Definition: **Einstein, Albert** from *Philip's Encyclopedia*

US physicist, b. Germany, who devised the famous theories of relativity. Einstein published many important theoretical papers: his explanation of Brownian movement confirmed the reality of atoms, his application of quantum theory to photoelectricity won him the 1921 Nobel Prize in physics. In 1905, he devised the special theory of relativity, which completely revolutionized physics and led, through its equivalence of mass and energy (\(E = mc^2\)), to the invention of the atomic bomb. In 1916, Einstein produced the general theory of relativity. He also made other fundamental contributions to quantum theory.

Summary Article: **Einstein, Albert (1879-1955)**
from *The Hutchinson Dictionary of Scientific Biography*

**Place**: United States of America, Germany

**Subject**: biography, physics

German-born US theoretical physicist who revolutionized our understanding of matter, space, and time with his two theories of relativity. Einstein also established that light may have a particle nature and deduced the photoelectric law that governs the production of electricity from light-sensitive metals. For this achievement, he was awarded the 1921 Nobel Prize for Physics. Einstein also investigated Brownian motion and was able to explain it so that it not only confirmed the existence of atoms but could be used to determine their dimensions. He also proposed the equivalence of mass and energy, which enabled physicists to deepen their understanding of the nature of the atom and explained radioactivity and other nuclear processes. Einstein, with his extraordinary insight into the workings of nature, may be compared with Isaac Newton (whose achievements he extended greatly) as one of the greatest scientists ever to have lived.

Einstein was born in Ulm, Germany, on 14 March 1879. His father's business enterprises were not successful in that town and soon the family moved to Munich, where Einstein attended school. He was not regarded as a genius by his teachers; indeed there was some delay because of his poor mathematics before he could enter the Eidgenössische Technische Hochschule in Zürich, Switzerland, when he was 17. As a student he was not outstanding and Hermann Minkowski, who was one of his mathematics professors, found it difficult in later years to believe that the famous scientist was the same person he had taught as a student.

Einstein graduated in 1900 and after spending some time as a teacher, he was appointed a year later to a technical post in the Swiss Patent Office in Berne. Also in 1901 he became a Swiss citizen and then in 1903 he married his first wife, Mileva Marié. This marriage ended in divorce in 1919. During his years with the Patent Office, Einstein worked on theoretical physics in his spare time and evolved the ideas that were to revolutionize physics. In 1905 he published three classic papers on Brownian motion, the photoelectric effect, and special relativity.

Einstein did not, however, find immediate recognition. When he applied to the University of Berne for an academic position, his work was returned with a rude remark. But by 1909 his discoveries were known and understood by a few people, and he was offered a junior professorship at the University of
Zürich. As his reputation spread, Einstein became full professor or Ordinariat, first in Prague in 1911 and then in Zürich in 1912, and he was then appointed director of the Institute of Physics at the Kaiser Wilhelm Institute in Berlin in 1914, where he was free from teaching duties.

The year 1915 saw the publication of Einstein's general theory of relativity, as a result of which Einstein predicted that light rays are bent by gravity. Confirmation of this prediction by the solar eclipse of 1919 made Einstein world famous. In the same year he married his second wife, his cousin Elsa, and then travelled widely to lecture on his discoveries. One of his many trips was to the California Institute of Technology during the winter of 1932. In 1933 Adolf Hitler came to power and Einstein, who was a Jew, did not return to Germany but accepted a position at the Princeton Institute for Advanced Study, where he spent the rest of his life. During these later years, he attempted to explain gravitational, electromagnetic, and nuclear forces by one unified field theory. Although he expended much time and effort in this pursuit, success was to elude him.

In 1939, Einstein used his reputation to draw the attention of the US president to the possibility that Germany might be developing the atomic bomb. This prompted US efforts to produce the bomb, though Einstein did not take part in them. In 1940 Einstein became a citizen of the USA. In 1952, the state of Israel paid him the highest honour it could by offering him the presidency, which he did not accept because he felt that he did not have the personality for such an office. Einstein was a devoted scientist who disliked publicity and preferred to live quietly, but after World War II he was actively involved in the movement to abolish nuclear weapons. He died at Princeton on 18 April 1955.

Einstein's first major achievement concerned Brownian motion, the random movement of fine particles that can be seen through a microscope and was first observed in 1827 by Robert Brown when studying a suspension of pollen grains in water. The motion of the particles increases when the temperature increases but decreases if larger particles are used. Einstein explained this phenomenon as being the effect of large numbers of molecules bombarding the particles. He was able to make predictions of the movement and size of the particles, which were later verified experimentally by the French physicist Jean Perrin. Experiments based on this work was used to obtain an accurate value of the Avogadro number, which is the number of atoms in one mole of a substance, and the first accurate values of atomic size. Einstein's explanation of Brownian motion and its subsequent experimental confirmation was one of the most important pieces of evidence for the hypothesis that matter is composed of atoms.

Einstein's work on photoelectricity began with an explanation of the radiation law proposed in 1901 by Max Planck. This is $E = h\nu$, where $E$ is the energy, $h$ is a number known as Planck's constant, and $\nu$ is the frequency of radiation. Planck had confined himself to black-body radiation, and Einstein suggested that packets of light energy are capable of behaving as particles called 'light quanta' (later called photons). Einstein used this hypothesis to explain the photoelectric effect, proposing that light particles striking the surface of certain metals cause electrons to be emitted. It had been found experimentally that electrons are not emitted by light of less than a certain frequency $\nu^0$; that when electrons are emitted, their energy increases with an increase in the frequency of the light; and that an increase in light intensity produces more electrons but does not increase their energy. Einstein suggested that the kinetic energy of each electron, $1/2mv^2$, is equal to the difference in the incident light energy $h\nu$ and the light energy needed to overcome the threshold of emission $h\nu^0$. This can be written mathematically as:

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\[ \frac{1}{2}mv^2 = h\nu - h\nu^0 \]

and this equation has become known as Einstein's photoelectric law. Its discovery earned Einstein the 1921 Nobel Prize for Physics.

Einstein's most revolutionary paper of 1905 contained the idea that was to make him famous, relativity. Up to this time, there had been a steady accumulation of knowledge that suggested that light and other electromagnetic radiation do not behave as predicted by classical physics. For example, no method had been found to determine the velocity of light in a single direction. All the known methods involved a reflection of light rays back along their original path. It had also proved impossible to measure the expected changes in the speed of light relative to the motion of the Earth. The Michelson-Morley experiment had demonstrated conclusively in 1881 and again in 1887 that the velocity of light is constant and does not vary with the motion of either the source or the observer. To account for this, Hendrik Lorentz and George FitzGerald independently suggested that all lengths contract in the direction of motion by a factor of \( \left(1 - \frac{v^2}{c^2}\right)^{1/2} \), where \( v \) is the velocity of the moving body and \( c \) is the speed of light.

The results of the Michelson-Morley experiment confirmed that no 'ether' can exist in the universe as a medium to carry light waves, as was required by classical physics. This did not worry Einstein, who viewed light as behaving like particles, and it enabled him to suggest that the lack of an ether removes any frame of reference against which absolute motion can be measured. All motion can only be measured as motion relative to the observer. This idea of relative motion is central to relativity, and is one of the two postulates of the special theory, which considers uniform relative motion. The other is that the velocity of light is constant and does not depend on the motion of the observer. From these two notions and little more than school algebra, Einstein derived that in a system in motion relative to an observer, length would be observed to decrease by the amount postulated by Lorentz and FitzGerald. Furthermore, he found that time would slow by this amount and that mass would increase.

The magnitude of these effects is negligible at ordinary velocities and Newton's laws still held good. But at velocities approaching that of light, they become substantial. If a system were to move at the velocity of light, to an observer its length would be zero, time would be at a stop, and its mass would be infinite. Einstein therefore concluded that no system can move at a velocity equal to or greater than the velocity of light.

Einstein's conclusions regarding time dilation and mass increase were later verified with observations of fast-moving subatomic particles and cosmic rays. Length contraction follows from these observations, and no velocity greater than light has ever been detected. Einstein went on to show in 1907 that mass is related to energy by the famous equation

\[ E = mc^2 \]

This indicates the enormous amount of energy that is stored as mass, some of which is released in radioactivity and nuclear reactions - for example, in the Sun. One of its many implications concerns the atomic masses of the elements, which are not quite what would be expected by the proportions of their isotopes. These are slightly decreased by the mass equivalent of the binding energy that holds their molecules together. This decrease can be explained by, and calculated from, the famous Einstein formula.

Minkowski, Einstein's former teacher, saw that relativity totally revised accepted ideas of space and time.
time and expressed Einstein's conclusions in a geometric form in 1908. He considered that everything exists in a four-dimensional space-time continuum made up of three dimensions of space and one of time. This interpretation of relativity expressed its conclusions very clearly and helped to make relativity acceptable to most physicists.

Einstein now sought to make the theory of relativity generally applicable by considering systems that are not in uniform motion but under acceleration. He introduced the notion that it is not possible to distinguish being in a uniform gravitational field from moving under constant acceleration without gravitation. Therefore, in a general view of relativity, gravitation must be taken into account. To extend the special theory, he investigated the effect of gravitation on light and in 1911 concluded that light rays would be bent in a gravitational field. He developed these ideas into his general theory of relativity, which was published in 1915. According to this theory, masses distort the structure of space-time.

Einstein was able to show that Newton's theory of gravitation is a close approximation of his more exact general theory of relativity. He was immediately successful in using the general theory to account for an anomaly in the orbit of the planet Mercury that could not be explained by Newtonian mechanics. Furthermore, the general theory made two predictions concerning light and gravitation. The first was that a red shift is produced if light passes through an intense gravitational field, and this was subsequently detected in astronomical observations in 1925. The second was a prediction that the apparent positions of stars would shift when they are seen near the Sun because the Sun's intense gravity would bend the light rays from the stars as they pass the Sun. Einstein was triumphantly vindicated when observations of a solar eclipse in 1919 showed apparent shifts of exactly the amount he had predicted.

Einstein later returned to the quantum theory. In 1909, he had expressed the need for a theory to reconcile both the particle and wave nature of light. In 1923, Louis de Broglie used Einstein's mass-energy equation and Planck's quantum theory to achieve an expression describing the wave nature of a particle. Einstein's support for de Broglie inspired Erwin Schrödinger to establish wave mechanics. The development of this system into one involving indeterminacy did not meet with Einstein's approval, however, because it was expressed in terms of probabilities and not definite values. Einstein could not accept that the fundamental structure of matter could rest on chance events, making the famous remark 'God does not play dice'. Nevertheless, the theory remains valid.

Albert Einstein towers above all other scientists of the 20th century. In changing our view of the nature of the universe, he has extended existing laws and discovered new ones, all of which have stood up to the test of experimental verification with ever-increasing precision. The development of science in the future is likely to continue to produce discoveries that accord with Einstein's ideas. In particular, it is possible that relativity will enable us to make fundamental advances in our understanding of the origin, structure, and future of the universe.

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