipment, many of these facilities were dispersed to other locations in the latter years of the war. The *Kaiser-Wilhelm-Institut für Physik* (KWIP, Kaiser Wilhelm Institute for Physics) had been bombed so it had mostly been moved in 1943 and 1944 to Hechingen and its neighboring town of Haigerloch, on the edge of the Black Forest, which eventually became included in the French occupation zone. This allowed the American task force of the Alsos Mission to take into custody a large number of German scientists associated with nuclear research.[100][101]

On 30 March, the Alsos Mission reached Heidelberg,[102] where important scientists were captured including Walther Bothe, Richard Kuhn, Philipp Lenard, and Wolfgang Gertner.[103] Their interrogation revealed that Otto Hahn was at his laboratory in Tailfingen, while Heisenberg and Max von Laue were at Heisenberg's laboratory in Hechingen, and that the experimental natural uranium reactor that Heisenberg's team had built in Berlin had been moved to Haigerloch. Henceforth, the main focus of the Alsos Mission was on these nuclear facilities in the Württemberg area.[104] Heisenberg was captured and arrested in Urfeld, on 3 May 1945, in an alpine operation in territory still under control by German forces. He was taken to Heidelberg, where, on 5 May, he met Goudsmit for the first time since the Ann Arbor visit in 1939. Germany surrendered just two days later. Heisenberg would not see his family again for eight months, as he was moved across France and Belgium and flown to England on 3 July 1945.[105][106][107]

1945: Reaction to Hiroshima[edit]

Nine of the prominent German scientists who published reports in *Kernphysikalische Forschungsberichte* as members of the *Uranverein*[108] were captured by Operation Alsos and incarcerated in England under Operation Epsilon.[109] Ten German scientists, including Heisenberg, were held at Farm Hall in England. The facility had been a safe house of the British foreign intelligence MI6. During their detention, their conversations were recorded. Conversations thought to be of intelligence value were transcribed and translated into English. The transcripts were released in 1992.[110][111] On 6 August 1945, the scientists at Farm Hall learned from media reports that the USA had dropped an atomic bomb in Hiroshima, Japan. At

first, there was disbelief that a bomb had been built and dropped. In the weeks that followed, the German scientists discussed how the USA may have built the bomb.[112]
The Farm Hall transcripts reveal that Heisenberg, along with other physicists interned at Farm Hall including Otto Hahn and Carl Friedrich von Weizsäcker, were glad the Allies had won World War II.[113] Heisenberg told other scientists that he had never contemplated a bomb, only an atomic pile to produce energy. The morality of creating a bomb for the Nazis was also discussed. Only a few of the scientists expressed genuine horror at the prospect of nuclear weapons, and Heisenberg himself was cautious in discussing the matter.[114][115] On the failure of the German nuclear weapons program to build an atomic bomb, Heisenberg remarked, "We wouldn't have had the moral courage to recommend to the Government in the spring of 1942 that they should employ 120,000 men just for building the thing up."[116]

On 3 January 1946, the ten Operation Epsilon detainees were transported to Alswede in Germany. Heisenberg settled in Göttingen, which was in the British zone of Allied-occupied Germany.[*citation needed*] Heisenberg immediately began to promote scientific research in Germany. Following the Kaiser Wilhelm Society's obliteration by the Allied Control Council and the establishment of the Max Planck Society in the British zone, Heisenberg became the director of the Max Planck Institute for Physics. Max von Laue was appointed vice director, while Karl Wirtz, Carl Friedrich von Weizsäcker and Ludwig Biermann joined to help Heisenberg establish the institute. Heinz Billing joined in 1950 to promote the development of electronic computing. The core research focus of the institute was cosmic radiation. The institute held a colloquium every Saturday morning.[117]
Heisenberg together with Hermann Rein [de] was instrumental in the establishment of the Forschungsrat (research council). Heisenberg envisaged for this council to promote the dialogue between the newly founded Federal Republic of Germany and the scientific community based in Germany.[117] Heisenberg was appointed president of the *Forschungsrat*. In 1951, the organization was fused with the Notgemeinschaft der Deutschen Wissenschaft (Emergency Association of German Science) and that same year renamed the Deutsche Forschungsgemeinschaft (German Research Foundation). Following the merger, Heisenberg was appointed to the presidium.[27]
In 1958, the Max-Planck-Institut für Physik was moved to Munich, expanded, and renamed Max-Planck-Institut für Physik und Astrophysik (MPIFA). In the interim, Heisenberg and the astrophysicist Ludwig Biermann were co-directors of MPIFA. Heisenberg also became an *ordentlicher Professor* (ordinarius professor) at the Ludwig-Maximilians-Universität München. Heisenberg was the sole director of MPIFA from 1960 to 1970. Heisenberg resigned his directorship of the MPIFA on 31 December 1970.[12][27]

Promotion of international scientific cooperation[edit]

In 1951 Heisenberg agreed to become the scientific representative of the Federal Republic of Germany at the UNESCO conference, with the aim of establishing a European laboratory for nuclear physics. Heisenberg's aim was to build a large particle accelerator, drawing on the resources and technical skills of scientists across the Western Bloc. On the 1st July 1953 Heisenberg signed the convention that established CERN on behalf of the Federal Republic of Germany. Although he was asked to become CERN's founding scientific director, he declined. Instead, he was appointed chair of CERN's science policy committee and went on to determine the scientific program at CERN.[118]
In December 1953 Heisenberg became the president of the Alexander von Humboldt Foundation.[118] During his tenure as president 550 Humboldt scholars from 78 nations received scientific research grants. Heisenberg resigned as president shortly before his death.[119]

Post 1945: Research interests[edit]

In 1946 the German scientist Heinz Pose, head of Laboratory V in Obninsk, wrote a letter to Heisenberg inviting him to work in the USSR. The letter lauded the working conditions in the USSR and the available resources, as well as the favorable attitude of the Soviets towards German scientists. A courier hand delivered the recruitment letter, dated 18 July 1946, to

Heisenberg; Heisenberg politely declined.[120][121] In 1947, Heisenberg presented lectures in Cambridge, Edinburgh and Bristol. Heisenberg contributed to the understanding of the phenomenon of superconductivity with a paper in 1947[122] and two papers in 1948,[123][124] one of them with Max von Laue.[27][125]

In the period shortly after World War II, Heisenberg briefly returned to the subject of his doctoral thesis, turbulence. Three papers were published in 1948[126][127][128] and one in 1950.[18][129] In the post-war period Heisenberg continued his interests in cosmic-ray showers with considerations on multiple production of mesons. He published three papers[130][131][132] in 1949, two[133][134] in 1952, and one[135] in 1955.[136]

In late 1955 to early 1956, Heisenberg gave the Gifford Lectures at St Andrews University, in Scotland, on the intellectual history of physics. The lectures were later published as *Physics and Philosophy: The Revolution in Modern Science*.[137] During 1956 and 1957, Heisenberg was the chairman of the *Arbeitskreis Kernphysik* (Nuclear Physics Working Group) of the *Fachkommission II "Forschung und Nachwuchs"* (Commission II "Research and Growth") of the *Deutschen Atomkommission* (DAtK, German Atomic Energy Commission). Other members of the Nuclear Physics Working Group in both 1956 and 1957 were: Walther Bothe, Hans Kopfermann (vice-chairman), Fritz Bopp, Wolfgang Gentner, Otto Haxel, Willibald Jentschke, Heinz Maier-Leibnitz, Josef Mattauch, Wolfgang Riezler, Wilhelm Walcher and Carl Friedrich von Weizsäcker. Wolfgang Paul was also a member of the group during 1957.[138]

In 1957 Heisenberg was a signatory of the Göttinger Manifest, taking a public stand against the Federal Republic of Germany arming itself with nuclear weapons. Heisenberg, like Pascual Jordan, thought politicians would ignore this statement by nuclear scientists. But Heisenberg believed that the Göttinger Manifest would "influence public opinion" which politicians would have to take into account. He wrote to Walther Gerlach: "We will probably have to keep coming back to this question in public for a long time because of the danger that public opinion will slacken."[139] In 1961 Heisenberg signed the Memorandum of Tübingen alongside a group of scientists who had been brought together by Carl Friedrich von Weizsäcker and Ludwig Raiser.[140] A public discussion between scientists and politicians ensued.[141] As prominent politicians, authors and socialites joined the debate on nuclear weapons, the signatories of the memorandum took a stand against "the full-time intellectual nonconformists".[142]

From 1957 onwards, Heisenberg was interested in plasma physics and the process of nuclear fusion. He also collaborated with the International Institute of Atomic Physics in Geneva. He was a member of the Institute's scientific policy committee, and for several years was the Committee's chair.[3] He was one of the eight signatories of the Memorandum of Tübingen which called for the recognition of the Oder-Neiße line as the official border between Germany and Poland and spoke against a possible nuclear armament of West Germany.[143]

In 1973, Heisenberg gave a lecture at Harvard University on the historical development of the concepts of quantum theory.[144] On 24 March 1973 Heisenberg gave a speech before the Catholic Academy of Bavaria, accepting the Romano Guardini Prize. An English translation of his speech was published under the title "Scientific and Religious Truth". The stated goal of this truth was, in his mind, the unassailable value of scientific truth.[145]

Philosophy[edit]

Heisenberg admired Eastern Philosophy and saw parallels between it and quantum mechanics, describing himself as in "complete agreement" with the book The Tao of Physics. Heisenberg even went as far to state that after conversations with Rabindranath Tagore about Indian Philosophy "some of the ideas that seemed so crazy suddenly made much more sense".[146]

Regarding the philosophy of Ludwig Wittgenstein, Heisenberg disliked Tractatus Logico-Philosophicus but he liked "very much the later ideas of Wittgenstein and his philosophy about language."[147]

Heisenberg, a devout Christian,[148][149] wrote:" We can console ourselves that the good Lord God would know the position of the [subatomic] particles, thus He would let the causality principle continue to have validity," in his last letter to Albert Einstein.[150] Einstein continued to maintain that quantum physics must be incomplete because it implies that the universe is indeterminate at a fundamental level.[151]

Autobiography and death[edit]

Heisenberg's son, Martin Heisenberg, became a neurobiologist at the University of Würzburg, while his son Jochen Heisenberg became a physics professor at the University of New Hampshire.[152] When Heisenberg accepted the Romano Guardini Prize in 1974, he gave a speech, which he later published under the title *Scientific and Religious Truth*. He mused:

> In the history of science, ever since the famous trial of Galileo, it has repeatedly been claimed that scientific truth cannot be reconciled with the religious interpretation of the world. Although I am now convinced that scientific truth is unassailable in its own field, I have never found it possible to dismiss the content of religious thinking as simply part of an outmoded phase in the consciousness of mankind, a part we shall have to give up from now on. Thus in the course of my life I have repeatedly been compelled to ponder on the relationship of these two regions of thought, for I have never been able to doubt the reality of that to which they point.
>
> —Heisenberg 1974, 213[153]

In his late-sixties Heisenberg penned his autobiography for the mass market. In 1969 the book was published in Germany, in early 1971 it was published in English and in the years thereafter in a string of other languages.[154] Heisenberg had initiated the project in 1966, when his public lectures increasingly turned to the subjects of philosophy and religion. Heisenberg had sent the manuscript for a textbook on the unified field theory to the Hirzel Verlag and John Wiley & Sons for publication. This manuscript, he wrote to one of his publishers, was the preparatory work for his autobiography. He structured his autobiography in themes, covering: 1) The goal of exact science, 2) The problematic of language in atomic physics, 3) Abstraction in mathematics and science, 4) The divisibility of matter or Kant's antinomy, 5) The basic symmetry and its substantiation, and 6) Science and religion.[155]

Heisenberg wrote his memoirs as a chain of conversations, covering the course of his life. The book became a popular success, but was regarded as troublesome by historians of science. In the preface Heisenberg wrote that he had abridged historical events, to make them more concise. At the time of publication it was reviewed by Paul Forman in the journal *Science* with the comment "Now here is a memoir in the form of rationally reconstructed dialogue. And the dialogue as Galileo well knew, is itself a most insidious literary device: lively, entertaining, and especially suited for insinuating opinions while yet evading responsibility for them."[156] Few scientific memoirs had been published, but Konrad Lorenz and Adolf Portmann had penned popular books that conveyed scholarship to a wide audience. Heisenberg worked on his autobiography and published it with the Piper Verlag in Munich. Heisenberg initially proposed the title *Gespräche im Umkreis der Atomphysik* (*Conversations on atomic physics*). The autobiography was published eventually under the title *Der Teil und das Ganze* (*The part and the whole*).[157] An English translation under the title *Physics and Beyond: Encounters and Conversations* was published in 1971.

Heisenberg died of kidney cancer at his home, on 1 February 1976.[158] The next evening, his colleagues and friends walked in remembrance from the Institute of Physics to his home, lit a candle and placed it in front of his door.[159]

In 1980 his widow, Elisabeth Heisenberg, published *Das politische Leben eines Unpolitischen* (*The Political Life of an Apolitical Person*) and characterized Heisenberg "first and foremost, a spontaneous person, thereafter a brilliant scientist, next a highly talented artist, and only in the fourth place, from a sense of duty, homo politicus."[160]

EINSTEIN

Albert Einstein (/ˈaɪnstaɪn/ *EYEN-styne*;[4] German: [ˈalbɛʁt ˈʔaɪnʃtaɪn] (listen); 14 March 1879 – 18 April 1955) was a German-born theoretical physicist[5] who developed the theory of relativity, one of the two pillars of modern physics (alongside quantum mechanics).[3][6]:274 His work is also known for its influence on the philosophy of science.[7][8] He is best known to the general public for his mass–energy equivalence formula $E = mc^2$, which has been dubbed "the world's most famous equation".[9] He received the 1921 Nobel Prize in Physics "for his services to theoretical physics, and especially for his discovery of the law of the photoelectric effect",[10] a pivotal step in the development of quantum theory.

The son of a salesman who later operated an electrochemical factory, Einstein was born in the German Empire but moved to Switzerland in 1895 and renounced his German citizenship in 1896.[5] Specializing in physics and mathematics, he received his academic teaching diploma from the Swiss Federal Polytechnic School (German: *eidgenössische polytechnische Schule*, later ETH) in Zürich in 1900. The following year, he acquired Swiss citizenship, which he kept for his entire life. After initially struggling to find work, from 1902 to 1909 he was employed as a patent examiner at the Swiss Patent Office in Bern.

Near the beginning of his career, Einstein thought that Newtonian mechanics was no longer enough to reconcile the laws of classical mechanics with the laws of the electromagnetic field. This led him to develop his special theory of relativity during his time at the Swiss Patent Office. In 1905, called his *annus mirabilis* (miracle year), he published four groundbreaking papers, which attracted the attention of the academic world; the first outlined the theory of the photoelectric effect, the second paper explained Brownian motion, the third paper introduced special relativity, and the fourth mass-energy equivalence. That year, at the age of 26, he was awarded a PhD by the University of Zurich.

Although initially treated with skepticism from many in the scientific community, Einstein's works gradually came to be recognized as significant advancements. He was invited to teach theoretical physics at the University of Bern in 1908 and the following year moved to the University of Zurich, then in 1911 to Charles University in Prague before returning to the Federal Polytechnic School in Zürich in 1912. In 1914, he was elected to the Prussian Academy of Sciences in Berlin, where he remained for 19 years. Soon after publishing his work on special relativity, Einstein began working to extend the theory to gravitational fields; he then published a paper on general relativity in 1916, introducing his theory of gravitation. He continued to deal with problems of statistical mechanics and quantum theory, which led to his explanations of particle theory and the motion of molecules. He also investigated the thermal properties of light and the quantum theory of radiation, the basis of laser, which laid the foundation of the photon theory of light. In 1917, he applied the general theory of relativity to model the structure of the universe.[11][12]

In 1933, while Einstein was visiting the United States, Adolf Hitler came to power. Because of his Jewish background, Einstein did not return to Germany.[13] He settled in the United States and became an American citizen in 1940.[14] On the eve of World War II, he endorsed a letter to President Franklin D. Roosevelt alerting FDR to the potential development of "extremely powerful bombs of a new type" and recommending that the US begin similar research. This eventually led to the Manhattan Project. Einstein supported the Allies, but he generally denounced the idea of using nuclear fission as a weapon. He signed the Russell–Einstein Manifesto with British philosopher Bertrand Russell, which highlighted the danger of nuclear weapons. He was affiliated with the Institute for Advanced Study in Princeton, New Jersey, until his death in 1955.

He published more than 300 scientific papers and more than 150 non-scientific works.[11][15] His intellectual achievements and originality have made the word "Einstein" synonymous with "genius".[16] Eugene Wigner compared him to his contemporaries, writing that "Einstein's understanding was deeper even than Jancsi von Neumann's. His mind was both more penetrating and more original".[1

Love of music

Einstein (right) with writer, musician and Nobel laureate Rabindranath Tagore, 1930

Einstein developed an appreciation for music at an early age. In his late journals he wrote: "If I were not a physicist, I would probably be a musician. I often think in music. I live my daydreams in music. I see my life in terms of music... I get most joy in life out of music."[127][128]

His mother played the piano reasonably well and wanted her son to learn the violin, not only to instill in him a love of music but also to help him assimilate into German culture. According to conductor Leon Botstein, Einstein began playing when he was 5. However, he did not enjoy it at that age.[129]

When he turned 13, he discovered the violin sonatas of Mozart, whereupon he became enamored of Mozart's compositions and studied music more willingly. Einstein taught himself to play without "ever practicing systematically". He said that "love is a better teacher than a sense of duty."[129] At age 17, he was heard by a school examiner in Aarau while playing Beethoven's violin sonatas. The examiner stated afterward that his playing was "remarkable and revealing of 'great insight'". What struck the examiner, writes Botstein, was that Einstein "displayed a deep love of the music, a quality that was and remains in short supply. Music possessed an unusual meaning for this student."[129]

Music took on a pivotal and permanent role in Einstein's life from that period on. Although the idea of becoming a professional musician himself was not on his mind at any time, among those with whom Einstein played chamber music were a few professionals, and he performed for private audiences and friends. Chamber music had also become a regular part of his social life while living in Bern, Zürich, and Berlin, where he played with Max Planck and his son, among others. He is sometimes erroneously credited as the editor of the 1937 edition of the Köchel catalog of Mozart's work; that edition was prepared by Alfred Einstein, who may have been a distant relation.[130][131]

In 1931, while engaged in research at the California Institute of Technology, he visited the Zoellner family conservatory in Los Angeles, where he played some of Beethoven and Mozart's works with members of the Zoellner Quartet.[132][133] Near the end of his life, when the young Juilliard Quartet visited him in Princeton, he played his violin with them, and the quartet was "impressed by Einstein's level of coordination and intonation".[129]

Special relativity

Main article: History of special relativity

Einstein's "*Zur Elektrodynamik bewegter Körper*"[168] ("On the Electrodynamics of Moving Bodies") was received on 30 June 1905 and published 26 September of that same year. It reconciled conflicts between Maxwell's equations (the laws of electricity and magnetism) and the laws of Newtonian mechanics by introducing changes to the laws of mechanics.[169]

Observationally, the effects of these changes are most apparent at high speeds (where objects are moving at speeds close to the speed of light). The theory developed in this paper later became known as Einstein's special theory of relativity.

This paper predicted that, when measured in the frame of a relatively moving observer, a clock carried by a moving body would appear to slow down, and the body itself would contract in its direction of motion. This paper also argued that the idea of a luminiferous aether—one of the leading theoretical entities in physics at the time—was superfluous.[note 4]

In his paper on mass–energy equivalence, Einstein produced $E = mc^2$ as a consequence of his special relativity equations.[170] Einstein's 1905 work on relativity remained controversial for many years, but was accepted by leading physicists, starting with Max Planck.[171][172]

Einstein originally framed special relativity in terms of kinematics (the study of moving bodies). In 1908, Hermann Minkowski reinterpreted special relativity in geometric terms as a theory of spacetime. Einstein adopted Minkowski's formalism in his 1915 general theory of relativity.[173]

General relativity

General relativity and the equivalence principle

Main article: History of general relativity

See also: Equivalence principle, Theory of relativity, and Einstein field equations

Eddington's photograph of a solar eclipse

General relativity (GR) is a theory of gravitation that was developed by Einstein between 1907 and 1915. According to general relativity, the observed gravitational attraction between masses results from the warping of space and time by those masses. General relativity has developed into an essential tool in modern astrophysics. It provides the foundation for the current understanding of black holes, regions of space where gravitational attraction is so strong that not even light can escape.

As Einstein later said, the reason for the development of general relativity was that the preference of inertial motions within special relativity was unsatisfactory, while a theory which from the outset prefers no state of motion (even accelerated ones) should appear more satisfactory.[174] Consequently, in 1907 he published an article on acceleration under special relativity. In that article titled "On the Relativity Principle and the Conclusions Drawn from It", he argued that free fall is really inertial motion, and that for a free-falling observer the rules of special relativity must apply. This argument is called the equivalence principle. In the same article, Einstein also predicted the phenomena of gravitational time dilation, gravitational redshift and deflection of light.[175][176]

In 1911, Einstein published another article "On the Influence of Gravitation on the Propagation of Light" expanding on the 1907 article, in which he estimated the amount of deflection of light by massive bodies. Thus, the theoretical prediction of general relativity could for the first time be tested experimentally.[177]

Gravitational waves

Main article: Gravitational wave

In 1916, Einstein predicted gravitational waves,[178][179] ripples in the curvature of spacetime which propagate as waves, traveling outward from the source, transporting energy as gravitational radiation. The existence of gravitational waves is possible under general relativity due to its Lorentz invariance which brings the concept of a finite speed of propagation of the physical interactions of gravity with it. By contrast, gravitational waves cannot exist in the Newtonian theory of gravitation, which postulates that the physical interactions of gravity propagate at infinite speed.

The first, indirect, detection of gravitational waves came in the 1970s through observation of a pair of closely orbiting neutron stars, PSR B1913+16.[180] The explanation of the decay in their orbital period was that they were emitting gravitational waves.[180][181] Einstein's prediction was confirmed on 11 February 2016, when researchers at LIGO published the first observation of gravitational waves,[182] detected on Earth on 14 September 2015, nearly one hundred years after the prediction.[180][183][184][185][186]

Hole argument and Entwurf theory

Main article: Hole argument

While developing general relativity, Einstein became confused about the gauge invariance in the theory. He formulated an argument that led him to conclude that a general relativistic field

theory is impossible. He gave up looking for fully generally covariant tensor equations and searched for equations that would be invariant under general linear transformations only.
In June 1913, the Entwurf ('draft') theory was the result of these investigations. As its name suggests, it was a sketch of a theory, less elegant and more difficult than general relativity, with the equations of motion supplemented by additional gauge fixing conditions. After more than two years of intensive work, Einstein realized that the hole argument was mistaken[187] and abandoned the theory in November 1915.

Physical cosmology

Main article: Physical cosmology

In 1917, Einstein applied the general theory of relativity to the structure of the universe as a whole.[188] He discovered that the general field equations predicted a universe that was dynamic, either contracting or expanding. As observational evidence for a dynamic universe was not known at the time, Einstein introduced a new term, the cosmological constant, to the field equations, in order to allow the theory to predict a static universe. The modified field equations predicted a static universe of closed curvature, in accordance with Einstein's understanding of Mach's principle in these years. This model became known as the Einstein World or Einstein's static universe.[189][190]

Following the discovery of the recession of the nebulae by Edwin Hubble in 1929, Einstein abandoned his static model of the universe, and proposed two dynamic models of the cosmos, The Friedmann-Einstein universe of 1931[191][192] and the Einstein–de Sitter universe of 1932.[193][194] In each of these models, Einstein discarded the cosmological constant, claiming that it was "in any case theoretically unsatisfactory".[191][192][195]

In many Einstein biographies, it is claimed that Einstein referred to the cosmological constant in later years as his "biggest blunder". The astrophysicist Mario Livio has recently cast doubt on this claim, suggesting that it may be exaggerated.[196]

In late 2013, a team led by the Irish physicist Cormac O'Raifeartaigh discovered evidence that, shortly after learning of Hubble's observations of the recession of the nebulae, Einstein considered a steady-state model of the universe.[197][198] In a hitherto overlooked manuscript, apparently written in early 1931, Einstein explored a model of the expanding universe in which the density of matter remains constant due to a continuous creation of matter, a process he associated with the cosmological constant.[199][200] As he stated in the paper, "In what follows, I would like to draw attention to a solution to equation (1) that can account for Hubbel's [*sic*] facts, and in which the density is constant over time" ... "If one considers a physically bounded volume, particles of matter will be continually leaving it. For the density to remain constant, new particles of matter must be continually formed in the volume from space."

It thus appears that Einstein considered a steady-state model of the expanding universe many years before Hoyle, Bondi and Gold.[201][202] However, Einstein's steady-state model contained a fundamental flaw and he quickly abandoned the idea.[199][200][203]

Energy momentum pseudotensor

Main article: Stress–energy–momentum pseudotensor

General relativity includes a dynamical spacetime, so it is difficult to see how to identify the conserved energy and momentum. Noether's theorem allows these quantities to be determined from a Lagrangian with translation invariance, but general covariance makes translation invariance into something of a gauge symmetry. The energy and momentum derived within general relativity by Noether's prescriptions do not make a real tensor for this reason.

Einstein argued that this is true for a fundamental reason: the gravitational field could be made to vanish by a choice of coordinates. He maintained that the non-covariant energy momentum pseudotensor was, in fact, the best description of the energy momentum distribution in a gravitational field. This approach has been echoed by Lev Landau and Evgeny Lifshitz, and others, and has become standard.

The use of non-covariant objects like pseudotensors was heavily criticized in 1917 by Erwin Schrödinger and others.

Wormholes

Main article: Wormhole
In 1935, Einstein collaborated with Nathan Rosen to produce a model of a wormhole, often called Einstein–Rosen bridges.[204][205] His motivation was to model elementary particles with charge as a solution of gravitational field equations, in line with the program outlined in the paper "Do Gravitational Fields play an Important Role in the Constitution of the Elementary Particles?". These solutions cut and pasted Schwarzschild black holes to make a bridge between two patches.[206]

If one end of a wormhole was positively charged, the other end would be negatively charged. These properties led Einstein to believe that pairs of particles and antiparticles could be described in this way.

Einstein–Cartan theory

Main article: Einstein–Cartan theory

Einstein at his office, University of Berlin, 1920

In order to incorporate spinning point particles into general relativity, the affine connection needed to be generalized to include an antisymmetric part, called the torsion. This modification was made by Einstein and Cartan in the 1920s.

Equations of motion

Main article: Einstein–Infeld–Hoffmann equations

The theory of general relativity has a fundamental law—the Einstein field equations, which describe how space curves. The geodesic equation, which describes how particles move, may be derived from the Einstein field equations.

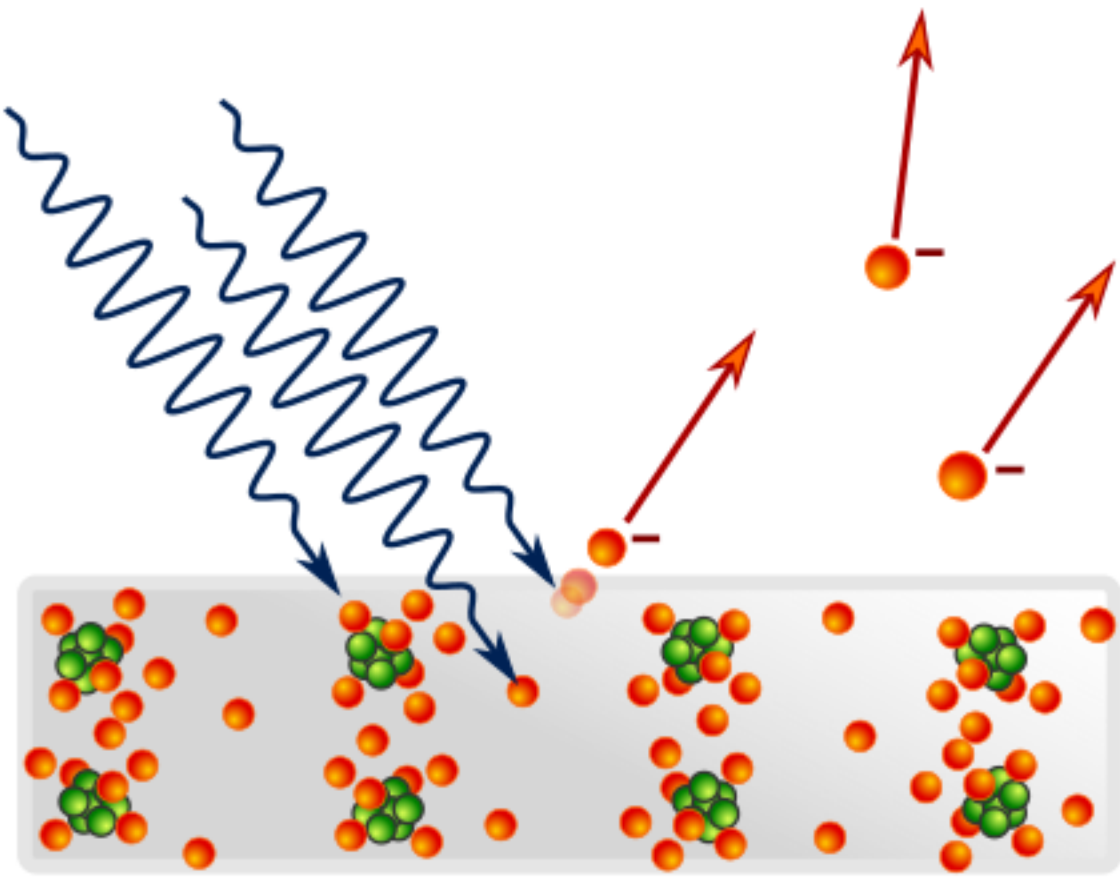
Since the equations of general relativity are non-linear, a lump of energy made out of pure gravitational fields, like a black hole, would move on a trajectory which is determined by the Einstein field equations themselves, not by a new law. So Einstein proposed that the path of a singular solution, like a black hole, would be determined to be a geodesic from general relativity itself.

This was established by Einstein, Infeld, and Hoffmann for pointlike objects without angular momentum, and by Roy Kerr for spinning objects.

Old quantum theory

Main article: Old quantum theory

Photons and energy quanta



The photoelectric effect. Incoming photons on the left strike a metal plate (bottom), and eject electrons, depicted as flying off to the right.

Main articles: Photon and Quantum

In a 1905 paper,[207] Einstein postulated that light itself consists of localized particles (*quanta*). Einstein's light quanta were nearly universally rejected by all physicists, including Max Planck and Niels Bohr. This idea only became universally accepted in 1919, with Robert Millikan's detailed experiments on the photoelectric effect, and with the measurement of Compton scattering.

Einstein concluded that each wave of frequency f is associated with a collection of photons with energy hf each, where h is Planck's constant. He does not say much more, because he is not sure how the particles are related to the wave. But he does suggest that this idea would explain certain experimental results, notably the photoelectric effect.[207]

Quantized atomic vibrations

Main article: Einstein solid

In 1907, Einstein proposed a model of matter where each atom in a lattice structure is an independent harmonic oscillator. In the Einstein model, each atom oscillates independently—a series of equally spaced quantized states for each oscillator. Einstein was aware that getting the frequency of the actual oscillations would be difficult, but he nevertheless proposed this theory because it was a particularly clear demonstration that quantum mechanics could solve the specific heat problem in classical mechanics. Peter Debye refined this model.[208]

Adiabatic principle and action-angle variables

Main article: Adiabatic invariant

Throughout the 1910s, quantum mechanics expanded in scope to cover many different systems. After Ernest Rutherford discovered the nucleus and proposed that electrons orbit like planets, Niels Bohr was able to show that the same quantum mechanical postulates introduced by Planck and developed by Einstein would explain the discrete motion of electrons in atoms, and the periodic table of the elements.

Einstein contributed to these developments by linking them with the 1898 arguments Wilhelm Wien had made. Wien had shown that the hypothesis of adiabatic invariance of a thermal equilibrium state allows all the blackbody curves at different temperature to be derived from one another by a simple shifting process. Einstein noted in 1911 that the same adiabatic principle shows that the quantity which is quantized in any mechanical motion must be an adiabatic invariant. Arnold Sommerfeld identified this adiabatic invariant as the action variable of classical mechanics.

Bose–Einstein statistics

Main article: Bose–Einstein statistics

In 1924, Einstein received a description of a statistical model from Indian physicist Satyendra Nath Bose, based on a counting method that assumed that light could be understood as a gas of indistinguishable particles. Einstein noted that Bose's statistics applied to some atoms as well as to the proposed light particles, and submitted his translation of Bose's paper to the *Zeitschrift für Physik*. Einstein also published his own articles describing the model and its implications, among them the Bose–Einstein condensate phenomenon that some particulates should appear at very low temperatures.[209] It was not until 1995 that the first such condensate was produced experimentally by Eric Allin Cornell and Carl Wieman using ultra-cooling equipment built at the NIST–JILA laboratory at the University of Colorado at Boulder.[210] Bose–Einstein statistics are now used to describe the behaviors of any assembly of bosons. Einstein's sketches for this project may be seen in the Einstein Archive in the library of the Leiden University.[160]

Wave–particle duality

Main article: Wave–particle duality

Although the patent office promoted Einstein to Technical Examiner Second Class in 1906, he had not given up on academia. In 1908, he became a *Privatdozent* at the University of Bern.[211] In "*Über die Entwicklung unserer Anschauungen über das Wesen und die Konstitution der Strahlung*" ("The Development of our Views on the Composition and Essence of Radiation"), on the quantization of light, and in an earlier 1909 paper, Einstein showed that Max Planck's energy quanta must have well-defined momenta and act in some respects as independent, point-like particles. This paper introduced the *photon* concept (although the name *photon* was introduced later by Gilbert N. Lewis in 1926) and inspired the notion of wave–particle duality in quantum mechanics. Einstein saw this wave–particle duality in radiation as concrete evidence for his conviction that physics needed a new, unified foundation.

Zero-point energy

Main article: Zero-point energy

In a series of works completed from 1911 to 1913, Planck reformulated his 1900 quantum theory and introduced the idea of zero-point energy in his "second quantum theory". Soon, this idea attracted the attention of Einstein and his assistant Otto Stern. Assuming the energy of rotating diatomic molecules contains zero-point energy, they then compared the theoretical specific heat of hydrogen gas with the experimental data. The numbers matched nicely. However, after publishing the findings, they promptly withdrew their support, because they no longer had confidence in the correctness of the idea of zero-point energy.[212]

Stimulated emission

Main article: Stimulated emission

In 1917, at the height of his work on relativity, Einstein published an article in *Physikalische Zeitschrift* that proposed the possibility of stimulated emission, the physical process that makes possible the maser and the laser.[213] This article showed that the statistics of absorption and emission of light would only be consistent with Planck's distribution law if the emission of light into a mode with n photons would be enhanced statistically compared to the emission of light into an empty mode. This paper was enormously influential in the later development of quantum mechanics, because it was the first paper to show that the statistics of atomic transitions had simple laws.

Matter waves

Main article: Matter wave

Einstein discovered Louis de Broglie's work and supported his ideas, which were received skeptically at first. In another major paper from this era, Einstein gave a wave equation for de Broglie waves, which Einstein suggested was the Hamilton–Jacobi equation of mechanics. This paper would inspire Schrödinger's work of 1926.

Quantum mechanics

Einstein's objections to quantum mechanics

Believes a whole description of “the physical can provided eventual

Einstein played a major role in developing quantum theory, beginning with his 1905 paper on the photoelectric effect. However, he became displeased with modern quantum mechanics as it had evolved after 1925, despite its acceptance by other physicists. He was skeptical that the randomness of quantum mechanics was fundamental rather than the result of determinism, stating that God "is not playing at dice".[214] Until the end of his life, he continued to maintain that quantum mechanics was incomplete.[215]

Bohr versus Einstein

Main article: Bohr–Einstein debates

The Bohr–Einstein debates were a series of public disputes about quantum mechanics between Einstein and Niels Bohr, who were two of its founders. Their debates are remembered because of their importance to the philosophy of science.[216][217][218] Their debates would influence later interpretations of quantum mechanics.

Einstein–Podolsky–Rosen paradox

Main article: EPR paradox

In 1935, Einstein returned to quantum mechanics, in particular to the question of its completeness, in the "EPR paper".[218] In a thought experiment, he considered two particles which had interacted such that their properties were strongly correlated. No matter how far the two particles were separated, a precise position measurement on one particle would result in equally precise knowledge of the position of the other particle; likewise a precise momentum measurement of one particle would result in equally precise knowledge of the momentum of the other particle, without needing to disturb the other particle in any way.[219]

Given Einstein's concept of local realism, there were two possibilities: (1) either the other particle had these properties already determined, or (2) the process of measuring the first particle instantaneously affected the reality of the position and momentum of the second particle. Einstein rejected this second possibility (popularly called "spooky action at a distance").[219]

Einstein's belief in local realism led him to assert that, while the correctness of quantum mechanics was not in question, it must be incomplete. But as a physical principle, local realism was shown to be incorrect when the Aspect experiment of 1982 confirmed Bell's theorem, which J. S. Bell had delineated in 1964. The results of these and subsequent experiments demonstrate that quantum physics cannot be represented by any version of the picture of physics in which "particles are regarded as unconnected independent classical-like entities, each one being unable to communicate with the other after they have separated."[220]

Although Einstein was wrong about local realism, his clear prediction of the unusual properties of its opposite, *entangled quantum states*, has resulted in the EPR paper becoming among the top ten papers published in Physical Review. It is considered a centerpiece of the development of quantum information theory.[221]

Unified field theory

Main article: Classical unified field theories

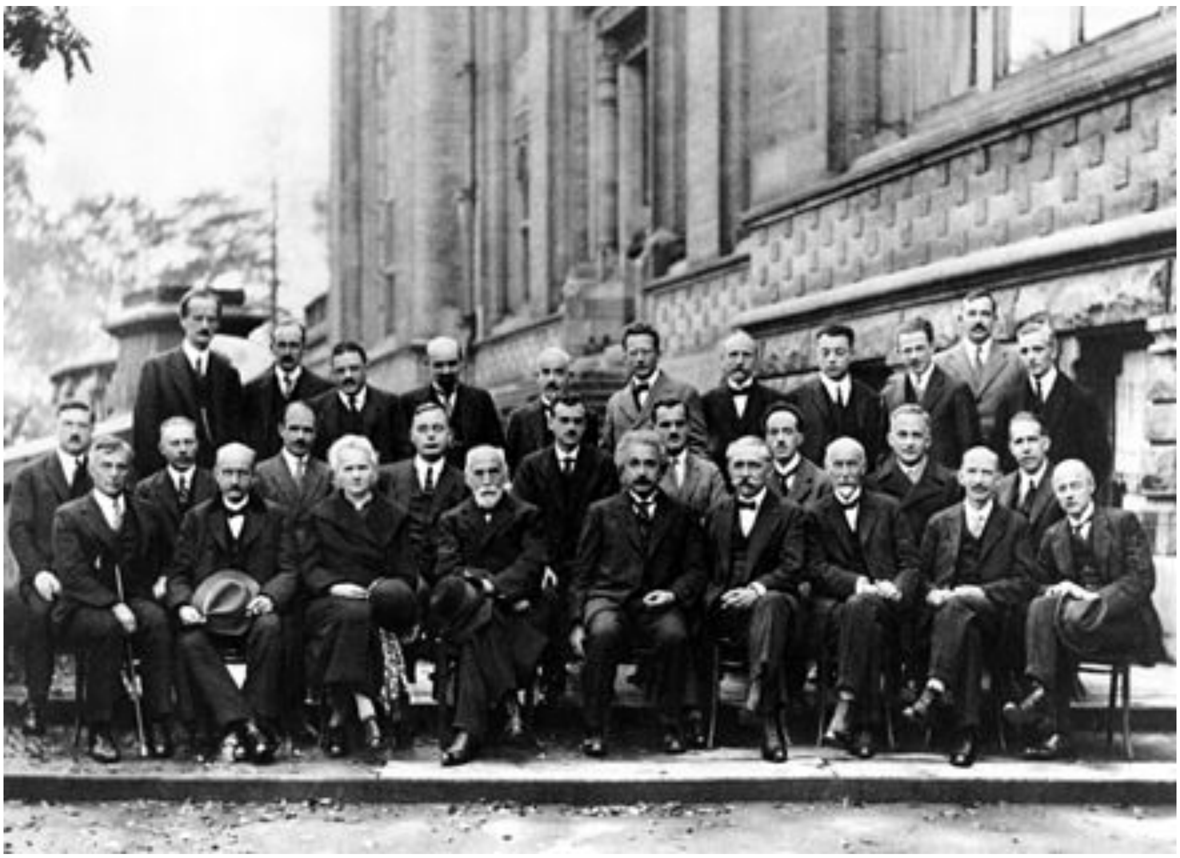
Following his research on general relativity, Einstein entered into a series of attempts to generalize his geometric theory of gravitation to include electromagnetism as another aspect of a single entity. In 1950, he described his "unified field theory" in a *Scientific American* article titled "On the Generalized Theory of Gravitation".[222] Although he continued to be lauded for his work, Einstein became increasingly isolated in his research, and his efforts were ultimately unsuccessful. In his pursuit of a unification of the fundamental forces, Einstein ignored some mainstream developments in physics, most notably the strong and weak nuclear forces, which were not well understood until many years after his death. Mainstream physics, in turn, largely ignored Einstein's approaches to unification. Einstein's dream of unifying other laws of physics with gravity motivates modern quests for a theory of everything and in particular string theory, where geometrical fields emerge in a unified quantum-mechanical setting.

Other investigations

Main article: Einstein's unsuccessful investigations

Einstein conducted other investigations that were unsuccessful and abandoned. These pertain to force, superconductivity, and other research.

Collaboration with other scientists



The 1927 Solvay Conference in Brussels, a gathering of the world's top physicists. Einstein is in the center.

In addition to longtime collaborators Leopold Infeld, Nathan Rosen, Peter Bergmann and others, Einstein also had some one-shot collaborations with various scientists.

Einstein–de Haas experiment

Main article: Einstein–de Haas effect

Einstein and De Haas demonstrated that magnetization is due to the motion of electrons, nowadays known to be the spin. In order to show this, they reversed the magnetization in an iron bar suspended on a torsion pendulum. They confirmed that this leads the bar to rotate, because the electron's angular momentum changes as the magnetization changes. This experiment needed to be sensitive because the angular momentum associated with electrons is small, but it definitively established that electron motion of some kind is responsible for magnetization.

Schrödinger gas model

Einstein suggested to Erwin Schrödinger that he might be able to reproduce the statistics of a Bose–Einstein gas by considering a box. Then to each possible quantum motion of a particle in a box associate an independent harmonic oscillator. Quantizing these oscillators, each level will have an integer occupation number, which will be the number of particles in it.[*citation needed*]

This formulation is a form of second quantization, but it predates modern quantum mechanics. Erwin Schrödinger applied this to derive the thermodynamic properties of a semiclassical ideal gas. Schrödinger urged Einstein to add his name as co-author, although Einstein declined the invitation.[223]

Einstein refrigerator

Main article: Einstein refrigerator

In 1926, Einstein and his former student Leó Szilárd co-invented (and in 1930, patented) the Einstein refrigerator. This absorption refrigerator was then revolutionary for having no moving parts and using only heat as an input.[224] On 11 November 1930, U.S. Patent 1,781,541 was awarded to Einstein and Leó Szilárd for the refrigerator. Their invention was not immediately put into commercial production, and the most promising of their patents were acquired by the Swedish company Electrolux.[225]

MAX PLANCK

Max Karl Ernst Ludwig Planck, ForMemRS[1] (German: [ˈplaŋk];[2] English: /ˈplæŋk/;[3] 23 April 1858 – 4 October 1947) was a German theoretical physicist whose discovery of energy quanta won him the Nobel Prize in Physics in 1918.[4]
Planck made many contributions to theoretical physics, but his fame as a physicist rests primarily on his role as the originator of quantum theory,[5] which revolutionized human understanding of atomic and subatomic processes. In 1948 the German scientific institution Kaiser Wilhelm Society (of which Planck was twice president) was renamed Max Planck Society (MPS). The MPS now includes 83 institutions representing a wide range of scientific directions.
Planck came from a traditional, intellectual family. His paternal great-grandfather and grandfather were both theology professors in Göttingen; his father was a law professor at the University of Kiel[6] and Munich. One of his uncles was also a judge.[7]

Planck was born in 1858 in Kiel, Holstein, to Johann Julius Wilhelm Planck and his second wife, Emma Patzig. He was baptized with the name of *Karl Ernst Ludwig Marx Planck*; of his given names, *Marx* (a now obsolete variant of *Markus* or maybe simply an error for *Max*, which is actually short for *Maximilian*) was indicated as the "appellation name".[8] However, by the age of ten he signed with the name *Max* and used this for the rest of his life.[9]
He was the 6th child in the family, though two of his siblings were from his father's first marriage. War was common during Planck's early years and among his earliest memories was the marching of Prussian and Austrian troops into Kiel during the Second Schleswig War in 1864.[7]
In 1867 the family moved to Munich, and Planck enrolled in the Maximilians gymnasium school, where he came under the tutelage of Hermann Müller, a mathematician who took an interest in the youth, and taught him astronomy and mechanics as well as mathematics. It was from Müller that Planck first learned the principle of conservation of energy. Planck graduated early, at age 17.[10] This is how Planck first came in contact with the field of physics.
Planck was gifted when it came to music. He took singing lessons and played piano, organ and cello, and composed songs and operas. However, instead of music he chose to study physics.

The Munich physics professor Philipp von Jolly advised Planck against going into physics, saying, "In this field, almost everything is already discovered, and all that remains is to fill a few holes."[11] Planck replied that he did not wish to discover new things, but only to understand the known fundamentals of the field, and so began his studies in 1874 at the University of Munich. Under Jolly's supervision, Planck performed the only experiments of his scientific career, studying the diffusion of hydrogen through heated platinum, but transferred to theoretical physics.
In 1877 he went to the Friedrich Wilhelms University in Berlin for a year of study with physicists Hermann von Helmholtz and Gustav Kirchhoff and mathematician Karl Weierstrass. He wrote that Helmholtz was never quite prepared, spoke slowly, miscalculated endlessly, and bored his listeners, while Kirchhoff spoke in carefully prepared lectures which were dry and monotonous. He soon became close friends with Helmholtz. While there he undertook a program of mostly self-study of Clausius's writings, which led him to choose thermodynamics as his field.
In October 1878 Planck passed his qualifying exams and in February 1879 defended his dissertation, *Über den zweiten Hauptsatz der mechanischen Wärmetheorie* (*On the second law of thermodynamics*). He briefly taught mathematics and physics at his former school in Munich.

By the year 1880, Planck had obtained the two highest academic degrees offered in Europe. The first was a doctorate degree after he completed his paper detailing his research and theory of thermodynamics.[7] He then presented his thesis called *Gleichgewichtszustände isotroper Körper in verschiedenen Temperaturen* (*Equilibrium states of isotropic bodies at different temperatures*), which earned him a habilitation.

Black-body radiation[edit]

In 1894 Planck turned his attention to the problem of black-body radiation. The problem had been stated by Kirchhoff in 1859: "how does the intensity of the electromagnetic radiation emitted by a black body (a perfect absorber, also known as a cavity radiator) depend on the frequency of the radiation (i.e., the color of the light) and the temperature of the body?". The question had been explored experimentally, but no theoretical treatment agreed with experimental values. Wilhelm Wien proposed Wien's law, which correctly predicted the behaviour at high frequencies, but failed at low frequencies. The Rayleigh–Jeans law, another approach to the problem, agreed with experimental results at low frequencies, but created what was later known as the "ultraviolet catastrophe" at high frequencies. However, contrary to many textbooks this was not a motivation for Planck.[20]

Planck's first proposed solution to the problem in 1899 followed from what Planck called the "principle of elementary disorder", which allowed him to derive Wien's law from a number of assumptions about the entropy of an ideal oscillator, creating what was referred-to as the Wien–Planck law. Soon it was found that experimental evidence did not confirm the new law at all, to Planck's frustration. Planck revised his approach, deriving the first version of the famous Planck black-body radiation law, which described the experimentally observed black-body spectrum well. It was first proposed in a meeting of the DPG on 19 October 1900 and published in 1901. This first derivation did not include energy quantisation, and did not use statistical mechanics, to which he held an aversion. In November 1900 Planck revised this first approach, relying on Boltzmann's statistical interpretation of the second law of thermodynamics as a way of gaining a more fundamental understanding of the principles behind his radiation law. As Planck was deeply suspicious of the philosophical and physical implications of such an interpretation of Boltzmann's approach, his recourse to them was, as he later put it, "an act of despair ... I was ready to sacrifice any of my previous convictions about physics".[20]

The central assumption behind his new derivation, presented to the DPG on 14 December 1900, was the supposition, now known as the Planck postulate, that electromagnetic energy could be emitted only in quantized form, in other words, the energy could only be a multiple of an elementary unit:

$$E=h\nu$$

where h is Planck's constant, also known as Planck's action quantum (introduced already in 1899), and ν is the frequency of the radiation. Note that the elementary units of energy discussed here are represented by $h\nu$ and not simply by ν. Physicists now call these quanta photons, and a photon of frequency ν will have its own specific and unique energy. The total energy at that frequency is then equal to $h\nu$ multiplied by the number of photons at that frequency.

At first Planck considered that quantisation was only "a purely formal assumption ... actually I did not think much about it ..."; nowadays this assumption, incompatible with classical physics, is regarded as the birth of quantum physics and the greatest intellectual accomplishment of Planck's career (Ludwig Boltzmann had been discussing in a theoretical paper in 1877 the possibility that the energy states of a physical system could be discrete). The discovery of Planck's constant enabled him to define a new universal set of physical units (such as the Planck length and the Planck mass), all based on fundamental physical constants upon which much of quantum theory is based. In recognition of Planck's fundamental contribution to a new branch of physics, he was awarded the Nobel Prize in Physics for 1918 (he actually received the award in 1919).[21][22]

Subsequently, Planck tried to grasp the meaning of energy quanta, but to no avail. "My unavailing attempts to somehow reintegrate the action quantum into classical theory extended over several years and caused me much trouble." Even several years later, other physicists like Rayleigh, Jeans, and Lorentz set Planck's constant to zero in order to align with classical physics, but Planck knew well that this constant had a precise nonzero value. "I am unable to understand Jeans' stubbornness – he is an example of a theoretician as should never be existing, the same as Hegel was for philosophy. So much the worse for the facts if they don't fit."[23]

Max Born wrote about Planck: "He was, by nature, a conservative mind; he had nothing of the revolutionary and was thoroughly skeptical about speculations. Yet his belief in the compelling force of logical reasoning from facts was so strong that he did not flinch from announcing the most revolutionary idea which ever has shaken physics."[1]

Einstein and the theory of relativity[edit]

In 1905 the three epochal papers by Albert Einstein were published in the journal *Annalen der Physik*. Einstein's hypothesis of light *quanta* (photons), based on Heinrich Hertz's 1887 discovery (and further investigation by Philipp Lenard) of the photoelectric effect, was initially rejected by Planck. He was unwilling to discard completely Maxwell's theory of electrodynamics. "The theory of light would be thrown back not by decades, but by centuries, into the age when Christiaan Huygens dared to fight against the mighty emission theory of Isaac Newton ..."[25]

In 1910 Einstein pointed out the anomalous behavior of specific heat at low temperatures as another example of a phenomenon which defies explanation by classical physics. Planck and Nernst, seeking to clarify the increasing number of contradictions, organized the First Solvay Conference (Brussels 1911). At this meeting Einstein was able to convince Planck.

Meanwhile, Planck had been appointed dean of Berlin University, whereby it was possible for him to call Einstein to Berlin and establish a new professorship for him (1914). Soon the two scientists became close friends and met frequently to play music together.

First World War[edit]

At the onset of the First World War Planck endorsed the general excitement of the public, writing that, "Besides much that is horrible, there is also much that is unexpectedly great and beautiful: the smooth solution of the most difficult domestic political problems by the unification of all parties (and) ... the extolling of everything good and noble."[26][27]

Nonetheless, Planck refrained from the extremes of nationalism. In 1915, at a time when Italy was about to join the Allied Powers, he voted successfully for a scientific paper from Italy, which received a prize from the Prussian Academy of Sciences, where Planck was one of four permanent presidents.

Planck also signed the infamous "Manifesto of the 93 intellectuals", a pamphlet of polemic war propaganda (while Einstein retained a strictly pacifistic attitude which almost led to his imprisonment, only being spared thanks to his Swiss citizenship).

Post-war and the Weimar Republic[edit]

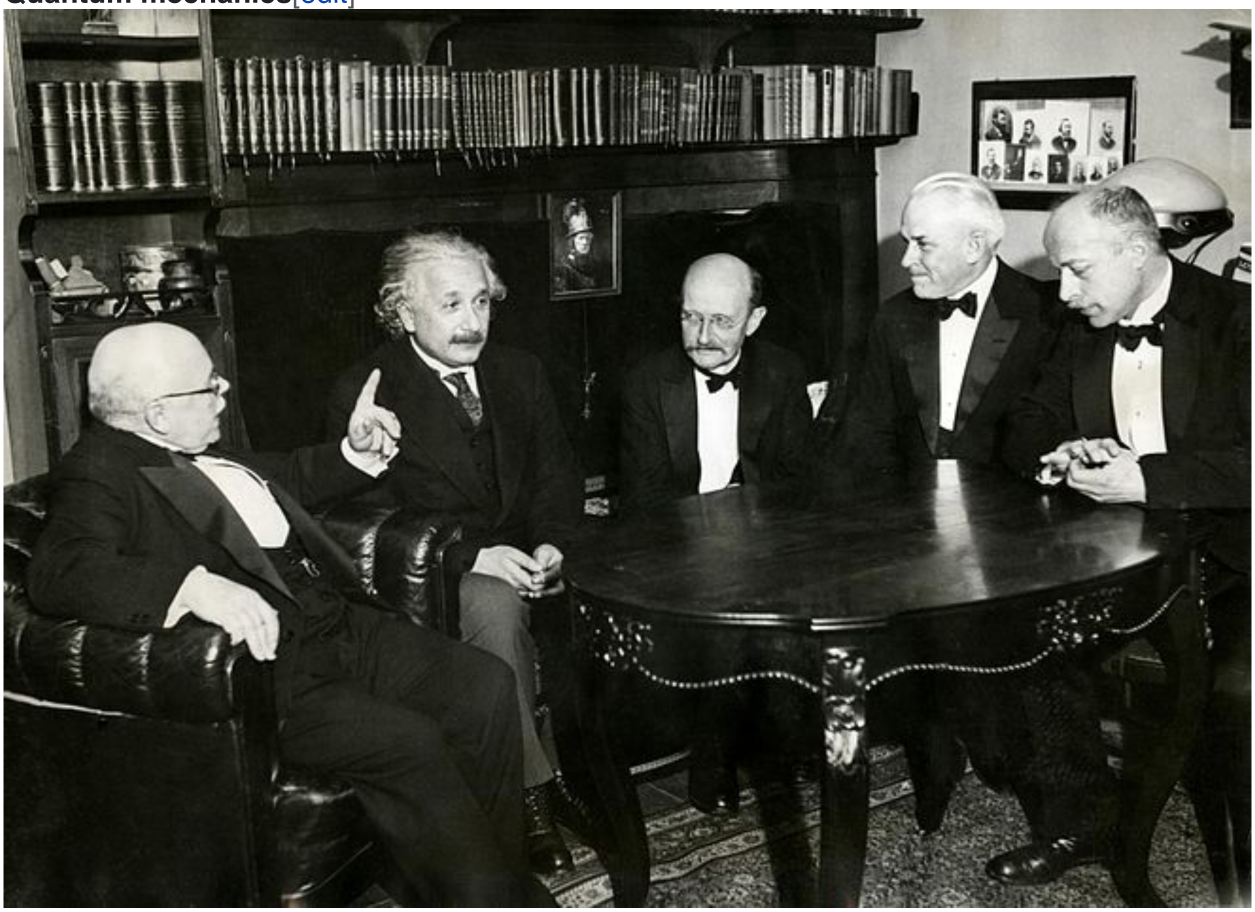
In the turbulent post-war years, Planck, now the highest authority of German physics, issued the slogan "persevere and continue working" to his colleagues.

In October 1920 he and Fritz Haber established the *Notgemeinschaft der Deutschen Wissenschaft* (Emergency Organization of German Science), aimed at providing financial support for scientific research. A considerable portion of the money the organization would distribute was raised abroad.

Planck also held leading positions at Berlin University, the Prussian Academy of Sciences, the German Physical Society and the Kaiser Wilhelm Society (which became the Max Planck Society in 1948). During this time economic conditions in Germany were such that he was hardly able to conduct research. In 1926, Planck became a foreign member of the Royal Netherlands Academy of Arts and Sciences.[28]

During the interwar period, Planck became a member of the Deutsche Volks-Partei (German People's Party), the party of Nobel Peace Prize laureate Gustav Stresemann, which aspired to liberal aims for domestic policy and rather revisionistic aims for politics around the world. Planck disagreed with the introduction of universal suffrage and later expressed the view that the Nazi dictatorship resulted from "the ascent of the rule of the crowds".[29]

Quantum mechanics[edit]



From left to right: W. Nernst, A. Einstein, ***M. Planck***, R.A. Millikan and von Laue at a dinner given by von Laue in Berlin on 11 November 1931

At the end of the 1920s Bohr, Heisenberg and Pauli had worked out the Copenhagen interpretation of quantum mechanics, but it was rejected by Planck, and by Schrödinger, Laue, and Einstein as well. Planck expected that wave mechanics would soon render quantum theory —his own child—unnecessary. This was not to be the case, however. Further work only cemented quantum theory, even against his and Einstein's philosophical revulsions. Planck experienced the truth of his own earlier observation from his struggle with the older views in his younger years: "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it."[30]

Nazi dictatorship and the Second World War[edit]

When the Nazis came to power in 1933, Planck was 74. He witnessed many Jewish friends and colleagues expelled from their positions and humiliated, and hundreds of scientists emigrate from Nazi Germany. Again he tried to "persevere and continue working" and asked scientists who were considering emigration to remain in Germany. Nevertheless, he did help his nephew, the economist Hermann Kranold, to emigrate to London after his arrest.[31] He hoped the crisis would abate soon and the political situation would improve.

Otto Hahn asked Planck to gather well-known German professors in order to issue a public proclamation against the treatment of Jewish professors, but Planck replied, "If you are able to gather today 30 such gentlemen, then tomorrow 150 others will come and speak against it, because they are eager to take over the positions of the others."[32] Under Planck's leadership, the Kaiser Wilhelm Society (KWG) avoided open conflict with the Nazi regime, except concerning Fritz Haber. Planck tried to discuss the issue with Adolf Hitler but was unsuccessful. In the following year, 1934, Haber died in exile.

One year later, Planck, having been the president of the KWG since 1930, organized in a somewhat provocative style an official commemorative meeting for Haber. He also succeeded in secretly enabling a number of Jewish scientists to continue working in institutes of the KWG for several years. In 1936, his term as president of the KWG ended, and the Nazi government pressured him to refrain from seeking another term.

As the political climate in Germany gradually became more hostile, Johannes Stark, prominent exponent of Deutsche Physik ("German Physics", also called "Aryan Physics") attacked Planck, Sommerfeld and Heisenberg for continuing to teach the theories of Einstein, calling them "white Jews". The "Hauptamt Wissenschaft" (Nazi government office for science) started an investigation of Planck's ancestry, claiming that he was "1/16 Jewish", but Planck himself denied it.[33]

In 1938 Planck celebrated his 80th birthday. The DPG held a celebration, during which the Max-Planck medal (founded as the highest medal by the DPG in 1928) was awarded to French physicist Louis de Broglie. At the end of 1938, the Prussian Academy lost its remaining independence and was taken over by Nazis (*Gleichschaltung*). Planck protested by resigning his presidency. He continued to travel frequently, giving numerous public talks, such as his talk on Religion and Science, and five years later he was sufficiently fit to climb 3,000-metre peaks in the Alps.

During the Second World War the increasing number of Allied bombing missions against Berlin forced Planck and his wife to temporarily leave the city and live in the countryside. In 1942 he wrote: "In me an ardent desire has grown to persevere this crisis and live long enough to be able to witness the turning point, the beginning of a new rise." In February 1944, his home in Berlin was completely destroyed by an air raid, annihilating all his scientific records and correspondence. His rural retreat was threatened by the rapid advance of the Allied armies from both sides.

In 1944 Planck's son Erwin was arrested by the Gestapo following the attempted assassination of Hitler in the 20 July plot. He was tried and sentenced to death by the People's Court in October 1944. Erwin was hanged at Berlin's Plötzensee Prison in January 1945. The death of his son destroyed much of Planck's will to live.[34] After the end of the war Planck, his second wife, and his son by her were brought to a relative in Göttingen, where Planck died on 4 October 1947. His grave is situated in the old Stadtfriedhof (City Cemetery) in Göttingen.[35]

Religious views[edit]

Planck was a member of the Lutheran Church in Germany.[36] He was very tolerant towards alternative views and religions.[37] In a lecture in 1937 entitled "Religion und Naturwissenschaft" (Religion and Natural Science) he suggested the importance of these symbols and rituals related directly with a believer's ability to worship God, but that one must be mindful that the symbols provide an imperfect illustration of divinity. He criticized atheism for being focused on the derision of such symbols, while at the same time warned of the over-estimation of the importance of such symbols by believers.[38]

Planck was tolerant and favorable to all religions. Although he remained in the Lutheran Church, he did not promote Christian or Biblical views. He believed "the faith in miracles must yield, step by step, before the steady and firm advance of the facts of science, and its total defeat is undoubtedly a matter of time." [39]

In his 1937 lecture "Religion and Naturwissenschaft", Planck expressed the view that God is everywhere present, and held that "the holiness of the unintelligible Godhead is conveyed by the holiness of symbols." Atheists, he thought, attach too much importance to what are merely symbols. He was a churchwarden from 1920 until his death, and believed in an almighty, all-knowing, beneficent God (though not necessarily a personal one). Both science and religion wage a "tireless battle against skepticism and dogmatism, against unbelief and superstition" with the goal "toward God!"[39]

Planck said in 1944, "As a man who has devoted his whole life to the most clear headed science, to the study of matter, I can tell you as a result of my research about atoms this much: There is no matter as such. All matter originates and exists only by virtue of a force which brings the particle of an atom to vibration and holds this most minute solar system of the atom together. We must assume behind this force the existence of a conscious and intelligent spirit (orig. geist). This spirit is the matrix of all matter."[40]

Planck regarded the scientist as a man of imagination and Christian faith. He said: "Both religion and science require a belief in God. For believers, God is in the beginning, and for physicists He is at the end of all considerations… To the former He is the foundation, to the latter, the crown of the edifice of every generalized world view".[41]

On the other hand, Planck wrote, "...'to believe' means 'to recognize as a truth,' and the knowledge of nature, continually advancing on incontestably safe tracks, has made it utterly impossible for a person possessing some training in natural science to recognize as founded on truth the many reports of extraordinary occurrences contradicting the laws of nature, of miracles which are still commonly regarded as essential supports and confirmations of religious doctrines, and which formerly used to be accepted as facts pure and simple, without doubt or criticism. The belief in miracles must retreat step by step before relentlessly and reliably progressing science and we cannot doubt that sooner or later it must vanish completely."[42]

Later in life, Planck's views on God were that of a deist.[43] For example, six months before his death a rumour started that he had converted to Catholicism, but when questioned what had brought him to make this step, he declared that, although he had always been deeply religious, he did not believe "in a personal God, let alone a Christian God”.[44]

Niels Bohr

From Wikipedia, the free encyclopedia
(Redirected from Neils Bohr)

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"Bohr" redirects here. For other uses, see Bohr (disambiguation).

Niels Henrik David Bohr (Danish: [ˈnels ˈpoɐ̯ˀ]; 7 October 1885 – 18 November 1962) was a Danish physicist who made foundational contributions to understanding atomic structure and quantum theory, for which he received the Nobel Prize in Physics in 1922. Bohr was also a philosopher and a promoter of scientific research.

Bohr developed the Bohr model of the atom, in which he proposed that energy levels of electrons are discrete and that the electrons revolve in stable orbits around the atomic nucleus but can jump from one energy level (or orbit) to another. Although the Bohr model has been supplanted by other models, its underlying principles remain valid. He conceived the principle of complementarity: that items could be separately analysed in terms of contradictory properties, like behaving as a wave or a stream of particles. The notion of complementarity dominated Bohr's thinking in both science and philosophy.

Bohr founded the Institute of Theoretical Physics at the University of Copenhagen, now known as the Niels Bohr Institute, which opened in 1920. Bohr mentored and collaborated with physicists including Hans Kramers, Oskar Klein, George de Hevesy, and Werner Heisenberg. He predicted the existence of a new zirconium-like element, which was named hafnium, after the Latin name for Copenhagen, where it was discovered. Later, the element bohrium was named after him.

During the 1930s Bohr helped refugees from Nazism. After Denmark was occupied by the Germans, he had a famous meeting with Heisenberg, who had become the head of the German nuclear weapon project. In September 1943 word reached Bohr that he was about to be arrested by the Germans, and he fled to Sweden. From there, he was flown to Britain, where he joined the British Tube Alloys nuclear weapons project, and was part of the British mission to the Manhattan Project. After the war, Bohr called for international cooperation on nuclear energy. He was involved with the establishment of CERN and the Research Establishment Risø of the Danish Atomic Energy Commission and became the first chairman of the Nordic Institute for Theoretical Physics in 1957.

Bohr model

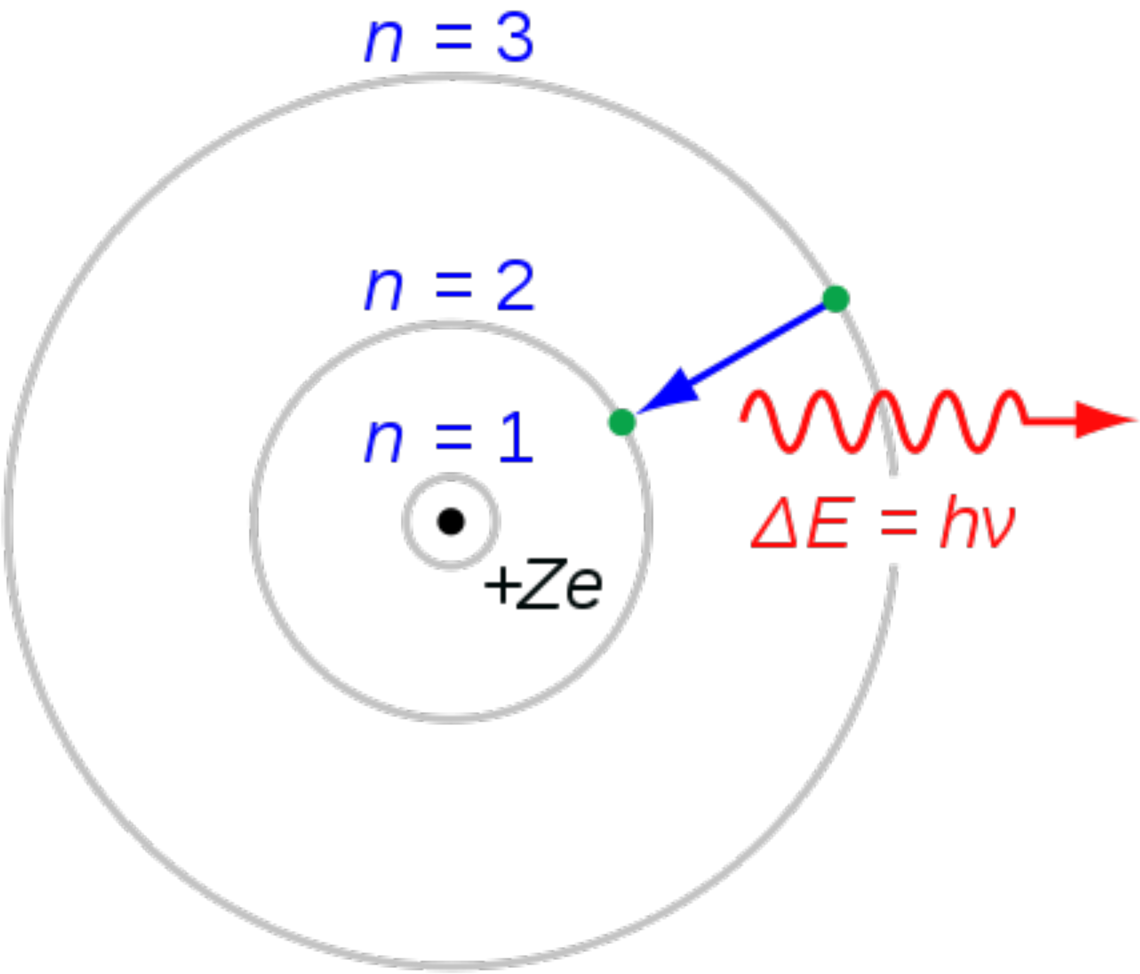
Main article: Bohr model

In September 1911, Bohr, supported by a fellowship from the Carlsberg Foundation, travelled to England. At the time, it was where most of the theoretical work on the structure of atoms and molecules was being done.[20] He met J. J. Thomson of the Cavendish Laboratory and Trinity College, Cambridge. He attended lectures on electromagnetism given by James Jeans and Joseph Larmor, and did some research on cathode rays, but failed to impress Thomson.[21][22] He had more success with younger physicists like the Australian William Lawrence Bragg,[23] and New Zealand's Ernest Rutherford, whose 1911 small central nucleus Rutherford model of the atom had challenged Thomson's 1904 plum pudding model.[24] Bohr received an invitation from Rutherford to conduct post-doctoral work at Victoria University of Manchester,[25] where Bohr met George de Hevesy and Charles Galton Darwin (whom Bohr referred to as "the grandson of the real Darwin").[26]

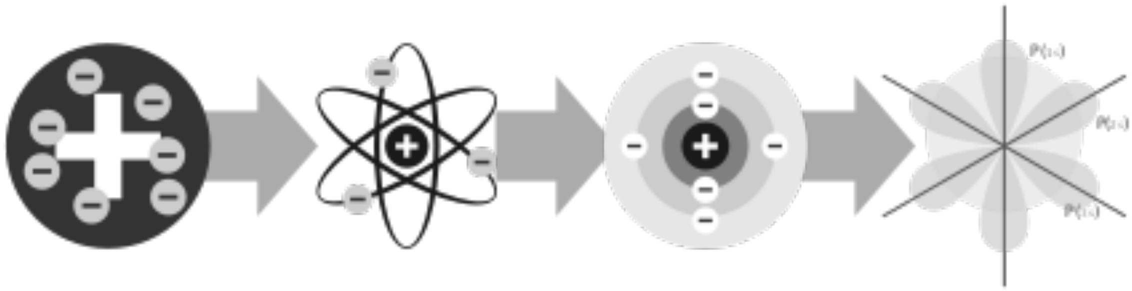
Bohr returned to Denmark in July 1912 for his wedding, and travelled around England and Scotland on his honeymoon. On his return, he became a *privatdocent* at the University of

Copenhagen, giving lectures on thermodynamics. Martin Knudsen put Bohr's name forward for a *docent*, which was approved in July 1913, and Bohr then began teaching medical students.[27] His three papers, which later became famous as "the trilogy",[25] were published in *Philosophical Magazine* in July, September and November of that year.[28][29][30][31] He adapted Rutherford's nuclear structure to Max Planck's quantum theory and so created his Bohr model of the atom.[29]

Planetary models of atoms were not new, but Bohr's treatment was.[32] Taking the 1912 paper by Darwin on the role of electrons in the interaction of alpha particles with a nucleus as his starting point,[33][34] he advanced the theory of electrons travelling in orbits around the atom's nucleus, with the chemical properties of each element being largely determined by the number of electrons in the outer orbits of its atoms.[35] He introduced the idea that an electron could drop from a higher-energy orbit to a lower one, in the process emitting a quantum of discrete energy. This became a basis for what is now known as the old quantum theory.[36]



The **Bohr model** of the hydrogen atom. A negatively charged electron, confined to an atomic orbital, orbits a small, positively charged nucleus; a quantum jump between orbits is accompanied by an emitted or absorbed amount of electromagnetic radiation.



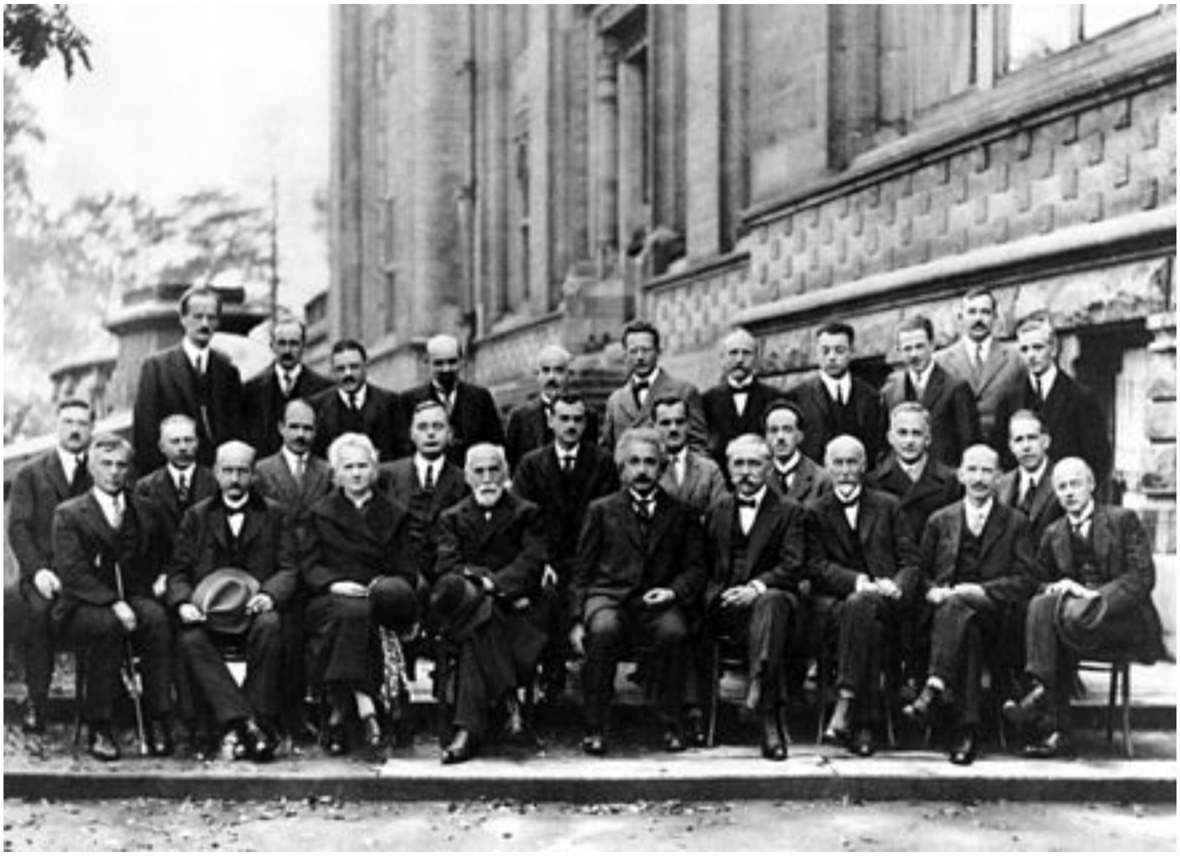
where m_e is the electron's mass, e is its charge, h is Planck's constant and Z is the atom's atomic number (1 for hydrogen).[38]

The model's first hurdle was the Pickering series, lines which did not fit Balmer's formula. When challenged on this by Alfred Fowler, Bohr replied that they were caused by ionised helium, helium atoms with only one electron. The Bohr model was found to work for such ions.[38] Many older physicists, like Thomson, Rayleigh and Hendrik Lorentz, did not like the trilogy, but the younger generation, including Rutherford, David Hilbert, Albert Einstein, Enrico Fermi, Max Born and Arnold Sommerfeld saw it as a breakthrough.[39][40] The trilogy's acceptance was entirely due to its ability to explain phenomena which stymied other models, and to predict results that were subsequently verified by experiments.[41] Today, the Bohr model of the atom has been superseded, but is still the best known model of the atom, as it often appears in high school physics and chemistry texts.[42]

Bohr did not enjoy teaching medical students. He decided to return to Manchester, where Rutherford had offered him a job as a reader in place of Darwin, whose tenure had expired. Bohr accepted. He took a leave of absence from the University of Copenhagen, which he started by taking a holiday in Tyrol with his brother Harald and aunt Hanna Adler. There, he visited the University of Göttingen and the Ludwig Maximilian University of Munich, where he met Sommerfeld and conducted seminars on the trilogy. The First World War broke out while they were in Tyrol, greatly complicating the trip back to Denmark and Bohr's subsequent voyage with Margrethe to England, where he arrived in October 1914. They stayed until July 1916, by which time he had been appointed to the Chair of Theoretical Physics at the University of Copenhagen, a position created especially for him. His docentship was abolished at the same time, so he still had to teach physics to medical students. New professors were formally introduced to King Christian X, who expressed his delight at meeting such a famous football player.[43]

Quantum mechanics

The introduction of spin by George Uhlenbeck and Samuel Goudsmit in November 1925 was a milestone. The next month, Bohr travelled to Leiden to attend celebrations of the 50th anniversary of Hendrick Lorentz receiving his doctorate. When his train stopped in Hamburg, he was met by Wolfgang Pauli and Otto Stern, who asked for his opinion of the spin theory. Bohr pointed out that he had concerns about the interaction between electrons and magnetic fields. When he arrived in Leiden, Paul Ehrenfest and Albert Einstein informed Bohr that Einstein had resolved this problem using relativity. Bohr then had Uhlenbeck and Goudsmit incorporate this into their paper. Thus, when he met Werner Heisenberg and Pascual Jordan in Göttingen on the way back, he had become, in his own words, "a prophet of the electron magnet gospel".[57]



1927 Solvay Conference in Brussels, October 1927. Bohr is on the right in the middle row, next to Max Born.

Heisenberg first came to Copenhagen in 1924, then returned to Göttingen in June 1925, shortly thereafter developing the mathematical foundations of quantum mechanics. When he showed his results to Max Born in Göttingen, Born realised that they could best be expressed using matrices. This work attracted the attention of the British physicist Paul Dirac,[58] who came to Copenhagen for six months in September 1926. Austrian physicist Erwin Schrödinger also visited in 1926. His attempt at explaining quantum physics in classical terms using wave mechanics impressed Bohr, who believed it contributed "so much to mathematical clarity and simplicity that it represents a gigantic advance over all previous forms of quantum mechanics".[59]

When Kramers left the Institute in 1926 to take up a chair as professor of theoretical physics at the Utrecht University, Bohr arranged for Heisenberg to return and take Kramers's place as a *lektor* at the University of Copenhagen.[60] Heisenberg worked in Copenhagen as a university lecturer and assistant to Bohr from 1926 to 1927.[61]

Bohr became convinced that light behaved like both waves and particles and, in 1927, experiments confirmed the de Broglie hypothesis that matter (like electrons) also behaved like waves.[62] He conceived the philosophical principle of complementarity: that items could have apparently mutually exclusive properties, such as being a wave or a stream of particles, depending on the experimental framework.[63] He felt that it was not fully understood by professional philosophers.[64]

In Copenhagen in 1927 Heisenberg developed his uncertainty principle,[65] which Bohr embraced. In a paper he presented at the Volta Conference at Como in September 1927, he demonstrated that the uncertainty principle could be derived from classical arguments, without quantum terminology or matrices.[65] Einstein preferred the determinism of classical physics over the probabilistic new quantum physics to which he himself had contributed. Philosophical issues that arose from the novel aspects of quantum mechanics became widely celebrated subjects of discussion. Einstein and Bohr had good-natured arguments over such issues throughout their lives.[66]

In 1914 Carl Jacobsen, the heir to Carlsberg breweries, bequeathed his mansion to be used for life by the Dane who had made the most prominent contribution to science, literature or the arts, as an honorary residence (Danish: *Æresbolig*). Harald Høffding had been the first occupant, and upon his death in July 1931, the Royal Danish Academy of Sciences and Letters gave Bohr occupancy. He and his family moved there in 1932.[67] He was elected president of the Academy on 17 March 1939.[68]

By 1929 the phenomenon of beta decay prompted Bohr to again suggest that the law of conservation of energy be abandoned, but Enrico Fermi's hypothetical neutrino and the subsequent 1932 discovery of the neutron provided another explanation. This prompted Bohr to create a new theory of the compound nucleus in 1936, which explained how neutrons could be captured by the nucleus. In this model, the nucleus could be deformed like a drop of liquid. He worked on this with a new collaborator, the Danish physicist Fritz Kalckar, who died suddenly in 1938.[69][70]

The discovery of nuclear fission by Otto Hahn in December 1938 (and its theoretical explanation by Lise Meitner) generated intense interest among physicists. Bohr brought the news to the United States where he opened the Fifth Washington Conference on Theoretical Physics with Fermi on 26 January 1939.[71] When Bohr told George Placzek that this resolved all the mysteries of transuranic elements, Placzek told him that one remained: the neutron capture energies of uranium did not match those of its decay. Bohr thought about it for a few minutes and then announced to Placzek, Léon Rosenfeld and John Wheeler that "I have understood everything."[72] Based on his liquid drop model of the nucleus, Bohr concluded that it was the uranium-235 isotope and not the more abundant uranium-238 that was primarily responsible for fission with thermal neutrons. In April 1940, John R. Dunning demonstrated that

Bohr was correct.[71] In the meantime, Bohr and Wheeler developed a theoretical treatment which they published in a September 1939 paper on "The Mechanism of Nuclear Fission".[73]

Philosophy

Heisenberg said of Bohr that he was "primarily a philosopher, not a physicist".[74] Bohr read the 19th-century Danish Christian existentialist philosopher, Søren Kierkegaard. Richard Rhodes argued in *The Making of the Atomic Bomb* that Bohr was influenced by Kierkegaard through Høffding.[75] In 1909, Bohr sent his brother Kierkegaard's *Stages on Life's Way* as a birthday gift. In the enclosed letter, Bohr wrote, "It is the only thing I have to send home; but I do not believe that it would be very easy to find anything better ... I even think it is one of the most delightful things I have ever read." Bohr enjoyed Kierkegaard's language and literary style, but mentioned that he had some disagreement with Kierkegaard's philosophy.[76] Some of Bohr's biographers suggested that this disagreement stemmed from Kierkegaard's advocacy of Christianity, while Bohr was an atheist.[77][78][79]

There has been some dispute over the extent to which Kierkegaard influenced Bohr's philosophy and science. David Favrholdt argued that Kierkegaard had minimal influence over Bohr's work, taking Bohr's statement about disagreeing with Kierkegaard at face value,[80] while Jan Faye argued that one can disagree with the content of a theory while accepting its general premises and structure.[81][76] Regarding the nature of physics and quantum mechanics Bohr opined that "There is no quantum world. This is only an abstract physical description. It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature”.[82]

Meeting with Heisenberg

Werner Heisenberg (left) with Bohr at the Copenhagen Conference in 1934

Bohr was aware of the possibility of using uranium-235 to construct an atomic bomb, referring to it in lectures in Britain and Denmark shortly before and after the war started, but he did not believe that it was technically feasible to extract a sufficient quantity of uranium-235.[87] In September 1941, Heisenberg, who had become head of the German nuclear energy project, visited Bohr in Copenhagen. During this meeting the two men took a private moment outside, the content of which has caused much speculation, as both gave differing accounts. According to Heisenberg, he began to address nuclear energy, morality and the war, to which Bohr seems to have reacted by terminating the conversation abruptly while not giving Heisenberg hints about his own opinions.[88] Ivan Supek, one of Heisenberg's students and friends, claimed that the main subject of the meeting was Carl Friedrich von Weizsäcker, who had proposed trying to persuade Bohr to mediate peace between Britain and Germany.[89]

In 1957, Heisenberg wrote to Robert Jungk, who was then working on the book *Brighter than a Thousand Suns: A Personal History of the Atomic Scientists*. Heisenberg explained that he had visited Copenhagen to communicate to Bohr the views of several German scientists, that production of a nuclear weapon was possible with great efforts, and this raised enormous responsibilities on the world's scientists on both sides.[90] When Bohr saw Jungk's depiction in the Danish translation of the book, he drafted (but never sent) a letter to Heisenberg, stating that he never understood the purpose of Heisenberg's visit, was shocked by Heisenberg's opinion that Germany would win the war, and that atomic weapons could be decisive.[91]

Michael Frayn's 1998 play *Copenhagen* explores what might have happened at the 1941 meeting between Heisenberg and Bohr.[92] A BBC television film version of the play was first screened on 26 September 2002, with Stephen Rea as Bohr, and Daniel Craig as Heisenberg. The same meeting had previously been dramatised by the BBC's *Horizon* science documentary series in 1992, with Anthony Bate as Bohr, and Philip Anthony as Heisenberg.[93] The meeting is also dramatized in the Norwegian/Danish/British miniseries *The Heavy Water War*.[94]

Manhattan Project

In September 1943, word reached Bohr and his brother Harald that the Nazis considered their family to be Jewish, since their mother was Jewish, and that they were therefore in danger of being arrested. The Danish resistance helped Bohr and his wife escape by sea to Sweden on 29 September.[95][96] The next day, Bohr persuaded King Gustaf V of Sweden to make public Sweden's willingness to provide asylum to Jewish refugees. On 2 October 1943, Swedish radio broadcast that Sweden was ready to offer asylum, and the mass rescue of the Danish Jews by their countrymen followed swiftly thereafter. Some historians claim that Bohr's actions led directly to the mass rescue, while others say that, though Bohr did all that he could for his countrymen, his actions were not a decisive influence on the wider events.[96][97][98][99] Eventually, over 7,000 Danish Jews escaped to Sweden.[100]

Bohr with James Franck, Albert Einstein and Isidor Isaac Rabi (LR)

When the news of Bohr's escape reached Britain, Lord Cherwell sent a telegram to Bohr asking him to come to Britain. Bohr arrived in Scotland on 6 October in a de Havilland Mosquito operated by the British Overseas Airways Corporation (BOAC).[101][102] The Mosquitos were unarmed high-speed bomber aircraft that had been converted to carry small, valuable cargoes or important passengers. By flying at high speed and high altitude, they could cross German-occupied Norway, and yet avoid German fighters. Bohr, equipped with parachute, flying suit and oxygen mask, spent the three-hour flight lying on a mattress in the aircraft's bomb bay.[103] During the flight, Bohr did not wear his flying helmet as it was too small, and consequently did not hear the pilot's intercom instruction to turn on his oxygen supply when the aircraft climbed to high altitude to overfly Norway. He passed out from oxygen starvation and only revived when the aircraft descended to lower altitude over the North Sea.[104][105][106] Bohr's son Aage followed his father to Britain on another flight a week later, and became his personal assistant.[107]

Bohr was warmly received by James Chadwick and Sir John Anderson, but for security reasons Bohr was kept out of sight. He was given an apartment at St James's Palace and an office with the British Tube Alloys nuclear weapons development team. Bohr was astonished at the amount of progress that had been made.[107][108] Chadwick arranged for Bohr to visit the United States as a Tube Alloys consultant, with Aage as his assistant.[109] On 8 December 1943, Bohr arrived in Washington, D.C., where he met with the director of the Manhattan Project, Brigadier General Leslie R. Groves, Jr. He visited Einstein and Pauli at the Institute for

Advanced Study in Princeton, New Jersey, and went to Los Alamos in New Mexico, where the nuclear weapons were being designed.[110] For security reasons, he went under the name of "Nicholas Baker" in the United States, while Aage became "James Baker".[111] In May 1944 the Danish resistance newspaper De frie Danske reported that they had learned that 'the famous son of Denmark Professor Niels Bohr' in October the previous year had fled his country via Sweden to London and from there travelled to Moscow from where he could be assumed to support the war effort.[112]

Bohr did not remain at Los Alamos, but paid a series of extended visits over the course of the next two years. Robert Oppenheimer credited Bohr with acting "as a scientific father figure to the younger men", most notably Richard Feynman.[113] Bohr is quoted as saying, "They didn't need my help in making the atom bomb."[114] Oppenheimer gave Bohr credit for an important contribution to the work on modulated neutron initiators. "This device remained a stubborn puzzle," Oppenheimer noted, "but in early February 1945 Niels Bohr clarified what had to be done."[113]

Bohr recognised early that nuclear weapons would change international relations. In April 1944, he received a letter from Peter Kapitza, written some months before when Bohr was in Sweden, inviting him to come to the Soviet Union. The letter convinced Bohr that the Soviets were aware of the Anglo-American project, and would strive to catch up. He sent Kapitza a non-committal response, which he showed to the authorities in Britain before posting.[115] Bohr met Churchill on 16 May 1944, but found that "we did not speak the same language".[116] Churchill disagreed with the idea of openness towards the Russians to the point that he wrote in a letter: "It seems to me Bohr ought to be confined or at any rate made to see that he is very near the edge of mortal crimes."[117]

Later years

Bohr's coat of arms, 1947. Argent, a *taijitu* (yin-yang symbol) Gules and Sable. Motto: *Contraria sunt complementa* ("opposites are complementary").[126]

With the war now ended, Bohr returned to Copenhagen on 25 August 1945, and was re-elected President of the Royal Danish Academy of Arts and Sciences on 21 September.[127] At a memorial meeting of the Academy on 17 October 1947 for King Christian X, who had died in April, the new king, Frederick IX, announced that he was conferring the Order of the Elephant on Bohr. This award was normally awarded only to royalty and heads of state, but the king said that it honoured not just Bohr personally, but Danish science.[128][129] Bohr designed his own coat of arms which featured a taijitu (symbol of yin and yang) and a motto in Latin: *contraria sunt complementa*, "opposites are complementary".[130][129]

The Second World War demonstrated that science, and physics in particular, now required considerable financial and material resources. To avoid a brain drain to the United States, twelve European countries banded together to create CERN, a research organisation along the lines of the national laboratories in the United States, designed to undertake Big Science projects beyond the resources of any one of them alone. Questions soon arose regarding the best location for the facilities. Bohr and Kramers felt that the Institute in Copenhagen would be the ideal site. Pierre Auger, who organised the preliminary discussions, disagreed; he felt that both Bohr and his Institute were past their prime, and that Bohr's presence would overshadow others. After a long debate, Bohr pledged his support to CERN in February 1952, and Geneva was chosen as the site in October. The CERN Theory Group was based in Copenhagen until their new accommodation in Geneva was ready in 1957.[131] Victor Weisskopf, who later became the Director General of CERN, summed up Bohr's role, saying that "there were other personalities who started and conceived the idea of CERN. The enthusiasm and ideas of the other people would not have been enough, however, if a man of his stature had not supported it."[132][133]

Meanwhile, Scandinavian countries formed the Nordic Institute for Theoretical Physics in 1957, with Bohr as its chairman. He was also involved with the founding of the Research

Establishment Risø of the Danish Atomic Energy Commission, and served as its first chairman from February 1956.[134]

Bohr died of heart failure at his home in Carlsberg on 18 November 1962.[135] He was cremated, and his ashes were buried in the family plot in the Assistens Cemetery in the Nørrebro section of Copenhagen, along with those of his parents, his brother Harald, and his son Christian. Years later, his wife's ashes were also interred there.[136] On 7 October 1965, on what would have been his 80th birthday, the Institute for Theoretical Physics at the University of Copenhagen was officially renamed to what it had been called unofficially for many years: the Niels Bohr Institute.[137][138]

Wolfgang Pauli

Wolfgang Ernst Pauli (/ˈpɔːli/;[5] German: [ˈvɔlfgaŋ ˈpaʊli]; 25 April 1900 – 15 December 1958) was an Austrian theoretical physicist and one of the pioneers of quantum physics. Later in life he got the citizenships of the United States and Switzerland. In 1945, after having been nominated by Albert Einstein,[6] Pauli received the Nobel Prize in Physics for his "decisive contribution through his discovery of a new law of Nature, the exclusion principle or Pauli principle". The discovery involved spin theory, which is the basis of a theory of the structure of matter. He also showed a precocious ability for physics getting his PhD at age 21 even though he graduated high school at 18 (about average age for graduation).

Early years[edit]

Pauli was born in Vienna to a chemist Wolfgang Joseph Pauli (*né* Wolf Pascheles, 1869–1955) and his wife Bertha Camilla Schütz; his sister was Hertha Pauli, a writer and actress. Pauli's middle name was given in honor of his godfather, physicist Ernst Mach. Pauli's paternal grandparents were from prominent Jewish families of Prague; his great-grandfather was the Jewish publisher Wolf Pascheles.[7] Pauli's father converted from Judaism to Roman Catholicism shortly before his marriage in 1899. Pauli's mother, Bertha Schütz, was raised in her own mother's Roman Catholic religion; her father was Jewish writer Friedrich Schütz. Pauli was raised as a Roman Catholic, although eventually he and his parents left the Church.[8] He is considered to have been a deist and a mystic.[9][10]

Pauli attended the Döblinger-Gymnasium in Vienna, graduating with distinction in 1918. Only two months after graduation, he published his first paper, on Albert Einstein's theory of general relativity. He attended the Ludwig-Maximilians University in Munich, working under Arnold Sommerfeld,[2] where he received his PhD in July 1921 for his thesis on the quantum theory of ionized diatomic hydrogen (H_2^+).[3][11]

Sommerfeld asked Pauli to review the theory of relativity for the *Encyklopädie der mathematischen Wissenschaften* (*Encyclopedia of Mathematical Sciences*). Two months after receiving his doctorate, Pauli completed the article, which came to 237 pages. It was praised by Einstein; published as a monograph, it remains a standard reference on the subject to this day.[12]

Pauli spent a year at the University of Göttingen as the assistant to Max Born, and the following year at the Institute for Theoretical Physics in Copenhagen, which later became the Niels Bohr Institute in 1965. From 1923 to 1928, he was a lecturer at the University of Hamburg. During this period, Pauli was instrumental in the development of the modern theory of quantum mechanics. In particular, he formulated the exclusion principle and the theory of nonrelativistic spin.

In 1928, he was appointed Professor of Theoretical Physics at ETH Zurich in Switzerland where he made significant scientific progress. He held visiting professorships at the University of Michigan in 1931, and the Institute for Advanced Study in Princeton in 1935. He was awarded the Lorentz Medal in 1931.

At the end of 1930, shortly after his postulation of the neutrino and immediately following his divorce and the suicide of his mother, Pauli experienced a personal crisis. He consulted psychiatrist and psychotherapist Carl Jung who, like Pauli, lived near Zurich. Jung immediately began interpreting Pauli's deeply archetypal dreams,[13] and Pauli became one of Jung's best students. He soon began to criticize the epistemology of Jung's theory scientifically, and this contributed to a certain clarification of the latter's thoughts, especially about the concept of synchronicity. A great many of these discussions are documented in the Pauli/Jung letters,

today published as *Atom and Archetype*. Jung's elaborate analysis of more than 400 of Pauli's dreams is documented in *Psychology and Alchemy*.
The German annexation of Austria in 1938 made him a German citizen, which became a problem for him in 1939 after the outbreak of World War II. In 1940, he tried in vain to obtain Swiss citizenship, which would have allowed him to remain at the ETH.[14]
Pauli moved to the United States in 1940, where he was employed as a professor of theoretical physics at the Institute for Advanced Study. In 1946, after the war, he became a naturalized citizen of the United States and subsequently returned to Zurich, where he mostly remained for the rest of his life. In 1949, he was granted Swiss citizenship.
In 1958, Pauli was awarded the Max Planck medal. In that same year, he fell ill with pancreatic cancer. When his last assistant, Charles Enz, visited him at the Rotkreuz hospital in Zurich, Pauli asked him: "Did you see the room number?" It was number 137. Throughout his life, Pauli had been preoccupied with the question of why the fine structure constant, a dimensionless fundamental constant, has a value nearly equal to 1/137.[15] Pauli died in that room on 15 December 1958.[16][17]

Pauli made many important contributions as a physicist, primarily in the field of quantum mechanics. He seldom published papers, preferring lengthy correspondences with colleagues such as Niels Bohr and Werner Heisenberg, with whom he had close friendships. Many of his ideas and results were never published and appeared only in his letters, which were often copied and circulated by their recipients.
Pauli proposed in 1924 a new quantum degree of freedom (or quantum number) with two possible values, to resolve inconsistencies between observed molecular spectra and the developing theory of quantum mechanics. He formulated the Pauli exclusion principle, perhaps his most important work, which stated that no two electrons could exist in the same quantum state, identified by four quantum numbers including his new two-valued degree of freedom. The idea of spin originated with Ralph Kronig. George Uhlenbeck and Samuel Goudsmit one year later identified Pauli's new degree of freedom as electron spin, a discovery in which Pauli for a very long time wrongly refused to believe.[18]
In 1926, shortly after Heisenberg published the matrix theory of modern quantum mechanics, Pauli used it to derive the observed spectrum of the hydrogen atom. This result was important in securing credibility for Heisenberg's theory.
Pauli introduced the 2 × 2 Pauli matrices as a basis of spin operators, thus solving the nonrelativistic theory of spin. This work, including the Pauli equation, is sometimes said to have influenced Paul Dirac in his creation of the Dirac equation for the relativistic electron, though Dirac stated that he invented these same matrices himself independently at the time, without Pauli's influence. Dirac invented similar but larger (4x4) spin matrices for use in his relativistic treatment of fermionic spin.
In 1930, Pauli considered the problem of beta decay. In a letter of 4 December to Lise Meitner *et al.*, beginning, "Dear radioactive ladies and gentlemen", he proposed the existence of a hitherto unobserved neutral particle with a small mass, no greater than 1% the mass of a proton, to explain the continuous spectrum of beta decay. In 1934, Enrico Fermi incorporated the particle, which he called a neutrino, 'little neutral one' in Fermi's native Italian, into his theory of beta decay. The neutrino was first confirmed experimentally in 1956 by Frederick Reines and Clyde Cowan, two and a half years before Pauli's death. On receiving the news, he replied by telegram: "Thanks for message. Everything comes to him who knows how to wait. Pauli."[19]
In 1940, he re-derived the spin-statistics theorem, a critical result of quantum field theory which states that particles with half-integer spin are fermions, while particles with integer spin are bosons.
In 1949, he published a paper on Pauli–Villars regularization: regularization is the term for techniques which modify infinite mathematical integrals to make them finite during calculations, so that one can identify whether the intrinsically infinite quantities in the theory

(mass, charge, wavefunction) form a finite and hence calculable set which can be redefined in terms of their experimental values, which criterion is termed renormalization, and which removes infinities from quantum field theories, but also importantly allows the calculation of higher order corrections in perturbation theory.

Pauli made repeated criticisms of the modern synthesis of evolutionary biology,[20][21] and his contemporary admirers point to modes of epigenetic inheritance as supportive of his arguments.[22]

Personality and reputation[edit]

The Pauli effect was named after the anecdotal bizarre ability of his to break experimental equipment simply by being in the vicinity. Pauli was aware of his reputation and was delighted whenever the Pauli effect manifested. These strange occurrences were in line with his controversial investigations into the legitimacy of parapsychology, particularly his collaboration with C. G. Jung on the concept of synchronicity.[23]

Regarding physics, Pauli was famously a perfectionist. This extended not just to his own work, but also to the work of his colleagues. As a result, he became known in the physics community as the "conscience of physics," the critic to whom his colleagues were accountable. He could be scathing in his dismissal of any theory he found lacking, often labelling it *ganz falsch*, utterly wrong.

However, this was not his most severe criticism, which he reserved for theories or theses so unclearly presented as to be untestable or unevaluatable and, thus, not properly belonging within the realm of science, even though posing as such. They were worse than wrong because they could not be proven wrong. Famously, he once said of such an unclear paper: "It is not even wrong!"[2]

His supposed remark when meeting another leading physicist, Paul Ehrenfest, illustrates this notion of an arrogant Pauli. The two met at a conference for the first time. Ehrenfest was familiar with Pauli's papers and was quite impressed with them. After a few minutes of conversation, Ehrenfest remarked, "I think I like your Encyclopedia article [on relativity theory] better than I like you," to which Pauli shot back, "That's strange. With me, regarding you, it is just the opposite."[24] The two became very good friends from then on.

A somewhat warmer picture emerges from this story, which appears in the article on Dirac:

Werner Heisenberg [in *Physics and Beyond*, 1971] recollects a friendly conversation among young participants at the 1927 Solvay Conference, about Einstein and Planck's views on religion. Wolfgang Pauli, Heisenberg, and Dirac took part in it. Dirac's contribution was a poignant and clear criticism of the political manipulation of religion, that was much appreciated for its lucidity by Bohr, when Heisenberg reported it to him later. Among other things, Dirac said: "I cannot understand why we idle discussing religion. If we are honest – and as scientists honesty is our precise duty – we cannot help but admit that any religion is a pack of false statements, deprived of any real foundation. The very idea of God is a product of human imagination. [...] I do not recognize any religious myth, at least because they contradict one another. [...]" Heisenberg's view was tolerant. Pauli had kept silent, after some initial remarks. But when finally he was asked for his opinion, jokingly he said: "Well, I'd say that also our friend Dirac has got a religion and the first commandment of this religion is 'God does not exist and Paul Dirac is his prophet'". Everybody burst into laughter, including Dirac.[25]

Many of Pauli's ideas and results were never published and appeared only in his letters, which were often copied and circulated by their recipients. Pauli may have been unconcerned that much of his work thus went uncredited, but when it came to Heisenberg's world-renowned 1958 lecture at Göttingen on their joint work on a unified field theory, and the press release calling Pauli a mere "assistant to Professor Heisenberg", Pauli became offended, denouncing Heisenberg's physics prowess. The deterioration between them resulted in Heisenberg ignoring Pauli's funeral, and writing in his autobiography that Pauli's criticisms were overwrought, though ultimately the field theory was proven untenable, validating Pauli's criticisms.[26] Pauli was elected a Foreign Member of the Royal Society (ForMemRS) in 1953.[2] In 1958 he became a foreign member of the Royal Netherlands Academy of Arts and Sciences.[27]

In May 1929, Pauli left the Roman Catholic Church. In December of that year, he married Käthe Margarethe Deppner, a cabaret dancer.[28] The marriage was an unhappy one, ending in divorce in 1930 after less than a year. He married again in 1934 to Franziska Bertram (1901–1987). They had no children.

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- Publications by and about Wolfgang Pauli in the catalogue Helveticat of the Swiss National Library
- Wolfgang Pauli on Nobelprize.org
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- Wolfgang Pauli, Carl Jung and Marie-Louise von Franz
- Virtual walk-through exhibition of the life and times of Pauli
- Annotated bibliography for Wolfgang Pauli from the Alsos Digital Library for Nuclear Issues
- Pauli Archives at CERN Document Server
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- Key Participants: Wolfgang Pauli – Linus Pauling and the Nature of the Chemical Bond: A Documentary History
- Pauli's letter (December 1930), the hypothesis of the neutrino (online and analyzed, for English version click 'Télécharger')
- Pauli exclusion principle with Melvyn Bragg, Frank Close, Michela

Edit links

Paul Dirac

Paul Adrien Maurice Dirac 8 August 1902 – 20 October 1984) was an English theoretical physicist who is regarded as one of the most significant physicists of the 20th century.[10]
Dirac made fundamental contributions to the early development of both quantum mechanics and quantum electrodynamics. Among other discoveries, he formulated the Dirac equation which describes the behaviour of fermions and predicted the existence of antimatter. Dirac shared the 1933 Nobel Prize in Physics with Erwin Schrödinger "for the discovery of new productive forms of atomic theory".[11] He also made significant contributions to the reconciliation of general relativity with quantum mechanics.
Dirac was regarded by his friends and colleagues as unusual in character. In a 1926 letter to Paul Ehrenfest, Albert Einstein wrote of Dirac, "I have trouble with Dirac. This balancing on the dizzying path between genius and madness is awful." In another letter he wrote, "I don't understand Dirac at all (Compton effect)."[12]:82
He was the Lucasian Professor of Mathematics at the University of Cambridge, a member of the Center for Theoretical Studies, University of Miami, and spent the last decade of his life at Florida State University.

Early years
Paul Adrien Maurice Dirac was born at his parents' home in Bristol, England, on 8 August 1902,[13] and grew up in the Bishopston area of the city.[14]:18–19 His father, Charles Adrien Ladislas Dirac, was an immigrant from Saint-Maurice, Switzerland, who worked in Bristol as a French teacher. His mother, Florence Hannah Dirac, née Holten, the daughter of a ship's captain, was born in Cornwall, England, and worked as a librarian at the Bristol Central Library. Paul had a younger sister, Béatrice Isabelle Marguerite, known as Betty, and an older brother, Reginald Charles Félix, known as Felix,[15][16] who committed suicide in March 1925.[17]:77–78 Dirac later recalled: "My parents were terribly distressed. I didn't know they cared so much ... I never knew that parents were supposed to care for their children, but from then on I knew."[18]:79
Charles and the children were officially Swiss nationals until they became naturalised on 22 October 1919.[19] Dirac's father was strict and authoritarian, although he disapproved of corporal punishment.[20] Dirac had a strained relationship with his father, so much so that after his father's death, Dirac wrote, "I feel much freer now, and I am my own man." Charles forced his children to speak to him only in French, so that they might learn the language. When Dirac found that he could not express what he wanted to say in French, he chose to remain silent.[21][22]
Education
Dirac was educated first at Bishop Road Primary School[23] and then at the all-boys Merchant Venturers' Technical College (later Cotham School), where his father was a French teacher.[24] The school was an institution attached to the University of Bristol, which shared grounds and staff.[25] It emphasised technical subjects like bricklaying, shoemaking and metal work, and modern languages.[26] This was unusual at a time when secondary education in Britain was still dedicated largely to the classics, and something for which Dirac would later express his gratitude.[25]
Dirac studied electrical engineering on a City of Bristol University Scholarship at the University of Bristol's engineering faculty, which was co-located with the Merchant Venturers' Technical College.[27] Shortly before he completed his degree in 1921, he sat for the entrance examination for St John's College, Cambridge. He passed and was awarded a £70 scholarship, but this fell short of the amount of money required to live and study at Cambridge. Despite his having graduated with a first class honours Bachelor of Science degree in engineering, the economic climate of the post-war depression was such that he was unable to find work as an engineer. Instead, he took up an offer to study for a Bachelor of Arts degree in mathematics at the University of Bristol free of charge. He was permitted to skip the first year of the course owing to his engineering degree.[28]

In 1923, Dirac graduated, once again with first class honours, and received a £140 scholarship from the Department of Scientific and Industrial Research.[29] Along with his £70 scholarship from St John's College, this was enough to live at Cambridge. There, Dirac pursued his interests in the theory of general relativity, an interest he had gained earlier as a student in Bristol, and in the nascent field of quantum physics, under the supervision of Ralph Fowler.[30] From 1925 to 1928 he held an 1851 Research Fellowship from the Royal Commission for the Exhibition of 1851.[31] He completed his PhD in June 1926 with the first thesis on quantum mechanics to be submitted anywhere.[32] He then continued his research in Copenhagen and Göttingen.[31]

In 1937, Dirac married Margit Wigner (Eugene Wigner's sister). He adopted Margit's two children, Judith and Gabriel. Paul and Margit Dirac had two children together, both daughters, Mary Elizabeth and Florence Monica.

Margit, known as Manci, visited her brother in 1934 in Princeton, New Jersey, from her native Hungary and, while at dinner at the Annex Restaurant, met the "lonely-looking man at the next table". This account from a Korean physicist, Y. S. Kim, who met and was influenced by Dirac, also says: "It is quite fortunate for the physics community that Manci took good care of our respected Paul A. M. Dirac. Dirac published eleven papers during the period 1939–46.... Dirac was able to maintain his normal research productivity only because Manci was in charge of everything else".[33]

Personality

Dirac was known among his colleagues for his precise and taciturn nature. His colleagues in Cambridge jokingly defined a unit called a "dirac", which was one word per hour.[34] When Niels Bohr complained that he did not know how to finish a sentence in a scientific article he was writing, Dirac replied, "I was taught at school never to start a sentence without knowing the end of it."[35] He criticised the physicist J. Robert Oppenheimer's interest in poetry: "The aim of science is to make difficult things understandable in a simpler way; the aim of poetry is to state simple things in an incomprehensible way. The two are incompatible."[36]:17–59

Dirac himself wrote in his diary during his postgraduate years that he concentrated solely on his research, and stopped only on Sunday when he took long strolls alone.[37]

An anecdote recounted in a review of the 2009 biography tells of Werner Heisenberg and Dirac sailing on an ocean liner to a conference in Japan in August 1929. "Both still in their twenties, and unmarried, they made an odd couple. Heisenberg was a ladies' man who constantly flirted and danced, while Dirac—'an Edwardian geek', as biographer Graham Farmelo puts it—suffered agonies if forced into any kind of socialising or small talk. 'Why do you dance?' Dirac asked his companion. 'When there are nice girls, it is a pleasure,' Heisenberg replied. Dirac pondered this notion, then blurted out: 'But, Heisenberg, how do you know beforehand that the girls are nice?'"[38]

Margit Dirac told both George Gamow and Anton Capri in the 1960s that her husband had said to a house visitor, "Allow me to present Wigner's sister, who is now my wife."[39][40]

Another story told of Dirac is that when he first met the young Richard Feynman at a conference, he said after a long silence, "I have an equation. Do you have one too?"[41]

After he presented a lecture at a conference, one colleague raised his hand and said: "I don't understand the equation on the top-right-hand corner of the blackboard". After a long silence, the moderator asked Dirac if he wanted to answer the question, to which Dirac replied: "That was not a question, it was a comment."[42][43]

Dirac was also noted for his personal modesty. He called the equation for the time evolution of a quantum-mechanical operator, which he was the first to write down, the "Heisenberg equation of motion". Most physicists speak of Fermi–Dirac statistics for half-integer-spin particles and Bose–Einstein statistics for integer-spin particles. While lecturing later in life, Dirac always insisted on calling the former "Fermi statistics". He referred to the latter as "Einstein statistics" for reasons, he explained, of "symmetry".[44]

Religious views

Heisenberg recollected a conversation among young participants at the 1927 Solvay Conference about Einstein and Planck's views on religion between Wolfgang Pauli, Heisenberg and Dirac. Dirac's contribution was a criticism of the political purpose of religion, which Bohr regarded as quite lucid when hearing it from Heisenberg later.[45]:320 Among other things, Dirac said:

I cannot understand why we idle discussing religion. If we are honest—and scientists have to be—we must admit that religion is a jumble of false assertions, with no basis in reality. The very idea of God is a product of the human imagination. It is quite understandable why primitive people, who were so much more exposed to the overpowering forces of nature than we are today, should have personified these forces in fear and trembling. But nowadays, when we understand so many natural processes, we have no need for such solutions. I can't for the life of me see how the postulate of an Almighty God helps us in any way. What I do see is that this assumption leads to such unproductive questions as why God allows so much misery and injustice, the exploitation of the poor by the rich and all the other horrors He might have prevented. If religion is still being taught, it is by no means because its ideas still convince us, but simply because some of us want to keep the lower classes quiet. Quiet people are much easier to govern than clamorous and dissatisfied ones. They are also much easier to exploit. Religion is a kind of opium that allows a nation to lull itself into wishful dreams and so forget the injustices that are being perpetrated against the people. Hence the close alliance between those two great political forces, the State and the Church. Both need the illusion that a kindly God rewards—in heaven if not on earth—all those who have not risen up against injustice, who have done their duty quietly and uncomplainingly. That is precisely why the honest assertion that God is a mere product of the human imagination is branded as the worst of all mortal sins.[46]

Heisenberg's view was tolerant. Pauli, raised as a Catholic, had kept silent after some initial remarks, but when finally he was asked for his opinion, said: "Well, our friend Dirac has got a religion and its guiding principle is 'There is no God, and Paul Dirac is His prophet.'" Everybody, including Dirac, burst into laughter.[47][48]:138

Later in life, Dirac's views towards the idea of God were less acerbic. As an author of an article appearing in the May 1963 edition of *Scientific American*, Dirac wrote:

It seems to be one of the fundamental features of nature that fundamental physical laws are described in terms of a mathematical theory of great beauty and power, needing quite a high standard of mathematics for one to understand it. You may wonder: Why is nature constructed along these lines? One can only answer that our present knowledge seems to show that nature is so constructed. We simply have to accept it. One could perhaps describe the situation by saying that God is a mathematician of a very high order, and He used very advanced mathematics in constructing the universe. Our feeble attempts at mathematics enable us to understand a bit of the universe, and as we proceed to develop higher and higher mathematics we can hope to understand the universe better.[49]

In 1971, at a conference meeting, Dirac expressed his views on the existence of God.[50] Dirac explained that the existence of God could only be justified if an improbable event were to have taken place in the past:

It could be that it is extremely difficult to start life. It might be that it is so difficult to start life that it has happened only once among all the planets... Let us consider, just as a conjecture, that the chance life starting when we have got suitable physical conditions is 10^{-100}. I don't have any logical reason for proposing this figure, I just want you to consider it as a possibility. Under those conditions ... it is almost certain that life would not have started. And I feel that under those conditions it will be necessary to assume the existence of a god to start off life. I would like, therefore, to set up this connection between the existence of a god and the physical laws: if physical laws are such that to start off life involves an excessively small chance, so that it will not be reasonable to suppose that life would have started just by blind chance, then there must be a god, and such a god would probably be showing his influence in the quantum jumps which are taking place later on. On the other hand, if life can start very easily and does not need any divine influence, then I will say that there is no god.[50]

Dirac did not commit himself to any definite view, but he described the possibilities for answering the question of God in a scientific manner.[50]

Honours

Dirac shared the 1933 Nobel Prize for physics with Erwin Schrödinger "for the discovery of new productive forms of atomic theory".[11] Dirac was also awarded the Royal Medal in 1939 and both the Copley Medal and the Max Planck Medal in 1952. He was elected a Fellow of the Royal Society in 1930,[9] an Honorary Fellow of the American Physical Society in 1948, and an Honorary Fellow of the Institute of Physics, London in 1971. He received the inaugural J. Robert Oppenheimer Memorial Prize in 1969.[51][52] Dirac became a member of the Order of Merit in 1973, having previously turned down a knighthood as he did not want to be addressed by his first name.[38][53]

Death

In 1984, Dirac died in Tallahassee, Florida, and was buried at Tallahassee's Roselawn Cemetery.[54] Dirac's childhood home in Bishopston, Bristol is commemorated with a blue plaque,[55]:40 and the nearby Dirac Road is named in recognition of his links with the city of Bristol. A commemorative stone was erected in a garden in Saint-Maurice, Switzerland, the town of origin of his father's family, on 1 August 1991. On 13 November 1995 a commemorative marker, made from Burlington green slate and inscribed with the Dirac equation, was unveiled in Westminster Abbey.[54][56] The Dean of Westminster, Edward Carpenter, had initially refused permission for the memorial, thinking Dirac to be anti-Christian, but was eventually (over a five-year period) persuaded to relent.[57]:414–415

Career

Dirac established the most general theory of quantum mechanics and discovered the relativistic equation for the electron, which now bears his name. The remarkable notion of an antiparticle to each fermion particle – e.g. the positron as antiparticle to the electron – stems from his equation. He was the first to develop quantum field theory, which underlies all theoretical work on sub-atomic or "elementary" particles today, work that is fundamental to our understanding of the forces of nature. He proposed and investigated the concept of a magnetic monopole, an object not yet known empirically, as a means of bringing even greater symmetry to James Clerk Maxwell's equations of electromagnetism.

Gravity

He quantised the gravitational field, and developed a general theory of quantum field theories with dynamical constraints, which forms the basis of the gauge theories and superstring theories of today.[58]:287 The influence and importance of his work have increased with the decades, and physicists use the concepts and equations that he developed daily.

Quantum theory

Dirac's first step into a new quantum theory was taken late in September 1925. Ralph Fowler, his research supervisor, had received a proof copy of an exploratory paper by Werner Heisenberg in the framework of the old quantum theory of Bohr and Sommerfeld. Heisenberg leaned heavily on Bohr's correspondence principle but changed the equations so that they involved directly observable quantities, leading to the matrix formulation of quantum mechanics. Fowler sent Heisenberg's paper on to Dirac, who was on vacation in Bristol, asking him to look into this paper carefully.

Dirac's attention was drawn to a mysterious mathematical relationship, at first sight unintelligible, that Heisenberg had reached. Several weeks later, back in Cambridge, Dirac suddenly recognised that this mathematical form had the same structure as the Poisson brackets that occur in the classical dynamics of particle motion. From this thought, he quickly developed a quantum theory that was based on non-commuting dynamical variables. This led him to a more profound and significant general formulation of quantum mechanics than was achieved by any other worker in this field.[59] Dirac's formulation allowed him to obtain the quantisation rules in a novel and more illuminating manner. For this work,[60] published in 1926, Dirac received a PhD from Cambridge. This formed the basis for Fermi-Dirac statistics that applies to systems consisting of many identical spin 1/2 particles (i.e. that obey the Pauli exclusion principle), e.g. electrons in solids and liquids, and importantly to the field of conduction in semi-conductors.

Dirac was famously not bothered by issues of interpretation in quantum theory. In fact, in a paper published in a book in his honour, he wrote: "The interpretation of quantum mechanics has been dealt with by many authors, and I do not want to discuss it here. I want to deal with more fundamental things."[61]:194

The Dirac equation

Further information: Dirac equation

In 1928, building on 2×2 spin matrices which he purported to have discovered independently of Wolfgang Pauli's work on non-relativistic spin systems (Dirac told Abraham Pais, "I believe I got these [matrices] independently of Pauli and possibly Pauli got these independently of me."),[62]:98 he proposed the Dirac equation as a relativistic equation of motion for the wave function of the electron.[63] This work led Dirac to predict the existence of the positron, the electron's antiparticle, which he interpreted in terms of what came to be called the *Dirac sea*.[64] The positron was observed by Carl Anderson in 1932. Dirac's equation also contributed to explaining the origin of quantum spin as a relativistic phenomenon.

The necessity of fermions (matter) being created and destroyed in Enrico Fermi's 1934 theory of beta decay led to a reinterpretation of Dirac's equation as a "classical" field equation for any point particle of spin $\hbar/2$, itself subject to quantisation conditions involving anti-commutators. Thus reinterpreted, in 1934 by Werner Heisenberg, as a (quantum) field equation accurately describing all elementary matter particles – today quarks and leptons – this Dirac field equation is as central to theoretical physics as the Maxwell, Yang–Mills and Einstein field equations.

Dirac is regarded as the founder of quantum electrodynamics, being the first to use that term. He also introduced the idea of vacuum polarisation in the early 1930s. This work was key to the development of quantum mechanics by the next generation of theorists, in particular Schwinger, Feynman, Sin-Itiro Tomonaga and Dyson in their formulation of quantum electrodynamics.

Dirac's *The Principles of Quantum Mechanics*, published in 1930, is a landmark in the history of science. It quickly became one of the standard textbooks on the subject and is still used today. In that book, Dirac incorporated the previous work of Werner Heisenberg on matrix mechanics and of Erwin Schrödinger on wave mechanics into a single mathematical formalism that associates measurable quantities to operators acting on the Hilbert space of vectors that describe the state of a physical system. The book also introduced the Dirac delta function. Following his 1939 article,[65] he also included the bra–ket notation in the third edition of his book,[66] thereby contributing to its universal use nowadays.

Magnetic monopoles

In 1931, Dirac proposed that the existence of a single magnetic monopole in the universe would suffice to explain the quantisation of electrical charge.[67] In 1975,[68] 1982[69] and 2009,[70][71][72] intriguing results suggested the possible detection of magnetic monopoles, but there is, to date, no direct evidence for their existence (see also Searches for magnetic monopoles).

Lucasian Chair

Dirac was the Lucasian Professor of Mathematics at Cambridge from 1932 to 1969. In 1937, he proposed a speculative cosmological model based on the so-called large numbers hypothesis. During World War II, he conducted important theoretical and experimental research on uranium enrichment by gas centrifuge.[73]

Dirac's quantum electrodynamics (QED) made predictions that were – more often than not – infinite and therefore unacceptable. A workaround known as renormalisation was developed, but Dirac never accepted this. "I must say that I am very dissatisfied with the situation", he said in 1975, "because this so-called 'good theory' does involve neglecting infinities which appear in its equations, neglecting them in an arbitrary way. This is just not sensible mathematics. Sensible mathematics involves neglecting a quantity when it is small – not neglecting it just

because it is infinitely great and you do not want it!"[74] His refusal to accept renormalisation resulted in his work on the subject moving increasingly out of the mainstream.
However, from his once rejected notes he managed to work on putting quantum electrodynamics on "logical foundations" based on Hamiltonian formalism that he formulated. He found a rather novel way of deriving the anomalous magnetic moment "Schwinger term" and also the Lamb shift, afresh in 1963, using the Heisenberg picture and without using the joining method used by Weisskopf and French, and by the two pioneers of modern QED, Schwinger and Feynman. That was two years before the Tomonaga–Schwinger–Feynman QED was given formal recognition by an award of the Nobel Prize for physics.
Weisskopf and French (FW) were the first to obtain the correct result for the Lamb shift and the anomalous magnetic moment of the electron. At first FW results did not agree with the incorrect but independent results of Feynman and Schwinger.[75] The 1963–1964 lectures Dirac gave on quantum field theory at Yeshiva University were published in 1966 as the Belfer Graduate School of Science, Monograph Series Number, 3. After having relocated to Florida to be near his elder daughter, Mary, Dirac spent his last fourteen years (of both life and physics research) at the University of Miami in Coral Gables, Florida, and Florida State University in Tallahassee, Florida.
In the 1950s in his search for a better QED, Paul Dirac developed the Hamiltonian theory of constraints[76] based on lectures that he delivered at the 1949 International Mathematical Congress in Canada. Dirac[77] had also solved the problem of putting the Schwinger–Tomonaga equation into the Schrödinger representation[78] and given explicit expressions for the scalar meson field (spin zero pion or pseudoscalar meson), the vector meson field (spin one rho meson), and the electromagnetic field (spin one massless boson, photon).
The Hamiltonian of constrained systems is one of Dirac's many masterpieces. It is a powerful generalisation of Hamiltonian theory that remains valid for curved spacetime. The equations for the Hamiltonian involve only six degrees of freedom described by
is a 3-dimensional scalar density in the surface $H_L \approx 0$; $H_r \approx 0$ (r = 1, 2, 3)
In the late 1950s, he applied the Hamiltonian methods he had developed to cast Einstein's general relativity in Hamiltonian form[79] and to bring to a technical completion the quantisation problem of gravitation and bring it also closer to the rest of physics according to Salam and DeWitt. In 1959 he also gave an invited talk on "Energy of the Gravitational Field" at the New York Meeting of the American Physical Society.[80]:368–371 In 1964 he published his *Lectures on Quantum Mechanics* (London: Academic) which deals with constrained dynamics of nonlinear dynamical systems including quantisation of curved spacetime. He also published a paper entitled "Quantization of the Gravitational Field" in the 1967 ICTP/IAEA Trieste Symposium on Contemporary Physics.
Professorship at Florida State University
From September 1970 to January 1971, Dirac was Visiting Professor at Florida State University in Tallahassee. During that time he was offered a permanent position there, which he accepted, becoming a full professor in 1972. Contemporary accounts of his time there describe it as happy except that he apparently found the summer heat oppressive and liked to escape from it to Cambridge.[81]
He would walk about a mile to work each day and was fond of swimming in one of the two nearby lakes (Silver Lake and Lost Lake), and was also more sociable than he had been at Cambridge, where he mostly worked at home apart from giving classes and seminars; at FSU he would usually eat lunch with his colleagues before taking a nap.[82]
Dirac published over 60 papers in those last twelve years of his life, including a short book on general relativity.[83]:3 His last paper (1984), entitled "The inadequacies of quantum field theory," contains his final judgment on quantum field theory: "These rules of renormalisation give surprisingly, excessively good agreement with experiments. Most physicists say that these working rules are, therefore, correct. I feel that is not an adequate reason. Just because the results happen to be in agreement with observation does not prove that one's theory is correct." The paper ends with the words: "I have spent many years searching for a Hamiltonian

to bring into the theory and have not yet found it. I shall continue to work on it as long as I can and other people, I hope, will follow along such lines."[84]

Students

Amongst his many students[4][85] were Homi J. Bhabha,[2] Fred Hoyle, John Polkinghorne[6] and Freeman Dyson.[86] Polkinghorne recalls that Dirac "was once asked what was his fundamental belief. He strode to a blackboard and wrote that the laws of nature should be expressed in beautiful equations."[87]

Legacy

In 1975, Dirac gave a series of five lectures at the University of New South Wales which were subsequently published as a book, *Directions in Physics* (1978). He donated the royalties from this book to the university for the establishment of the Dirac Lecture Series. The Silver Dirac Medal for the Advancement of Theoretical Physics is awarded by the University of New South Wales to commemorate the lecture.[88]

Immediately after his death, two organisations of professional physicists established annual awards in Dirac's memory. The Institute of Physics, the United Kingdom's professional body for physicists, awards the Paul Dirac Medal for "outstanding contributions to theoretical (including mathematical and computational) physics".[89] The first three recipients were Stephen Hawking (1987), John Stewart Bell (1988), and Roger Penrose (1989). The International Centre for Theoretical Physics awards the Dirac Medal of the ICTP each year on Dirac's birthday (8 August).[90]

The Dirac-Hellman Award at Florida State University was endowed by Dr Bruce P. Hellman in 1997 to reward outstanding work in theoretical physics by FSU researchers.[91] The Paul A.M. Dirac Science Library at Florida State University, which Manci opened in December 1989,[92] is named in his honour, and his papers are held there.[93] Outside is a statue of him by Gabriella Bollobás.[94] The street on which the National High Magnetic Field Laboratory in Innovation Park of Tallahassee, Florida, is located is named Paul Dirac Drive. As well as in his hometown of Bristol, there is also a road named after him, Dirac Place, in Didcot, Oxfordshire.[95] The BBC named a video codec, Dirac, in his honour. An asteroid discovered in 1983 was named after Dirac.[96] The Distributed Research utilising Advanced Computing (DiRAC) and Dirac software are named in his honour.

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- *The Principles of Quantum Mechanics* (1930): This book summarises the ideas of quantum mechanics using the modern formalism that was largely developed by Dirac himself. Towards the end of the book, he also discusses the relativistic theory of the electron (the Dirac equation), which was also pioneered by him. This work does not refer to any other writings then available on quantum mechanics.
- *Lectures on Quantum Mechanics* (1966): Much of this book deals with quantum mechanics in curved space-time.
- *Lectures on Quantum Field Theory* (1966): This book lays down the foundations of quantum field theory using the Hamiltonian formalism.
- *Spinors in Hilbert Space* (1974): This book based on lectures given in 1969 at the University of Miami, Coral Gables, Florida, USA, deals with the basic aspects of spinors starting with a real Hilbert space formalism. Dirac concludes with the prophetic words "We have boson variables appearing automatically in a theory that starts with only fermion variables, provided the number of fermion variables is infinite. There must be such boson variables connected with electrons..."
- *General Theory of Relativity* (1975): This 69-page work summarises Einstein's general theory of relativity.

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Roger Penrose

(Excerpt from Saltafide, Ciampa)

Roger Penrose, another philosophical mathematician and physicist, (famous for the black hole work with Stephen Hawkins) suggested that the slack created by the "uncertainty principle could be the hole in the plan for "free will". Like Epicurus he tries to make the hole part of the plan, but not a divine plan. I don't think Penrose would mind being called a Platonist. In his book Shadows of the Mind, (page 414), he connects the Platonic world of ideals with the mental world and the physical world.

If not a spiritualist, Penrose is at least an idealist in that he insists that consciousness and machine intelligence are different and will never be the same. In both his books: Shadows of the Mind, and The Emperor's New Mind, and in his fascinating YouTube presentations, he refutes the artificial intelligence promise that eventually computers will be able to mimic consciousness. According to Penrose, mechanical intelligence is the limit of computers and it is always and only algorithmic. Computers can only follow algorithms; they can't create them. Only human minds can do that. Penrose makes it clear that human intelligence is different from the paint by numbers, algorithmic artificial intelligence. Algorithms can be invented by human minds but can only be followed by computers.

Penrose tells us in so many words that the other side of the Plato coin connects to human consciousness which can invent computers, but computers can never invent consciousness.

Penrose points out that no artificial intelligence could have had Einstein's inspirational leap which led to the theory of general relativity.

The connection of human consciousness to divine consciousness can be deduced **from** what Penrose says, but not **by** him. No, Penrose's insists: "the human mind is neither a gift of God nor a cosmic accident." (You Tube). He believes we just need time to bring the ocean home in our tea cup. He believes that physics will one day find a new theory that explains the micro universe of the brain where subatomic, micro-tubules are "entangled" and there, in that current mystery, non-computational consciousness will be proven and there will be no need for a leap of faith.

I have to point out with all due respect that this future oceanic tea cup Penrose is waiting for is the same as our leap of faith.

Penrose subscribes to the mystery club but only as a temporary member. Like all good physicists, he has to believe that what we don't know now, science will eventually discover.

That's as far as his faith goes. Unlike Einstein or Bohr, or Schrodinger, Penrose does not believe that any god is involved, Penrose cites the law or the plan which makes sublime thinking possible for humans, but refuses to call it 'divine'.

Sir Roger Penrose OM FRS (born 8 August 1931) is an English mathematical physicist, mathematician and philosopher of science. He is Emeritus Rouse Ball Professor of Mathematics at the University of Oxford, an emeritus fellow of Wadham College, Oxford and an honorary fellow of St John's College, Cambridge.

Penrose has made contributions to the mathematical physics of general relativity and cosmology. He has received several prizes and awards, including the 1988 Wolf Prize for physics, which he shared with Stephen Hawking for the Penrose–Hawking singularity theorems.[1]

Born in Colchester, Essex, Roger Penrose is a son of psychiatrist and geneticist Lionel Penrose and Margaret Leathes,[a] and the grandson of the physiologist John Beresford Leathes and his wife, a Russian national, Sonia Marie Natanson,[2] who had left St. Petersburg in the late 1880s.[3] His uncle was artist Roland Penrose, whose son with photographer Lee Miller is Antony Penrose. Penrose is the brother of physicist Oliver Penrose and of chess Grandmaster Jonathan Penrose. Penrose attended University College School and University College, London, where he graduated with a first class degree in mathematics. In 1955, while still a student, Penrose reintroduced the E. H. Moore generalised matrix inverse, also known as the Moore–Penrose inverse,[4] after it had been reinvented by Arne Bjerhammar in 1951. Having started research under the professor of geometry and astronomy, Sir W. V. D. Hodge, Penrose finished his PhD at St John's College, Cambridge in 1958, with a thesis on "tensor methods in algebraic geometry" under algebraist and geometer John A. Todd. He devised and popularised the Penrose triangle in the 1950s, describing it as "impossibility in its purest form", and exchanged material with the artist M. C. Escher, whose earlier depictions of impossible objects partly inspired it. Escher's Waterfall, and Ascending and Descending were in turn inspired by Penrose.
As reviewer Manjit Kumar puts it:
As a student in 1954, Penrose was attending a conference in Amsterdam when by chance he came across an exhibition of Escher's work. Soon he was trying to conjure up impossible figures of his own and discovered the tribar [see tri-bar for an image] – a triangle that looks like a real, solid three-dimensional object, but isn't. Together with his father, a physicist and mathematician, Penrose went on to design a staircase that simultaneously loops up and down. An article followed and a copy was sent to Escher. Completing a cyclical flow of creativity, the Dutch master of geometrical illusions was inspired to produce his two masterpieces.[5]
Having become a reader at Birkbeck College, London (and having had his attention drawn from pure mathematics to astrophysics by the cosmologist Dennis Sciama, then at Cambridge) it was in 1964 that, in the words of Kip Thorne of Caltech, "Roger Penrose revolutionised the mathematical tools that we use to analyse the properties of spacetime". Until then work on the curved geometry of general relativity had been confined to configurations with sufficiently high symmetry for Einstein's equations to be soluble explicitly, and there was doubt about whether such cases were typical. One approach to this issue was by the use of perturbation theory, as developed under the leadership of John Archibald Wheeler at Princeton. The other, more radically innovative, approach initiated by Penrose was to overlook the detailed geometrical structure of spacetime and instead concentrate attention just on the topology of the space, or at most its conformal structure, since it is the latter – as determined by the lay of the lightcones – that determines the trajectories of lightlike geodesics, and hence their causal relationships. The importance of Penrose's epoch-making paper "Gravitational collapse and space-time singularities"[6] was not only its result (roughly that if an object such as a dying star implodes beyond a certain point, then nothing can prevent the gravitational field getting so strong as to form some kind of singularity). It also showed a way to obtain similarly general conclusions in other contexts, notably that of the cosmological Big Bang, which he dealt with in collaboration with Dennis Sciama's most famous student, Stephen Hawking.

It was in the local context of gravitational collapse that the contribution of Penrose was most decisive, starting with his 1969 cosmic censorship conjecture, to the effect that any ensuing singularities would be confined within a well-behaved event horizon surrounding a hidden space-time region for which Wheeler coined the term black hole, leaving a visible exterior region with strong but finite curvature, from which some of the gravitational energy may be

extractable by what is known as the Penrose process, while accretion of surrounding matter may release further energy that can account for astrophysical phenomena such as quasars. Following up his "weak cosmic censorship hypothesis", Penrose went on, in 1979, to formulate a stronger version called the "strong censorship hypothesis". Together with the BKL conjecture and issues of nonlinear stability, settling the censorship conjectures is one of the most important outstanding problems in general relativity. Also from 1979 dates Penrose's influential Weyl curvature hypothesis on the initial conditions of the observable part of the universe and the origin of the second law of thermodynamics.[7] Penrose and James Terrell independently realised that objects travelling near the speed of light will appear to undergo a peculiar skewing or rotation. This effect has come to be called the Terrell rotation or Penrose–Terrell rotation.[8][9]
Penrose is well known for his 1974 discovery of Penrose tilings, which are formed from two tiles that can only tile the plane nonperiodically, and are the first tilings to exhibit fivefold rotational symmetry. Penrose developed these ideas based on the article *Deux types fondamentaux de distribution statistique*[10] (1938; an English translation *Two Basic Types of Statistical Distribution*) by Czech geographer, demographer and statistician Jaromír Korčák. In 1984, such patterns were observed in the arrangement of atoms in quasicrystals.[11] Another noteworthy contribution is his 1971 invention of spin networks, which later came to form the geometry of spacetime in loop quantum gravity. He was influential in popularising what are commonly known as Penrose diagrams (causal diagrams).
In 1983, Penrose was invited to teach at Rice University in Houston, by the then provost Bill Gordon. He worked there from 1983 to 1987.[12]

In 2004, Penrose released *The Road to Reality: A Complete Guide to the Laws of the Universe*, a 1,099-page comprehensive guide to the Laws of Physics that includes an explanation of his own theory. The Penrose Interpretation predicts the relationship between quantum mechanics and general relativity, and proposes that a quantum state remains in superposition until the difference of space-time curvature attains a significant level.[13][14]
Penrose is the Francis and Helen Pentz Distinguished Visiting Professor of Physics and Mathematics at Pennsylvania State University.[15]

WMAP image of the (extremely tiny) anisotropies in the cosmic background radiation
In 2010, Penrose reported possible evidence, based on concentric circles found in WMAP data of the CMB sky, of an earlier universe existing before the Big Bang of our own present universe.[16] He mentions this evidence in the epilogue of his 2010 book *Cycles of Time*,[17] a book in which he presents his reasons, to do with Einstein's field equations, the Weyl curvature C, and the Weyl curvature hypothesis (WCH), that the transition at the Big Bang could have been smooth enough for a previous universe to survive it. He made several conjectures about C and the WCH, some of which were subsequently proved by others, and he also popularized his conformal cyclic cosmology (CCC) theory.
In simple terms, he believes that the singularity in Einstein's field equation at the Big Bang is only an apparent singularity, similar to the well-known apparent singularity at the event horizon of a black hole. The latter singularity can be removed by a change of coordinate system, and Penrose proposes a different change of coordinate system that will remove the singularity at the big bang. One implication of this is that the major events at the Big Bang can be understood without unifying general relativity and quantum mechanics, and therefore we are not necessarily constrained by the Wheeler–DeWitt equation, which disrupts time. Alternatively, one can use the Einstein–Maxwell–Dirac equations.

Penrose has written books on the connection between fundamental physics and human (or animal) consciousness. In *The Emperor's New Mind* (1989), he argues that known laws of physics are inadequate to explain the phenomenon of consciousness. Penrose proposes the characteristics this new physics may have and specifies the requirements for a bridge between classical and quantum mechanics (what he calls *correct quantum gravity*). Penrose uses a variant of Turing's halting theorem to demonstrate that a system can be deterministic without being algorithmic. (For example, imagine a system with only two states, ON and OFF. If the system's state is ON when a given Turing machine halts and OFF when the Turing machine does not halt, then the system's state is completely determined by the machine; nevertheless, there is no algorithmic way to determine whether the Turing machine stops.)

Penrose believes that such deterministic yet non-algorithmic processes may come into play in the quantum mechanical wave function reduction, and may be harnessed by the brain. He argues that computers today are unable to have intelligence because they are algorithmically deterministic systems. He argues against the viewpoint that the rational processes of the mind are completely algorithmic and can thus be duplicated by a sufficiently complex computer. This contrasts with supporters of strong artificial intelligence, who contend that thought can be simulated algorithmically. He bases this on claims that consciousness transcends formal logic because things such as the insolubility of the halting problem and Gödel's incompleteness theorem prevent an algorithmically based system of logic from reproducing such traits of human intelligence as mathematical insight. These claims were originally espoused by the philosopher John Lucas of Merton College, Oxford.

The Penrose–Lucas argument about the implications of Gödel's incompleteness theorem for computational theories of human intelligence has been widely criticised by mathematicians, computer scientists and philosophers, and the consensus among experts in these fields seems to be that the argument fails, though different authors may choose different aspects of the argument to attack.[18] Marvin Minsky, a leading proponent of artificial intelligence, was particularly critical, stating that Penrose "tries to show, in chapter after chapter, that human thought cannot be based on any known scientific principle." Minsky's position is exactly the opposite – he believed that humans are, in fact, machines, whose functioning, although complex, is fully explainable by current physics. Minsky maintained that "one can carry that quest [for scientific explanation] too far by only seeking new basic principles instead of attacking the real detail. This is what I see in Penrose's quest for a new basic principle of physics that will account for consciousness."[19]

Penrose responded to criticism of *The Emperor's New Mind* with his follow up 1994 book *Shadows of the Mind*, and in 1997 with *The Large, the Small and the Human Mind*. In those works, he also combined his observations with that of anesthesiologist Stuart Hameroff.

Penrose and Hameroff have argued that consciousness is the result of quantum gravity effects in microtubules, which they dubbed Orch-OR (orchestrated objective reduction). Max Tegmark, in a paper in *Physical Review E*,[20] calculated that the time scale of neuron firing and excitations in microtubules is slower than the decoherence time by a factor of at least 10,000,000,000. The reception of the paper is summed up by this statement in Tegmark's support: "Physicists outside the fray, such as IBM's John A. Smolin, say the calculations confirm what they had suspected all along. 'We're not working with a brain that's near absolute zero. It's reasonably unlikely that the brain evolved quantum behavior'".[21] Tegmark's paper has been widely cited by critics of the Penrose–Hameroff position.

In their reply to Tegmark's paper, also published in *Physical Review E*, the physicists Scott Hagan, Jack Tuszyński and Hameroff[22][23] claimed that Tegmark did not address the Orch-OR model, but instead a model of his own construction. This involved superpositions of quanta separated by 24 nm rather than the much smaller separations stipulated for Orch-OR. As a result, Hameroff's group claimed a decoherence time seven orders of magnitude greater than Tegmark's, but still well short of the 25 ms required if the quantum processing in the theory was to be linked to the 40 Hz gamma synchrony, as Orch-OR suggested. To bridge this gap, the group made a series of proposals.

They supposed that the interiors of neurons could alternate between liquid and gel states. In the gel state, it was further hypothesized that the water electrical dipoles are oriented in the same direction, along the outer edge of the microtubule tubulin subunits. Hameroff et al. proposed that this ordered water could screen any quantum coherence within the tubulin of the microtubules from the environment of the rest of the brain. Each tubulin also has a tail extending out from the microtubules, which is negatively charged, and therefore attracts positively charged ions. It is suggested that this could provide further screening. Further to this, there was a suggestion that the microtubules could be pumped into a coherent state by biochemical energy.

Finally, he suggested that the configuration of the microtubule lattice might be suitable for quantum error correction, a means of holding together quantum coherence in the face of environmental interaction.

Hameroff, in a lecture in part of a Google Tech talks series exploring quantum biology, gave an overview of current research in the area, and responded to subsequent criticisms of the Orch-OR model.[24] In addition to this, a 2011 paper by Roger Penrose and Stuart Hameroff published in the fringe *Journal of Cosmology* gives an updated model of their Orch-OR theory, in light of criticisms, and discusses the place of consciousness within the universe.[25]

Phillip Tetlow, although himself supportive of Penrose's views, acknowledges that Penrose's ideas about the human thought process are at present a minority view in scientific circles, citing Minsky's criticisms and quoting science journalist Charles Seife's description of Penrose as "one of a handful of scientists" who believe that the nature of consciousness suggests a quantum process.[21]

In January 2014 Hameroff and Penrose claimed that a discovery of quantum vibrations in microtubules by Anirban Bandyopadhyay of the National Institute for Materials Science in Japan[26] confirms the hypothesis of Orch-OR theory.[27] A reviewed and updated version of the theory was published along with critical commentary and debate in the March 2014 issue of *Physics of Life Reviews*.[

Family life

Penrose is married to Vanessa Thomas, director of Academic Development at Cokethorpe School and former head of mathematics at Abingdon School, with whom he has one son. He has three sons from a previous marriage to American Joan Isabel Penrose (née Wedge), whom he married in 1959.

Religious views

During an interview with BBC Radio 4 on 25 September 2010, Penrose states, "I'm not a believer myself. I don't believe in established religions of any kind. I would say I'm an atheist", during a discussion on the Big Bang Theory.[31]

In the film *A Brief History of Time*, he said, "I think I would say that the universe has a purpose, it's not somehow just there by chance ... some people, I think, take the view that the universe is just there and it runs along – it's a bit like it just sort of computes, and we happen somehow by accident to find ourselves in this thing. But I don't think that's a very fruitful or helpful way of looking at the universe, I think that there is something much deeper about it."He went on to explain that he believed our universe would end in a Big Crunch, a scenario cosmology has since found to be unlikely. Penrose's model regarding the ultimate fate of the universe is called Conformal Cyclic Cosmology. It refers to the expansion of the universe, not a Big Crunch [33]

Penrose is a patron of Humanists UK.

Penrose has been awarded many prizes for his contributions to science. He was elected a Fellow of the Royal Society (FRS) in 1972. In 1975, Stephen Hawking and Penrose were jointly awarded the Eddington Medal of the Royal Astronomical Society. In 1985, he was awarded the Royal Society Royal Medal. Along with Stephen Hawking, he was awarded the prestigious Wolf Foundation Prize for Physics in 1988. In 1989 he was awarded the Dirac Medal and Prize of the British Institute of Physics. In 1990 Penrose was awarded the Albert Einstein Medal for outstanding work related to the work of Albert Einstein by the Albert Einstein Society. In 1991, he was awarded the Naylor Prize of the London Mathematical Society. From 1992 to 1995 he served as President of the International Society on General Relativity and Gravitation. In 1994, Penrose was knighted for services to science.[34] In the same year he was also awarded an Honorary Degree (Doctor of Science) by the University of Bath.[35] In 1998, he was elected Foreign Associate of the United States National Academy of Sciences. In 2000 he was appointed to the Order of Merit. In 2004 he was awarded the De Morgan Medal for his wide and original contributions to mathematical physics. To quote the citation from the London Mathematical Society:

His deep work on General Relativity has been a major factor in our understanding of black holes. His development of Twistor Theory has produced a beautiful and productive approach to the classical equations of mathematical physics. His tilings of the plane underlie the newly discovered quasi-crystals.[36]

In 2005 Penrose was awarded an honorary doctorate by Warsaw University and Katholieke Universiteit Leuven (Belgium), and in 2006 by the University of York. In 2008 Penrose was awarded the Copley Medal. He is also a Distinguished Supporter of Humanists UK and one of the patrons of the Oxford University Scientific Society. In 2011, Penrose was awarded the Fonseca Prize by the University of Santiago de Compostela. In 2012, Penrose was awarded the Richard R. Ernst Medal by ETH Zürich for his contributions to science and strengthening the connection between science and society. In 2015 Penrose was awarded an honorary doctorate by CINVESTAV-IPN (Mexico).

Works[edit]

Popular publications[edit]

- The Emperor's New Mind: Concerning Computers, Minds, and The Laws of Physics (1989)
- Shadows of the Mind: A Search for the Missing Science of Consciousness (1994)
- The Road to Reality: A Complete Guide to the Laws of the Universe (2004)
- Cycles of Time: An Extraordinary New View of the Universe (2010)
- Fashion, Faith, and Fantasy in the New Physics of the Universe (2016)

Co-authored[edit]

- The Nature of Space and Time (with Stephen Hawking) (1996)
- *The Large, the Small and the Human Mind* (with Abner Shimony, Nancy Cartwright, and Stephen Hawking) (1997)
- White Mars: The Mind Set Free (with Brian Aldiss) (1999)

Academic books[edit]

- Techniques of Differential Topology in Relativity (1972, ISBN 0-89871-005-7)
- Spinors and Space-Time: Volume 1, Two-Spinor Calculus and Relativistic Fields (with Wolfgang Rindler, 1987) ISBN 0-521-33707-0 (paperback)
- Spinors and Space-Time: Volume 2, Spinor and Twistor Methods in Space-Time Geometry (with Wolfgang Rindler, 1988) (reprint), ISBN 0-521-34786-6 (paperback)

Foreword to other books[edit]

- Foreword to “The Map and the Territory: Exploring the foundations of science, thought and reality” by Shyam Wuppuluri and Francisco Antonio Doria. Published by Springer in "The Frontiers Collection", 2018.
- Foreword to *Beating the Odds: The Life and Times of E. A. Milne*, written by Meg Weston Smith. Published by World Scientific Publishing Co in June 2013.
- Foreword to "A Computable Universe" by Hector Zenil. Published by World Scientific Publishing Co in December 2012.
- Foreword to *Quantum Aspects of Life* by Derek Abbott, Paul C. W. Davies, and Arun K. Pati. Published by Imperial College Press in 2008.
- Foreword to *Fearful Symmetry* by Anthony Zee's. Published by Princeton University Press in 2007.

See also[edit]

- Illumination problem
- Quantum mind

Notes[edit]

- ^ Penrose and his father shared mathematical concepts with Dutch graphic artist M. C. Escher which were incorporated into a lot of pieces, including Waterfall, which is based on the 'Penrose triangle', and Up and Down.

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External links[edit]

Wikiquote has quotations related to: ***Roger Penrose***

- Roger Penrose on IMDb
- Awake in the Universe - Penrose debates how creativity, the most elusive of faculties, has helped us unlock the country of the mind and the mysteries of the cosmos with Bonnie Greer.
- Dangerous Knowledge on YouTube – Penrose was one of the principal interviewees in a BBC documentary about the mathematics of infinity directed by David Malone
- Penrose's new theory "Aeons Before the Big Bang?":
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- Hilary Putnam's review of Penrose's 'Shadows of the Mind' claiming that Penrose's use of Godel's Incompleteness Theorem is fallacious
    - **Beyond the Doubting of a Shadow**: A Reply to Commentaries on Shadows of the Mind at the Wayback Machine (archived 18 June 2008)
- Penrose Tiling found in Islamic Architecture
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- Tegmark, Max (2000). "The importance of quantum decoherence in brain processes". *Physical Review E*. **61** (4): 4194–4206. arXiv:quant-ph/9907009. Bibcode:2000PhRvE..61.4194T. doi:10.1103/physreve.61.4194. PMID 11088215. S2CID 17140058.
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- Roger Penrose: A Knight on the tiles (*Plus Magazine*)
- Penrose's Gifford Lecture biography
- Quantum-Mind
- Audio: Roger Penrose in conversation on the BBC World Service discussion show
- Roger Penrose speaking about Hawking's new book on Premier Christian Radio
- "The Cyclic Universe – A conversation with Roger Penrose", *Ideas Roadshow*, 2013
- Forbidden crystal symmetry in mathematics and architecture, filmed event at the Royal Institution, October 2013
- *Oxford Mathematics Interviews*: "Extra Time: Professor Sir Roger Penrose in conversation with Andrew Hodges." These two films explore the development of Sir Roger Penrose's thought over more than 60 years, ending with his most recent theories and predictions. 51 min and 42 min. (Mathematical Institute)
- BBC Radio 4 – The Life Scientific – Roger Penrose on Black Holes – 22 November 2016 Sir Roger Penrose talks to Jim Al-Khalili about his trailblazing work on how black holes form, the problems with quantum physics and his portrayal in films about Stephen Hawking.
- The Penrose Institute Website
- A chess problem holds the key to human consciousness?, Chessbase

Stephen Hawking

Stephen William Hawking CH CBE FRS FRSA (8 January 1942 – 14 March 2018) was an English theoretical physicist, cosmologist, and author who was director of research at the Centre for Theoretical Cosmology at the University of Cambridge at the time of his death.[18][19][8] He was the Lucasian Professor of Mathematics at the University of Cambridge between 1979 and 2009.

Hawking was born in Oxford into a family of doctors. Hawking began his university education at University College, Oxford in October 1959 at the age of 17, where he received a first-class BA (Hons.) degree in physics. He began his graduate work at Trinity Hall, Cambridge in October 1962, where he obtained his PhD degree in applied mathematics and theoretical physics, specializing in general relativity and cosmology in March 1966. During this period—in 1963—Hawking was diagnosed with an early-onset slow-progressing form of motor neurone disease (also known as amyotrophic lateral sclerosis (ALS) or Lou Gehrig's disease) that gradually paralyzed him over the decades.[After the loss of his speech, he was able to communicate through a speech-generating device—initially through use of a handheld switch, and eventually by using a single cheek muscle.

Hawking's scientific works included a collaboration with Roger Penrose on gravitational singularity theorems in the framework of general relativity and the theoretical prediction that black holes emit radiation, often called Hawking radiation. Initially, Hawking radiation was controversial. By the late 1970s and following the publication of further research, the discovery was widely accepted as a significant breakthrough in theoretical physics. Hawking was the first to set out a theory of cosmology explained by a union of the general theory of relativity and quantum mechanics. He was a vigorous supporter of the many-worlds interpretation of quantum mechanics.

Hawking achieved commercial success with several works of popular science in which he discussed his theories and cosmology in general. His book *A Brief History of Time* appeared on the *Sunday Times* bestseller list for a record-breaking 237 weeks. Hawking was a Fellow of the Royal Society, a lifetime member of the Pontifical Academy of Sciences, and a recipient of the Presidential Medal of Freedom, the highest civilian award in the United States. In 2002, Hawking was ranked number 25 in the BBC's poll of the 100 Greatest Britons. He died on 14 March 2018 at the age of 76, after living with motor neurone disease for more than 50 years.

Family

Hawking was born on 8 January 1942 in Oxford to Frank (1905–1986) and Isobel Eileen Hawking (née Walker; 1915–2013).[Hawking's mother was born into a family of doctors in Glasgow, Scotland. His wealthy paternal great-grandfather, from Yorkshire, over-extended himself buying farm land and then went bankrupt in the great agricultural depression during the early 20th century His paternal great-grandmother saved the family from financial ruin by opening a school in their home.[31] Despite their families' financial constraints, both parents attended the University of Oxford, where Frank read medicine and Isobel read Philosophy, Politics and Economics.[28] Isobel worked as a secretary for a medical research institute, and Frank was a medical researcher.[28][32] Hawking had two younger sisters, Philippa and Mary, and an adopted brother, Edward Frank David (1955–2003).[33][34]

In 1950, when Hawking's father became head of the division of parasitology at the National Institute for Medical Research, the family moved to St Albans, Hertfordshire.[35][36] In St Albans, the family was considered highly intelligent and somewhat eccentric;[35][37] meals were often spent with each person silently reading a book.[35] They lived a frugal existence in a large, cluttered, and poorly maintained house and travelled in a converted London taxicab.[38][39] During one of Hawking's father's frequent absences working in Africa,[40] the rest of the family spent four months in Majorca visiting his mother's friend Beryl and her husband, the poet Robert Graves.[41]

Primary and secondary school years

Hawking began his schooling at the Byron House School in Highgate, London. He later blamed its "progressive methods" for his failure to learn to read while at the school.[42][35] In St Albans, the eight-year-old Hawking attended St Albans High School for Girls for a few months. At that time, younger boys could attend one of the houses.[41][43]

Hawking attended two independent (i.e. fee-paying) schools, first Radlett School[43] and from September 1952, St Albans School,[25][44] after passing the eleven-plus a year early.[45] The family placed a high value on education.[35] Hawking's father wanted his son to attend the well-regarded Westminster School, but the 13-year-old Hawking was ill on the day of the scholarship examination. His family could not afford the school fees without the financial aid of a scholarship, so Hawking remained at St Albans.[46][47] A positive consequence was that Hawking remained close to a group of friends with whom he enjoyed board games, the manufacture of fireworks, model aeroplanes and boats,[48] and long discussions about Christianity and extrasensory perception.[49] From 1958 on, with the help of the mathematics teacher Dikran Tahta, they built a computer from clock parts, an old telephone switchboard and other recycled components.[50][51]

Although known at school as "Einstein", Hawking was not initially successful academically.[52] With time, he began to show considerable aptitude for scientific subjects and, inspired by Tahta, decided to read mathematics at university.[53][54][55] Hawking's father advised him to study medicine, concerned that there were few jobs for mathematics graduates.[56] He also wanted his son to attend University College, Oxford, his own *alma mater*. As it was not possible to read mathematics there at the time, Hawking decided to study physics and chemistry. Despite his headmaster's advice to wait until the next year, Hawking was awarded a scholarship after taking the examinations in March 1959.[57][58]

Undergraduate years

Hawking began his university education at University College, Oxford,[25] in October 1959 at the age of 17.[59] For the first 18 months, he was bored and lonely – he found the academic work "ridiculously easy".[60][61] His physics tutor, Robert Berman, later said, "It was only necessary for him to know that something could be done, and he could do it without looking to see how other people did it."[4] A change occurred during his second and third year when, according to Berman, Hawking made more of an effort "to be one of the boys". He developed into a popular, lively and witty college member, interested in classical music and science fiction.[59] Part of the transformation resulted from his decision to join the college boat club, the University College Boat Club, where he coxed a rowing crew.[62][63] The rowing coach at the time noted that Hawking cultivated a daredevil image, steering his crew on risky courses that led to damaged boats.[62][64] Hawking estimated that he studied about 1,000 hours during his three years at Oxford. These unimpressive study habits made sitting his finals a challenge, and he decided to answer only theoretical physics questions rather than those requiring factual knowledge. A first-class honours degree was a condition of acceptance for his planned graduate study in cosmology at the University of Cambridge.[65][66] Anxious, he slept poorly the night before the examinations, and the final result was on the borderline between first- and second-class honours, making a *viva* (oral examination) with the Oxford examiners necessary.[66][67]

Hawking was concerned that he was viewed as a lazy and difficult student. So, when asked at the viva to describe his plans, he said, "If you award me a First, I will go to Cambridge. If I receive a Second, I shall stay in Oxford, so I expect you will give me a First."[66][68] He was held in higher regard than he believed; as Berman commented, the examiners "were intelligent enough to realise they were talking to someone far cleverer than most of themselves".[66] After receiving a first-class BA (Hons.) degree in physics and completing a trip to Iran with a friend, he began his graduate work at Trinity Hall, Cambridge, in October 1962.[25][69][70]

Graduate years

Hawking's first year as a doctoral student was difficult. He was initially disappointed to find that he had been assigned Dennis William Sciama, one of the founders of modern cosmology, as a supervisor rather than the noted astronomer Fred Hoyle,[71][72] and he found his training in

mathematics inadequate for work in general relativity and cosmology.[73] After being diagnosed with motor neurone disease, Hawking fell into a depression – though his doctors advised that he continue with his studies, he felt there was little point.[74] His disease progressed more slowly than doctors had predicted. Although Hawking had difficulty walking unsupported, and his speech was almost unintelligible, an initial diagnosis that he had only two years to live proved unfounded. With Sciama's encouragement, he returned to his work.[75][76] Hawking started developing a reputation for brilliance and brashness when he publicly challenged the work of Fred Hoyle and his student Jayant Narlikar at a lecture in June 1964.[77][78]
When Hawking began his graduate studies, there was much debate in the physics community about the prevailing theories of the creation of the universe: the Big Bang and Steady State theories.[79] Inspired by Roger Penrose's theorem of a spacetime singularity in the centre of black holes, Hawking applied the same thinking to the entire universe; and, during 1965, he wrote his thesis on this topic.[80][81] Hawking's thesis[82] was approved in 1966.[82] There were other positive developments: Hawking received a research fellowship at Gonville and Caius College at Cambridge;[83] he obtained his PhD degree in applied mathematics and theoretical physics, specialising in general relativity and cosmology, in March 1966;[84] and his essay "Singularities and the Geometry of Space-Time" shared top honours with one by Penrose to win that year's prestigious Adams Prize.[85][84]

1966–1975
In his work, and in collaboration with Penrose, Hawking extended the singularity theorem concepts first explored in his doctoral thesis. This included not only the existence of singularities but also the theory that the universe might have started as a singularity. Their joint essay was the runner-up in the 1968 Gravity Research Foundation competition.[86][87] In 1970, they published a proof that if the universe obeys the general theory of relativity and fits any of the models of physical cosmology developed by Alexander Friedmann, then it must have begun as a singularity.[88][89][90] In 1969, Hawking accepted a specially created Fellowship for Distinction in Science to remain at Caius.[91]
In 1970, Hawking postulated what became known as the second law of black hole dynamics, that the event horizon of a black hole can never get smaller. With James M. Bardeen and Brandon Carter, he proposed the four laws of black hole mechanics, drawing an analogy with thermodynamics.[To Hawking's irritation, Jacob Bekenstein, a graduate student of John Wheeler, went further—and ultimately correctly—to apply thermodynamic concepts literally.
In the early 1970s, Hawking's work with Carter, Werner Israel, and David C. Robinson strongly supported Wheeler's no-hair theorem, one that states that no matter what the original material from which a black hole is created, it can be completely described by the properties of mass, electrical charge and rotation.[96][97] His essay titled "Black Holes" won the Gravity Research Foundation Award in January 1971.[98] Hawking's first book, *The Large Scale Structure of Space-Time,* written with George Ellis, was published in 1973.[99]
Beginning in 1973, Hawking moved into the study of quantum gravity and quantum mechanics.[100][99] His work in this area was spurred by a visit to Moscow and discussions with Yakov Borisovich Zel'dovich and Alexei Starobinsky, whose work showed that according to the uncertainty principle, rotating black holes emit particles.[101] To Hawking's annoyance, his much-checked calculations produced findings that contradicted his second law, which claimed black holes could never get smaller,[102] and supported Bekenstein's reasoning about their entropy.
His results, which Hawking presented from 1974, showed that black holes emit radiation, known today as Hawking radiation, which may continue until they exhaust their energy and evaporate. Initially, Hawking radiation was controversial. By the late 1970s and following the publication of further research, the discovery was widely accepted as a significant breakthrough in theoretical physics. Hawking was elected a Fellow of the Royal Society (FRS) in 1974, a few weeks after the announcement of Hawking radiation. At the time, he was one of the youngest scientists to become a Fellow.[110][111]

Hawking was appointed to the Sherman Fairchild Distinguished Visiting Professorship at the California Institute of Technology (Caltech) in 1974. He worked with a friend on the faculty, Kip Thorne,[112][8] and engaged him in a scientific wager about whether the X-ray source Cygnus X-1 was a black hole. The wager was an "insurance policy" against the proposition that black holes did not exist.[113] Hawking acknowledged that he had lost the bet in 1990, a bet that was the first of several he was to make with Thorne and others.[114] Hawking had maintained ties to Caltech, spending a month there almost every year since this first visit.[115]

1975–1990

Hawking returned to Cambridge in 1975 to a more academically senior post, as reader in gravitational physics. The mid to late 1970s were a period of growing public interest in black holes and the physicists who were studying them. Hawking was regularly interviewed for print and television.[116][117] He also received increasing academic recognition of his work.[118] In 1975, he was awarded both the Eddington Medal and the Pius XI Gold Medal, and in 1976 the Dannie Heineman Prize, the Maxwell Medal and Prize and the Hughes Medal.[119][120] He was appointed a professor with a chair in gravitational physics in 1977.[121] The following year he received the Albert Einstein Medal and an honorary doctorate from the University of Oxford.[122][118]

In 1979, Hawking was elected Lucasian Professor of Mathematics at the University of Cambridge. His inaugural lecture in this role was titled: "Is the End in Sight for Theoretical Physics?" and proposed N=8 Supergravity as the leading theory to solve many of the outstanding problems physicists were studying.[124] His promotion coincided with a health crisis which led to his accepting, albeit reluctantly, some nursing services at home.[125] At the same time, he was also making a transition in his approach to physics, becoming more intuitive and speculative rather than insisting on mathematical proofs. "I would rather be right than rigorous", he told Kip Thorne.[126] In 1981, he proposed that information in a black hole is irretrievably lost when a black hole evaporates. This information paradox violates the fundamental tenet of quantum mechanics, and led to years of debate, including "the Black Hole War" with Leonard Susskind and Gerard 't Hooft.[127][128]

Cosmological inflation – a theory proposing that following the Big Bang, the universe initially expanded incredibly rapidly before settling down to a slower expansion – was proposed by Alan Guth and also developed by Andrei Linde.[129] Following a conference in Moscow in October 1981, Hawking and Gary Gibbons[8] organised a three-week Nuffield Workshop in the summer of 1982 on "The Very Early Universe" at Cambridge University, a workshop that focused mainly on inflation theory.[130][131][132] Hawking also began a new line of quantum theory research into the origin of the universe. In 1981 at a Vatican conference, he presented work suggesting that there might be no boundary – or beginning or ending – to the universe.[133][134] Hawking subsequently developed the research in collaboration with Jim Hartle,[8] and in 1983 they published a model, known as the Hartle–Hawking state. It proposed that prior to the Planck epoch, the universe had no boundary in space-time; before the Big Bang, time did not exist and the concept of the beginning of the universe is meaningless. The initial singularity of the classical Big Bang models was replaced with a region akin to the North Pole. One cannot travel north of the North Pole, but there is no boundary there – it is simply the point where all north-running lines meet and end. Initially, the no-boundary proposal predicted a closed universe, which had implications about the existence of God. As Hawking explained, "If the universe has no boundaries but is self-contained... then God would not have had any freedom to choose how the universe began."[

Hawking did not rule out the existence of a Creator, asking in *A Brief History of Time* "Is the unified theory so compelling that it brings about its own existence?" In his early work, Hawking spoke of God in a metaphorical sense. In *A Brief History of Time* he wrote: "If we discover a complete theory, it would be the ultimate triumph of human reason – for then we should know the mind of God."In the same book he suggested that the existence of God was not necessary to explain the origin of the universe. Later discussions with Neil Turok led to the realization that the existence of God was also compatible with an open universe.

Further work by Hawking in the area of arrows of time led to the 1985 publication of a paper theorizing that if the no-boundary proposition were correct, then when the universe stopped expanding and eventually collapsed, time would run backwards.[142] A paper by Don Page and independent calculations by Raymond Laflamme led Hawking to withdraw this concept.[143]
Honours continued to be awarded: in 1981 he was awarded the American Franklin Medal,[144] and in the 1982 New Year Honours appointed a Commander of the Order of the British Empire (CBE).[145][146][147] These awards did not significantly change Hawking's financial status, and motivated by the need to finance his children's education and home expenses, he decided in 1982 to write a popular book about the universe that would be accessible to the general public.[148][149] Instead of publishing with an academic press, he signed a contract with Bantam Books, a mass market publisher, and received a large advance for his book.[150][151] A first draft of the book, called *A Brief History of Time*, was completed in 1984.[152]
One of the first messages Hawking produced with his speech-generating device was a request for his assistant to help him finish writing *A Brief History of Time*.[153] Peter Guzzardi, his editor at Bantam, pushed him to explain his ideas clearly in non-technical language, a process that required many revisions from an increasingly irritated Hawking.The book was published in April 1988 in the US and in June in the UK, and it proved to be an extraordinary success, rising quickly to the top of best-seller lists in both countries and remaining there for months.The book was translated into many languages,[158] and ultimately sold an estimated 9 million copies.[157]
Media attention was intense, and a *Newsweek* magazine cover and a television special both described him as "Master of the Universe".[159] Success led to significant financial rewards, but also the challenges of celebrity status.[160] Hawking travelled extensively to promote his work, and enjoyed partying and dancing into the small hours.[158] A difficulty refusing the invitations and visitors left him limited time for work and his students.[161] Some colleagues were resentful of the attention Hawking received, feeling it was due to his disability.[162][163]
He received further academic recognition, including five more honorary degrees,[159] the Gold Medal of the Royal Astronomical Society (1985),[164] the Paul Dirac Medal (1987)[159] and, jointly with Penrose, the prestigious Wolf Prize (1988).[165] In the 1989 Birthday Honours, he was appointed a Companion of Honour (CH).[161][166] He reportedly declined a knighthood in the late 1990s in objection to the UK's science funding policy.[167][168]
1990–2000

Hawking pursued his work in physics: in 1993 he co-edited a book on Euclidean quantum gravity with Gary Gibbons and published a collected edition of his own articles on black holes and the Big Bang.[169] In 1994, at Cambridge's Newton Institute, Hawking and Penrose delivered a series of six lectures that were published in 1996 as "The Nature of Space and Time".[170] In 1997, he conceded a 1991 public scientific wager made with Kip Thorne and John Preskill of Caltech. Hawking had bet that Penrose's proposal of a "cosmic censorship conjecture" – that there could be no "naked singularities" unclothed within a horizon – was correct.[171]
After discovering his concession might have been premature, a new and more refined wager was made. This one specified that such singularities would occur without extra conditions.[172] The same year, Thorne, Hawking and Preskill made another bet, this time concerning the black hole information paradox.[173][174] Thorne and Hawking argued that since general relativity made it impossible for black holes to radiate and lose information, the mass-energy and information carried by Hawking radiation must be "new", and not from inside the black hole event horizon. Since this contradicted the quantum mechanics of microcausality, quantum mechanics theory would need to be rewritten. Preskill argued the opposite, that since quantum mechanics suggests that the information emitted by a black hole relates to information that fell in at an earlier time, the concept of black holes given by general relativity must be modified in some way.[175]

Hawking also maintained his public profile, including bringing science to a wider audience. A film version of *A Brief History of Time*, directed by Errol Morris and produced by Steven Spielberg, premiered in 1992. Hawking had wanted the film to be scientific rather than biographical, but he was persuaded otherwise. The film, while a critical success, was not widely released.[176] A popular-level collection of essays, interviews, and talks titled *Black Holes and Baby Universes and Other Essays* was published in 1993,[177] and a six-part television series *Stephen Hawking's Universe* and a companion book appeared in 1997. As Hawking insisted, this time the focus was entirely on science.[178][179]
2000–2018

Hawking continued his writings for a popular audience, publishing *The Universe in a Nutshell* in 2001,[180] and *A Briefer History of Time*, which he wrote in 2005 with Leonard Mlodinow to update his earlier works with the aim of making them accessible to a wider audience, and *God Created the Integers*, which appeared in 2006.[181] Along with Thomas Hertog at CERN and Jim Hartle, from 2006 on Hawking developed a theory of "top-down cosmology", which says that the universe had not one unique initial state but many different ones, and therefore that it is inappropriate to formulate a theory that predicts the universe's current configuration from one particular initial state.[182] Top-down cosmology posits that the present "selects" the past from a superposition of many possible histories. In doing so, the theory suggests a possible resolution of the fine-tuning question.[183][184]
Hawking continued to travel widely, including trips to Chile, Easter Island, South Africa, Spain (to receive the Fonseca Prize in 2008),[185][186] Canada,[187] and numerous trips to the United States.[188] For practical reasons related to his disability, Hawking increasingly travelled by private jet, and by 2011 that had become his only mode of international travel.[189]

By 2003, consensus among physicists was growing that Hawking was wrong about the loss of information in a black hole.[190] In a 2004 lecture in Dublin, he conceded his 1997 bet with Preskill, but described his own, somewhat controversial solution to the information paradox problem, involving the possibility that black holes have more than one topology.[191][175] In the 2005 paper he published on the subject, he argued that the information paradox was explained by examining all the alternative histories of universes, with the information loss in those with black holes being cancelled out by those without such loss.[174][192] In January 2014, he called the alleged loss of information in black holes his "biggest blunder".[193]
As part of another longstanding scientific dispute, Hawking had emphatically argued, and bet, that the Higgs boson would never be found.[194] The particle was proposed to exist as part of the Higgs field theory by Peter Higgs in 1964. Hawking and Higgs engaged in a heated and public debate over the matter in 2002 and again in 2008, with Higgs criticising Hawking's work and complaining that Hawking's "celebrity status gives him instant credibility that others do not have."[195] The particle was discovered in July 2012 at CERN following construction of the Large Hadron Collider. Hawking quickly conceded that he had lost his bet[196][197] and said that Higgs should win the Nobel Prize for Physics,[198] which he did in 2013.[199]

In 2007, Hawking and his daughter Lucy published *George's Secret Key to the Universe*, a children's book designed to explain theoretical physics in an accessible fashion and featuring characters similar to those in the Hawking family.[200] The book was followed by sequels in 2009, 2011, 2014 and 2016.[201]
In 2002, following a UK-wide vote, the BBC included Hawking in their list of the 100 Greatest Britons He was awarded the Copley Medal from the Royal Society (2006),[203] the Presidential Medal of Freedom, which is America's highest civilian honour (2009),[204] and the Russian Special Fundamental Physics Prize (2013).[205]
Several buildings have been named after him, including the Stephen W. Hawking Science Museum in San Salvador, El Salvador,[206] the Stephen Hawking Building in Cambridge,[207] and the Stephen Hawking Centre at the Perimeter Institute in Canada.[208] Appropriately, given

Hawking's association with time, he unveiled the mechanical "Chronophage" (or time-eating) Corpus Clock at Corpus Christi College, Cambridge in September 2008.[209][210]

During his career, Hawking supervised 39 successful PhD students.[3] One doctoral student did not successfully complete the PhD.[3][*better source needed*] As required by Cambridge University regulations, Hawking retired as Lucasian Professor of Mathematics in 2009.[123][211] Despite suggestions that he might leave the United Kingdom as a protest against public funding cuts to basic scientific research,[212] Hawking worked as director of research at the Cambridge University Department of Applied Mathematics and Theoretical Physics.[213]

On 28 June 2009, as a tongue-in-cheek test of his 1992 conjecture that travel into the past is effectively impossible, Hawking held a party open to all, complete with hors d'oeuvres and iced champagne, but publicised the party only after it was over so that only time-travellers would know to attend; as expected, nobody showed up to the party.[214]

On 20 July 2015, Hawking helped launch Breakthrough Initiatives, an effort to search for extraterrestrial life.[215] Hawking created *Stephen Hawking: Expedition New Earth*, a documentary on space colonisation, as a 2017 episode of *Tomorrow's World*.[216][217]

In August 2015, Hawking said that not all information is lost when something enters a black hole and there might be a possibility to retrieve information from a black hole according to his theory.[218] In July 2017, Hawking was awarded an Honorary Doctorate from Imperial College London.[219]

Hawking's final paper – A smooth exit from eternal inflation? – was posthumously published in the Journal of High Energy Physics on 27 April 2018.

Hawking met his future wife, Jane Wilde, at a party in 1962. The following year, Hawking was diagnosed with motor neuron disease. In October 1964, the couple became engaged to marry, aware of the potential challenges that lay ahead due to Hawking's shortened life expectancy and physical limitations.[122][222] Hawking later said that the engagement gave him "something to live for".[223] The two were married on 14 July 1965 in their shared hometown of St Albans.[83]

The couple resided in Cambridge, within Hawking's walking distance to the Department of Applied Mathematics and Theoretical Physics (DAMTP). During their first years of marriage, Jane lived in London during the week as she completed her degree at Westfield College. They travelled to the United States several times for conferences and physics-related visits. Jane began a PhD programme through Westfield College in medieval Spanish poetry (completed in 1981). The couple had three children: Robert, born May 1967,[224][225] Lucy, born November 1969,[226] and Timothy, born April 1979.[118]

Hawking rarely discussed his illness and physical challenges, even – in a precedent set during their courtship – with Jane.[227] His disabilities meant that the responsibilities of home and family rested firmly on his wife's increasingly overwhelmed shoulders, leaving him more time to think about physics.[228] Upon his appointment in 1974 to a year-long position at the California Institute of Technology in Pasadena, California, Jane proposed that a graduate or post-doctoral student live with them and help with his care. Hawking accepted, and Bernard Carr travelled with them as the first of many students who fulfilled this role.[229][230] The family spent a generally happy and stimulating year in Pasadena.[231]

Hawking returned to Cambridge in 1975 to a new home and a new job, as reader. Don Page, with whom Hawking had begun a close friendship at Caltech, arrived to work as the live-in graduate student assistant. With Page's help and that of a secretary, Jane's responsibilities were reduced so she could return to her doctoral thesis and her new interest in singing.[232]

Around December 1977, Jane met organist Jonathan Hellyer Jones when singing in a church choir. Hellyer Jones became close to the Hawking family, and by the mid-1980s, he and Jane had developed romantic feelings for each other. According to Jane, her husband was accepting of the situation, stating "he would not object so long as I continued to love him". Jane and Hellyer Jones were determined not to break up the family, and their relationship remained platonic for a long period.[237]

By the 1980s, Hawking's marriage had been strained for many years. Jane felt overwhelmed by the intrusion into their family life of the required nurses and assistants.[238] The impact of his celebrity was challenging for colleagues and family members, while the prospect of living up to a worldwide fairytale image was daunting for the couple.[239][183] Hawking's views of religion also contrasted with her strong Christian faith and resulted in tension.[183][240][241] After a tracheotomy in 1985, Hawking required a nurse 24/7 and nursing care was split across 3 shifts daily. In the late 1980s, Hawking grew close to one of his nurses, Elaine Mason, to the dismay of some colleagues, caregivers, and family members, who were disturbed by her strength of personality and protectiveness.[242] In February 1990, Hawking told Jane that he was leaving her for Mason,[243] and departed the family home.[145] After his divorce from Jane in 1995, Hawking married Mason in September,[145][244] declaring, "It's wonderful – I have married the woman I love."[245]

In 1999, Jane Hawking published a memoir, *Music to Move the Stars*, describing her marriage to Hawking and its breakdown. Its revelations caused a sensation in the media but, as was his usual practice regarding his personal life, Hawking made no public comment except to say that he did not read biographies about himself.[246] After his second marriage, Hawking's family felt excluded and marginalised from his life.[241] For a period of about five years in the early 2000s, his family and staff became increasingly worried that he was being physically abused.[247] Police investigations took place, but were closed as Hawking refused to make a complaint.

In 2006, Hawking and Mason quietly divorced,[249][250] and Hawking resumed closer relationships with Jane, his children, and his grandchildren.[183][250] Reflecting on this happier period, a revised version of Jane's book, re-titled *Travelling to Infinity: My Life with Stephen*, appeared in 2007,[248] and was made into a film, *The Theory of Everything*, in 2014.[251]

Disability

Hawking had a rare early-onset slow-progressing form of motor neuron disease (MND; also known as amyotrophic lateral sclerosis (ALS), or Lou Gehrig's disease), a fatal neurodegenerative disease that results in the death of motor neurones in the brain and spinal cord, which gradually paralysed him over decades.[21]

Hawking had experienced increasing clumsiness during his final year at Oxford, including a fall on some stairs and difficulties when rowing.[252][253] The problems worsened, and his speech became slightly slurred and his family noticed the changes when he returned home for Christmas, and medical investigations were begun.[254][255] The MND diagnosis came when Hawking was 21, in 1963. At the time, doctors gave him a life expectancy of two years.[256][257]

In the late 1960s, Hawking's physical abilities declined: he began to use crutches and could no longer give lectures regularly.[258] As he slowly lost the ability to write, he developed compensatory visual methods, including seeing equations in terms of geometry.[259][260] The physicist Werner Israel later compared the achievements to Mozart composing an entire symphony in his head.[261][262] Hawking was fiercely independent and unwilling to accept help or make concessions for his disabilities. He preferred to be regarded as "a scientist first, popular science writer second, and, in all the ways that matter, a normal human being with the same desires, drives, dreams, and ambitions as the next person."[263] His wife, Jane Hawking, later noted: "Some people would call it determination, some obstinacy. I've called it both at one time or another."[264] He required much persuasion to accept the use of a wheelchair at the end of the 1960s,[265] but ultimately became notorious for the wildness of his wheelchair driving.[266] Hawking was a popular and witty colleague, but his illness, as well as his reputation for brashness, distanced him from some.[264]

When Hawking first began using a wheelchair in the late 1970s he was using standard motorised models. The earliest surviving example of these chairs was made by BEC Mobility and sold by Christie's in November 2018 for £296,750.[267] Hawking continued to use this type of chair until the early 1990s, at which time his ability to use his hands to drive a wheelchair deteriorated. Hawking used a variety of different chairs from that time, including a DragonMobility Dragon elevating powerchair from 2007, as shown in the April 2008 photo of

Hawking attending NASA's 50th anniversary;[268] a Permobil C350 from 2014; and then a Permobil F3 from 2016.[269]
Hawking's speech deteriorated, and by the late 1970s he could be understood by only his family and closest friends. To communicate with others, someone who knew him well would interpret his speech into intelligible speech.[270] Spurred by a dispute with the university over who would pay for the ramp needed for him to enter his workplace, Hawking and his wife campaigned for improved access and support for those with disabilities in Cambridge,[271][272] including adapted student housing at the university.[273] In general, Hawking had ambivalent feelings about his role as a disability rights champion: while wanting to help others, he also sought to detach himself from his illness and its challenges.[274] His lack of engagement in this area led to some criticism.[275]
During a visit to CERN on the border of France and Switzerland in mid-1985, Hawking contracted pneumonia, which in his condition was life-threatening; he was so ill that Jane was asked if life support should be terminated. She refused, but the consequence was a tracheotomy, which required round-the-clock nursing care and the removal of what remained of his speech.[276][277] The National Health Service was ready to pay for a nursing home, but Jane was determined that he would live at home. The cost of the care was funded by an American foundation.[278][279] Nurses were hired for the three shifts required to provide the round-the-clock support he required. One of those employed was Elaine Mason, who was to become Hawking's second wife.[280]
For his communication, Hawking initially raised his eyebrows to choose letters on a spelling card,[281] but in 1986 he received a computer program called the "Equalizer" from Walter Woltosz, CEO of Words Plus, who had developed an earlier version of the software to help his mother-in-law, who also suffered from ALS and had lost her ability to speak and write.[282] In a method he used for the rest of his life, Hawking could now simply press a switch to select phrases, words or letters from a bank of about 2,500–3,000 that were scanned.[283][284] The program was originally run on a desktop computer. Elaine Mason's husband, David, a computer engineer, adapted a small computer and attached it to his wheelchair.[285]
Released from the need to use somebody to interpret his speech, Hawking commented that "I can communicate better now than before I lost my voice."[286] The voice he used had an American accent and is no longer produced.[287][288] Despite the later availability of other voices, Hawking retained this original voice, saying that he preferred it and identified with it.[289]
Originally, Hawking activated a switch using his hand and could produce up to 15 words a minute.[153] Lectures were prepared in advance and were sent to the speech synthesizer in short sections to be delivered.[287]
Hawking gradually lost the use of his hand, and in 2005 he began to control his communication device with movements of his cheek muscles,[290][291][292] with a rate of about one word per minute.[291] With this decline there was a risk of his developing locked-in syndrome, so Hawking collaborated with Intel researchers on systems that could translate his brain patterns or facial expressions into switch activations. After several prototypes that did not perform as planned, they settled on an adaptive word predictor made by the London-based startup SwiftKey, which used a system similar to his original technology. Hawking had an easier time adapting to the new system, which was further developed after inputting large amounts of Hawking's papers and other written materials and uses predictive software similar to other smartphone keyboards.[183][282][292][293]
By 2009, he could no longer drive his wheelchair independently, but the same people who created his new typing mechanics were working on a method to drive his chair using movements made by his chin. This proved difficult, since Hawking could not move his neck, and trials showed that while he could indeed drive the chair, the movement was sporadic and jumpy.[282][294] Near the end of his life, Hawking experienced increased breathing difficulties, often resulting in his requiring the usage of a ventilator, and being regularly hospitalised.[183]
Disability outreach
Starting in the 1990s, Hawking accepted the mantle of role model for disabled people, lecturing and participating in fundraising activities.[295] At the turn of the century, he and eleven

other luminaries signed the *Charter for the Third Millennium on Disability*, which called on governments to prevent disability and protect the rights of the disabled.[296][297] In 1999, Hawking was awarded the Julius Edgar Lilienfeld Prize of the American Physical Society.[298] In August 2012, Hawking narrated the "Enlightenment" segment of the 2012 Summer Paralympics opening ceremony in London.[299] In 2013, the biographical documentary film *Hawking*, in which Hawking himself is featured, was released.[300] In September 2013, he expressed support for the legalisation of assisted suicide for the terminally ill.[301] In August 2014, Hawking accepted the Ice Bucket Challenge to promote ALS/MND awareness and raise contributions for research. As he had pneumonia in 2013, he was advised not to have ice poured over him, but his children volunteered to accept the challenge on his behalf.[302]

Hawking taking a zero-gravity flight in a reduced-gravity aircraft, April 2007

In late 2006, Hawking revealed in a BBC interview that one of his greatest unfulfilled desires was to travel to space;[303] on hearing this, Sir Richard Branson offered a free flight into space with Virgin Galactic, which Hawking immediately accepted. Besides personal ambition, he was motivated by the desire to increase public interest in spaceflight and to show the potential of people with disabilities.[304] On 26 April 2007, Hawking flew aboard a specially-modified Boeing 727-200 jet operated by Zero-G Corp off the coast of Florida to experience weightlessness.[305] Fears the manoeuvres would cause him undue discomfort proved groundless, and the flight was extended to eight parabolic arcs.[303] It was described as a successful test to see if he could withstand the g-forces involved in space flight.[306] At the time, the date of Hawking's trip to space was projected to be as early as 2009, but commercial flights to space did not commence before his death.[307]

Hawking died at his home in Cambridge on 14 March 2018, at the age of 76.[308][309][310] His family stated that he "died peacefully".[311][312] He was eulogised by figures in science, entertainment, politics, and other areas.[313][314][315][316] The Gonville and Caius College flag flew at half-mast and a book of condolences was signed by students and visitors.[317][318][319] A tribute was made to Hawking in the closing speech by IPC President Andrew Parsons at the closing ceremony of the 2018 Paralympic Winter Games in Pyeongchang, South Korea.[320] His private funeral took place on 31 March 2018,[321] at Great St Mary's Church, Cambridge.[321][322] Guests at the funeral included *The Theory of Everything* actors Eddie Redmayne and Felicity Jones, Queen guitarist and astrophysicist Brian May, and model Lily Cole.[323][324] In addition, actor Benedict Cumberbatch, who played Stephen Hawking in *Hawking*, astronaut Tim Peake, Astronomer Royal Martin Rees and physicist Kip Thorne provided readings at the service.[325] Although Hawking was an atheist the funeral took place with a traditional Anglican service.[326][327] Following the cremation, a service of thanksgiving was held at Westminster Abbey on 15 June 2018, after which his ashes were interred in the Abbey's nave, between the graves of Sir Isaac Newton and Charles Darwin.[1][323][328][329]

Inscribed on his memorial stone are the words "Here lies what was mortal of Stephen Hawking 1942–2018" and his most famed equation.[330] He directed, at least fifteen years before his death, that the Bekenstein–Hawking entropy equation be his epitaph.[331][332][note 1] In June 2018, it was announced that Hawking's words, set to music by Greek composer Vangelis, would be beamed into space from a European space agency satellite dish in Spain with the aim of reaching the nearest black hole, 1A 0620-00.[337]

Hawking's final broadcast interview, about the detection of gravitational waves resulting from the collision of two neutron stars, occurred in October 2017.[338] His final words to the world appeared posthumously, in April 2018, in the form of a Smithsonian TV Channel documentary entitled, *Leaving Earth: Or How to Colonize a Planet*.[339][340] One of his final research studies, entitled *A smooth exit from eternal inflation?*, about the origin of the universe, was published in the Journal of High Energy Physics in May 2018.[341][342][343][344] Later, in October 2018, another of his final research studies, entitled *Black Hole Entropy and Soft Hair*,[345] was published, and dealt with the "mystery of what happens to the information held by objects once they disappear into a black hole".[346][347] Also in October 2018, Hawking's last book, *Brief Answers to the Big Questions*, a popular science book presenting his final comments on the most important questions facing humankind, was published.[348][349][350]

On 8 November 2018, an auction of 22 personal possessions of Stephen Hawking, including his doctoral thesis ("*Properties of Expanding Universes*", PhD thesis, Cambridge University, 1965) and wheelchair, took place, and fetched about £1.8 m.[351][352] Proceeds from the auction sale of the wheelchair went to two charities, the Motor Neurone Disease Association and the Stephen Hawking Foundation;[353] proceeds from Hawking's other items went to his estate.[352]

In March 2019, it was announced that the Royal Mint issued a commemorative 50 pence coin in honour of Hawking.[354] The same month, it was reported that Hawking's nurse, Patricia Dowdy, had been handed an interim suspension in 2016 for "failures over his care and financial misconduct."[355]

In 2006, Hawking posed an open question on the Internet: "In a world that is in chaos politically, socially and environmentally, how can the human race sustain another 100 years?", later clarifying: "I don't know the answer. That is why I asked the question, to get people to think about it, and to be aware of the dangers we now face."

Hawking expressed concern that life on Earth is at risk from a sudden nuclear war, a genetically engineered virus, global warming, or other dangers humans have not yet thought of.[304][357]

Hawking stated: "I regard it as almost inevitable that either a nuclear confrontation or environmental catastrophe will cripple the Earth at some point in the next 1,000 years", and considered an "asteroid collision" to be the biggest threat to the planet.[348] Such a planet-wide disaster need not result in human extinction if the human race were to be able to colonise additional planets before the disaster.[357] Hawking viewed spaceflight and the colonisation of space as necessary for the future of humanity.[304][358]

Hawking stated that, given the vastness of the universe, aliens likely exist, but that contact with them should be avoided.[359][360] He warned that aliens might pillage Earth for resources. In 2010 he said, "If aliens visit us, the outcome would be much as when Columbus landed in America, which didn't turn out well for the Native Americans."[360]

Hawking warned that superintelligent artificial intelligence could be pivotal in steering humanity's fate, stating that "the potential benefits are huge... Success in creating AI would be the biggest event in human history. It might also be the last, unless we learn how to avoid the risks."[361][362] However, he argued that we should be more frightened of capitalism exacerbating economic inequality than robots.[363]

Hawking was concerned about the future emergence of a race of "superhumans" that would be able to design their own evolution[348] and, as well, argued that computer viruses in today's world should be considered a new form of life, stating that "maybe it says something about human nature, that the only form of life we have created so far is purely destructive. Talk about creating life in our own image."[364]

Science vs. philosophy

At Google's Zeitgeist Conference in 2011, Hawking said that "philosophy is dead". He believed that philosophers "have not kept up with modern developments in science" and that scientists "have become the bearers of the torch of discovery in our quest for knowledge". He said that philosophical problems can be answered by science, particularly new scientific theories which "lead us to a new and very different picture of the universe and our place in it".[365]

Religion and atheism

Hawking was an atheist and believed that "the universe is governed by the laws of science". He stated: "There is a fundamental difference between religion, which is based on authority, [and] science, which is based on observation and reason. Science will win because it works."

In an interview published in *The Guardian*, Hawking regarded "the brain as a computer which will stop working when its components fail", and the concept of an afterlife as a "fairy story for people afraid of the dark" In 2011, narrating the first episode of the American television series *Curiosity* on the Discovery Channel, Hawking declared:

We are each free to believe what we want and it is my view that the simplest explanation is there is no God. No one created the universe and no one directs our fate. This leads me to a profound realization. There is probably no heaven, and no afterlife either. We have this one life to appreciate the grand design of the universe, and for that, I am extremely grateful.

Hawking's association with atheism and freethinking was in evidence from his university years onwards, when he had been a member of Oxford University's humanist group. He was later scheduled to appear as the keynote speaker at a 2017 Humanists UK conference.[371] In an interview with *El Mundo*, he said:

Before we understand science, it is natural to believe that God created the universe. But now science offers a more convincing explanation. What I meant by 'we would know the mind of God' is, we would know everything that God would know, if there were a God, which there isn't. I'm an atheist.[366]

In addition, Hawking stated:

If you like, you can call the laws of science 'God', but it wouldn't be a personal God that you would meet and put questions to.[348]

Politics

Hawking was a longstanding Labour Party supporter.[372][373] He recorded a tribute for the 2000 Democratic presidential candidate Al Gore,[374] called the 2003 invasion of Iraq a "war crime",[373][375] supported the academic boycott of Israel,[376][377] campaigned for nuclear disarmament,[372][373] and supported stem cell research,[373][378] universal health care,[379] and action to prevent climate change.[380] In August 2014, Hawking was one of 200 public figures who were signatories to a letter to *The Guardian* expressing their hope that Scotland would vote to remain part of the United Kingdom in September's referendum on that issue.[381] Hawking believed a United Kingdom withdrawal from the European Union (Brexit) would damage the UK's contribution to science as modern research needs international collaboration, and that free movement of people in Europe encourages the spread of ideas.[382] Hawking was disappointed by Brexit and warned against envy and isolationism.[383]

Hawking was greatly concerned over health care, and maintained that without the UK National Health Service, he could not have survived into his 70s.[384] He stated, "I have received excellent medical attention in Britain, and I felt it was important to set the record straight. I believe in universal health care. And I am not afraid to say so."[368]

Hawking feared privatisation. He stated, "The more profit is extracted from the system, the more private monopolies grow and the more expensive healthcare becomes. The NHS must be preserved from commercial interests and protected from those who want to privatise it."[385] Hawking alleged ministers damaged the NHS, he blamed the Conservatives for cutting funding, weakening the NHS by privatisation, lowering staff morale through holding pay back and reducing social care.[386] Hawking accused Jeremy Hunt of cherry picking evidence which Hawking maintained debased science.[384] Hawking also stated, "There is overwhelming evidence that NHS funding and the numbers of doctors and nurses are inadequate, and it is getting worse."[387] In June 2017, Hawking endorsed the Labour Party in the 2017 UK general election, citing the Conservatives' proposed cuts to the NHS. But he was also critical of Labour leader Jeremy Corbyn, expressing scepticism over whether the party could win a general election under him.[388]

Hawking feared Donald Trump's policies on global warming could endanger the planet and make global warming irreversible. He said, "Climate change is one of the great dangers we face, and it's one we can prevent if we act now. By denying the evidence for climate change, and pulling out of the Paris Agreement, Donald Trump will cause avoidable environmental damage to our beautiful planet, endangering the natural world, for us and our children."[389] Hawking further stated that this could lead Earth "to become like Venus, with a temperature of two hundred and fifty degrees, and raining sulphuric acid".[390]

In 1988, Hawking, Arthur C. Clarke and Carl Sagan were interviewed in *God, the Universe and Everything Else*. They discussed the Big Bang theory, God and the possibility of extraterrestrial life.[391]

At the release party for the home video version of the *A Brief History of Time*, Leonard Nimoy, who had played Spock on *Star Trek*, learned that Hawking was interested in appearing on the show. Nimoy made the necessary contact, and Hawking played a holographic simulation of himself in an episode of *Star Trek: The Next Generation* in 1993.[392][393] The same year, his synthesiser voice was recorded for the Pink Floyd song "Keep Talking",[394][177] and in 1999 for an appearance on *The Simpsons*.[395] Hawking appeared in documentaries titled *The Real Stephen Hawking* (2001),[297] *Stephen Hawking: Profile* (2002)[396] and *Hawking* (2013), and the documentary series *Stephen Hawking, Master of the Universe* (2008).[397] Hawking also guest-starred in *Futurama*[183] and had a recurring role in *The Big Bang Theory*.[398]

Hawking allowed the use of his copyrighted voice[399][400] in the biographical 2014 film *The Theory of Everything*, in which he was portrayed by Eddie Redmayne in an Academy Award-winning role.[401] Hawking was featured at the *Monty Python Live (Mostly)* in 2014. He was shown to sing an extended version of the "Galaxy Song", after running down Brian Cox with his wheelchair, in a pre-recorded video.[402][403]

Hawking used his fame to advertise products, including a wheelchair,[297] National Savings,[404] British Telecom, Specsavers, Egg Banking,[405] and Go Compare.[406] In 2015, he applied to trademark his name.[407]

Broadcast in March 2018 just a week or two before his death, Hawking was the voice of The Book Mark II on *The Hitchhiker's Guide to the Galaxy* radio series, and he was the guest of Neil deGrasse Tyson on *StarTalk*.[408]

Hawking received numerous awards and honours. Already early in the list, in 1974 he was elected a Fellow of the Royal Society (FRS).[409] At that time, his nomination read:

Hawking has made major contributions to the field of general relativity. These derive from a deep understanding of what is relevant to physics and astronomy, and especially from a mastery of wholly new mathematical techniques. Following the pioneering work of Penrose he established, partly alone and partly in collaboration with Penrose, a series of successively stronger theorems establishing the fundamental result that all realistic cosmological models must possess singularities. Using similar techniques, Hawking has proved the basic theorems on the laws governing black holes: that stationary solutions of Einstein's equations with smooth event horizons must necessarily be axisymmetric; and that in the evolution and interaction of black holes, the total surface area of the event horizons must increase. In collaboration with G. Ellis, Hawking is the author of an impressive and original treatise on "Space-time in the Large".

The citation continues, "Other important work by Hawking relates to the interpretation of cosmological observations and to the design of gravitational wave detectors."[410]

Hawking received the 2015 BBVA Foundation Frontiers of Knowledge Award in Basic Sciences shared with Viatcheslav Mukhanov for discovering that the galaxies were formed from quantum fluctuations in the early Universe. At the 2016 Pride of Britain Awards, Hawking received the lifetime achievement award "for his contribution to science and British culture".[411] After receiving the award from Prime Minister Theresa May, Hawking humorously requested that she not seek his help with Brexit.[411]

Medal for Science Communication

Main article: Stephen Hawking Medal for Science Communication

Hawking was a member of the Advisory Board of the Starmus Festival, and had a major role in acknowledging and promoting science communication. The Stephen Hawking Medal for Science Communication is an annual award initiated in 2016 to honour members of the arts community for contributions that help build awareness of science.[412] Recipients receive a medal bearing a portrait of Hawking by Alexei Leonov, and the other side represents an image of Leonov himself performing the first spacewalk along with an image of the "Red Special", the guitar of Queen musician and astrophysicist Brian May (with music being another major component of the Starmus Festival).[413]

The Starmus III Festival in 2016 was a tribute to Stephen Hawking and the book of all Starmus III lectures, "Beyond the Horizon", was also dedicated to him. The first recipients of the medals, which were awarded at the festival, were chosen by Hawking himself. They were composer Hans Zimmer, physicist Jim Al-Khalili, and the science documentary *Particle Fever*.[414]

Publications

Popular books

- A Brief History of Time (1988)[201]
- Black Holes and Baby Universes and Other Essays (1993)[415]
- The Universe in a Nutshell (2001)[201]
- On the Shoulders of Giants (2002)[201]
- God Created the Integers: The Mathematical Breakthroughs That Changed History (2005)[201]
- The Dreams That Stuff Is Made of: The Most Astounding Papers of Quantum Physics and How They Shook the Scientific World (2011)[416]
- My Brief History (2013)[201]
- Brief Answers to the Big Questions (2018)[348][417]

Co-authored

- The Nature of Space and Time (with Roger Penrose) (1996)
- *The Large, the Small and the Human Mind* (with Roger Penrose, Abner Shimony and Nancy Cartwright) (1997)
- *The Future of Spacetime* (with Kip Thorne, Igor Novikov, Timothy Ferris and introduction by Alan Lightman, Richard H. Price) (2002)
- *A Briefer History of Time* (with Leonard Mlodinow) (2005)[201]
- *The Grand Design* (with Leonard Mlodinow) (2010)[201]

Forewords

- *Black Holes & Time Warps: Einstein's Outrageous Legacy* (Kip Thorne, and introduction by Frederick Seitz) (1994)

Children's fiction

Co-written with his daughter Lucy.

- George's Secret Key to the Universe (2007)[201]
- George's Cosmic Treasure Hunt (2009)[201]
- George and the Big Bang (2011)[201]
- George and the Unbreakable Code (2014)
- George and the Blue Moon (2016)

Films and series

- A Brief History of Time (1992)[418]
- Stephen Hawking's Universe (1997)[419][235]
- *Hawking* – BBC television film (2004) starring Benedict Cumberbatch
- Horizon: The Hawking Paradox (2005)[420]
- Masters of Science Fiction (2007)[421]
- Stephen Hawking and the Theory of Everything (2007)
- Stephen Hawking: Master of the Universe (2008)[422]
- Into the Universe with Stephen Hawking (2010)[423]
- Brave New World with Stephen Hawking (2011)[424]
- Stephen Hawking's Grand Design (2012)[425]
- *The Big Bang Theory* (2012, 2014–2015, 2017)
- Stephen Hawking: A Brief History of Mine (2013)[426]
- *The Theory of Everything* – Feature film (2014) starring Eddie Redmayne[427]
- Genius by Stephen Hawking (2016)

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