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ALBERT EINSTEIN

G. TEMPLE.

Albert Einstein was born on 14 March, 1879, at Ulm in Württemberg, Germany, the son of Hermann Einstein and his wife, Pauline, *née* Koch. His education was somewhat irregular, owing chiefly to changes in domicile brought about by unsatisfactory circumstances in his father's business. Between the ages of 10 and 15 he attended the Luitpold Gymnasium at Munich. Later for a year he became a pupil of the cantonal school at Aarau in Switzerland, and at the age of 17 he entered the Technische Hochschule at Zurich, each successive move involving some discontinuity in the curriculum. By 1901 Einstein had completed his studies at Zurich Polytechnic School and had taken the step of becoming a Swiss citizen. He then obtained a position in the Patent Office in Berne, and married a lady, Mileva Maric, who had been a student with him at Zurich. She was a native of Hungary, of Serbian race, and nominally of the Greek Orthodox religion. Two sons, Hans Albert and Eduard, were born to them on 14 May, 1904, and 26 July, 1910, respectively.

Einstein made his first contribution to theoretical physics in 1901, but it was in the year 1905 that he made his name with three remarkable papers, each of which has had a profound influence.

The papers of 1905 made such an impression that Einstein was widely recognized as a man worthy of exalted academic position, and after becoming a *Privatdozent* at the University of Berne he was, in 1909, appointed "Professor Extraordinary" of Theoretical Physics in the University of Zurich, and in the autumn of the following year, Professor of Theoretical Physics in the German University of Prague. This was one of the two parts, German and Czech, into which the ancient University of Prague had, in 1888, been divided, for political reasons. In 1912 he was offered and accepted a Chair of Theoretical Physics in his *Alma Mater*, the Polytechnic School at Zurich. In 1913 it was decided to invite Einstein to settle in Berlin as a member of the Royal Prussian Academy of Sciences in connexion with the Kaiser Wilhelm Gesellschaft, which had recently been founded by Wilhelm II as a centre of research institutes. Max Planck and Walther Nernst, who were at the time the leading German physicists, journeyed to Zurich to convince Einstein of the desirability of the plan, and persuaded him to accept it; he left Zurich for Berlin at the end of 1913.

Not long after making the change he separated from his wife Mileva Maric. He now became attached to another lady, his cousin, Elsa, whom he had known as a child in Munich. She was the daughter of a business man, and was now a widow with two daughters. The marriage to Mileva was dissolved on 14 February, 1919, although in 1924 she formally obtained leave to continue to use the name Einstein. She and Einstein's two sons continued to live in Switzerland. Mileva never left Switzerland, and died in Zurich on 4 August, 1948; the elder son became a civil engineer, and eventually settled in America. He is now professor of hydraulic engineering at the University of California, Berkeley. The younger son had a nervous breakdown at about the age of 20, from which he never recovered. Elsa was married to Einstein and lived with him as his wife until her death in 1936.

After 1918 there were many exhibitions of feeling in Germany hostile to Einstein, led by the eminent physicist Philipp Lenard of Heidelberg, who was an early member of Hitler's party. The Prussian Minister of Education, Hänisch, wrote to Einstein begging him to take no notice of these attacks, with such effect that Einstein, who in Imperial Germany had retained his Swiss nationality, now became a German citizen.

In 1922 he was awarded a Nobel prize for his work on quantum theory, and in 1925 he received the Copley medal of the Royal Society.

For the winter of 1932 the Einsteins went to the California Institute of Technology at Pasadena. In January 1933 Adolf Hitler was appointed Chancellor of the German Reich and the " purge " of Jews began. Einstein went back to Europe, but not to Germany; in the spring of 1933 he settled in a Belgian town near Ostend and wrote to Planck resigning his position in Berlin. In October 1933 he sailed from Southampton for New York, to accept a position in the Institute for Advanced Study, being appointed a member of the Institute for life. Later he acquired American citizenship.

Einstein died on 18 April, 1955, at the age of 76. Further biographical details, including some autobiographical notes by Einstein himself, will be found in *Albert Einstein, Philosopher-Scientist*, edited by P. A. Schilpp, Cambridge University Press, 1950.

Work.

A careful chronological study of Einstein's contributions to theoretical physics would undoubtedly be of great value in showing the impact of his thought on contemporary research, but for the purpose of this short obituary it is probably better to discuss Einstein's work under the three headings of (1) atomic theory, (2) quantum theory, and (3) relativity.

Einstein's first contributions to theoretical physics were two papers in classical statistical mechanics. In these papers he rediscovered Willard Gibbs' theory of canonical ensembles and also the theory of micro-canonical ensembles. Einstein's approach, however, was somewhat different and is more physical in outlook than the rather abstract theory of Willard Gibbs. But the most remarkable contribution which Einstein made to atomic theory was undoubtedly his researches on the Brownian movement (1905)—an impetuous irregular motion of microscopic particles that is produced by molecular bombardment. Einstein showed how the number of molecules per unit of volume could be inferred from measurements made of the diffusion of the visible particles under the impact of the molecules of the fluid. The mathematical analysis of this diffusion process by Einstein yielded an integral equation for the concentration $\nu(x, t)$ of the particles. This integral equation

$$\nu(x', t+\tau) = \int_{-\infty}^{\infty} \nu(x, t) f_\tau(x'-x)\, dx = \int_{-\infty}^{\infty} \nu(x'-X, t) f_\tau(X)\, dX$$

is expressed in terms of the fraction $f_\tau(x'-x)\,dx'$ which are found after a time τ in the interval $x', x'+dx'$, having migrated from the interval $x, x+dx$. This integral equation can be solved approximately by expanding both functions ν. From a first approximation we then obtain a diffusion equation from which it appears that the coefficient of diffusion D is equal to $\xi^2/2\tau$, where $\xi^2 = \int_{-\infty}^{\infty} X^2 f_\tau(X)\, dX$. This constant is directly measurable and it can be made to lead at once to a determination of Boltzmann's constant. Subsequent measurements made by Perrin verified Einstein's theory so well that the Brownian movement has ever since been regarded as one of the most direct—and impressive—pieces of evidence for the reality of molecules. Subsequent extensions of this theory are conveniently accessible in Chapter 20 of the 2nd Edition of *Statistical Mechanics* by R. H. Fowler, Cambridge University Press, 1936.

Quantum Theory.

In the same year (1905) Einstein published two revolutionary papers which have had decisive importance for the modern quantum theory of light. The first paper was based on Wien's formula for black body radiation and on the Boltzmann-Planck relation between entropy and probability. From these premises Einstein inferred that radiation behaves as if it consisted of quanta of energy or *photons* each of amount $h\nu$, when h is Planck's constant and ν is the frequency.

Einstein applied his idea in order to construct a theory of photo-electricity. In 1899 J. J. Thomson and P. Lenard had shown independently that a metal irradiated by ultra-violet light emits negative electrons; and in 1902 Lenard, continuing his researches, had shown that the number of electrons liberated is proportional to the intensity of the incident light, so long as its frequency remains the same, and that the initial velocity of the electrons is altogether independent of the intensity of the light, but depends on its frequency. In Einstein's work, the photo-electric effect was deduced from statistical concepts. The further application of these ideas led him to put forward a new theory of the specific heats of solids at low temperatures. Perhaps the most spectacular speculation by Einstein related to the frequency distribution of energy in complete radiation. Here Einstein analyses the processes of emission and absorption of radiant energy by molecules and expresses these in terms of the now well-known Einstein coefficients A and B. By assuming the Boltzmann-Gibbs formula for the number of molecules in each energy level he was able to deduce Planck's law of radiation. Conversely, the argument may be employed, as in fact it was by Einstein himself, to deduce from the known form of this law the existence of those discrete units of radiant energy now known as photons.

Another important result established at the same time related to exchanges of momentum between molecules and radiation. Einstein showed that when a molecule, in making a transition from the state Z_n to Z_m, receives the energy $\epsilon_m - \epsilon_n$, it receives also momentum of amount $(\epsilon_m - \epsilon_n)/c$ in a definite direction: and, moreover that when a molecule, in the transition from Z_m to the state of lower energy Z_n, emits radiant energy of amount $(\epsilon_m - \epsilon_n)$, it acquires momentum of amount $(\epsilon_m - \epsilon_n)/c$ in the opposite direction. Thus the processes of emission and absorption are directed processes; there seems to be no emission or absorption of spherical waves. These results were published in 1916. Some years later in 1924 Einstein applied similar ideas to develop the new statistics of radiation put forward by Bose. Einstein extended these ideas to the study of a monatomic ideal gas and obtained the fundamental distribution law and made explicit the characteristic features of the statistics of a gas of indistinguishable molecules. These results have now become "classical" and are referred to as the Bose-Einstein statistics.

Relativity.

It is of course with the theories of relativity that the name of Einstein will always be associated. A careful study of the history of relativity theory, such as is given in Chapter 2 of Volume II of *History of the Theories of Aether and Electricity* by Sir Edmund Whittaker, F.R.S. (London:

Nelson, 1953) suggests that Einstein's contribution to the special theory of relativity consisted primarily in an emphasis on its physical significance, and in an exposition of the mathematical principles in a form which was widely appreciated by experimental physicists. Einstein's approach may be compared and contrasted with the theories of relativity put forward by Whitehead and Milne. Whitehead's theory was a development from his general philosophy of nature, and Milne's theory proceeded with the very minimum of an appeal to physical procedures, but Einstein began with the electrodynamics of moving bodies and was always in close touch with the established results of experimental physics.

The fundamental problem of the "special theory of relativity" is to correlate the spatial and temporal measurements made by two observers in relative motion. Earlier investigations of this problem had been made by Larmor, Lorentz and Poincaré, and the solution is implicit in the purely mathematical transformation given by Voigt. Einstein's theory gave a simple and systematic expression of those results and a direct interpretation in terms of measurement made by a rigid rod and a perfect clock. He was thus able to give a complete and satisfactory account of the optics of moving media and to generalize Newtonian dynamics so as to incorporate the variation of mass with velocity. Einstein's relation, $E = mc^2$, where E is energy, m is mass and c the velocity of light, became of fundamental importance in atomic transformations and was found to be supported by numerous experiments in nuclear physics.

But Einstein's most famous and individual work was the creation of the general theory of relativity. This is a development of the "principle of equivalence" which he enunciated in papers published in 1907 and 1911. According to this principle a uniform gravitational field is physically equivalent to a field which is due to the accelerated motion of the coordinate system. An immediate inference was the prediction of a spectral shift towards the infra-red in radiation emitted in a strong gravitational field such as that surrounding the sun; and a further argument suggested that rays of light must be curved by passage near a powerful gravitating body.

These speculations were given a systematic form in the general theory of relativity. The two guiding principles of this theory are respectively physical and mathematical. The physical principle is that gravity is due to a change in the curvature of space-time, produced by the presence of matter. The mathematical principle is that the appropriate geometry for space time is Riemannian as expressed in the absolute tensor calculus of Ricci and Levi-Civita. In the general theory of relativity the paths of material particles are given as the geodesics of the 4-dimensional Riemannian manifold, which Einstein identified with physical space time. The line element in this manifold is specified by ten coefficients, the gravitational potentials $g_{\mu\nu}$. These gravitational potentials satisfy a set of ten highly non-linear partial differential equations, which express the fact that the contracted curvature tensor $K_{\mu\nu}$ vanishes in empty space. In order to discuss continuous distributions of matter Einstein took advantage of the fact that the divergence of the tensor $K_{\mu\nu}-\frac{1}{2}g_{\mu\nu}K$ is identically zero and he proposed to equate this tensor to a multiple of the energy tensor $T_{\mu\nu}$. The equations thus obtained should be sufficient to discuss all gravitational problems.

In 1915 Einstein showed that the new gravitational theory could explain an anomaly that had long been known to affect the motion of the perihelion of the planet Mercury, namely that the line of apsides advances 43″ in a century. It was shown much later by H. R. Morgan that the earth's perihelion also has a secular motion, much smaller in amount, which agrees with the amount calculated by Einstein's theory. Other explanations of these perihelion effects are, however, not altogether impossible.

A second comparison of General Relativity with observation proposed by Einstein, was that a ray of light coming from a star and passing close to the sun's gravitational field, when observed by a terrestial observer, should be deflected through an angle of about 1.75″. This prediction was tested at the solar eclipse of May 1919, and was at the time regarded as confirmed observationally; but later eclipses gave somewhat different results, and the matter must be regarded as still unsettled.

A third observational test proposed was the displacement to the red of spectral lines emitted in a strong gravitational field: here, however, complications are introduced by other possible factors. On the whole question of the comparison of General Relativity with observation, as it was regarded in the early days, see E. Weichert, *Ann. Phys. Lpz.*, 63, 301-381 (1920).

In 1917 Einstein pointed out that the field equations of gravitation, as he had given them in 1915, do not satisfy Mach's principle, according to which no space-time could exist except in so far as it is due to the existence of matter (or energy). Einstein's equations of 1915, however, admit the particular solution

$$g_{\mu\nu}=\text{constant}, \quad T_{\mu\nu}=0 \quad (\mu,\ \nu=0,\ 1,\ 2,\ 3),$$

so that a field is thinkable without any energy to generate it. He therefore proposed now to modify the equations by writing them

$$K_{\mu\nu}-\tfrac{1}{2}g_{\mu\nu}K-\lambda g_{\mu\nu}=-T_{\mu\nu} \quad (\mu,\ \nu=0,\ 1,\ 2,\ 3).$$

The effect of the λ-term is to add to the ordinary gravitational attraction between particles a small repulsion from the origin varying directly as the distance; at very great distance this repulsion will no longer be small, but will be sufficient to balance the attraction; and in fact, as Einstein showed, it is possible to have a statical universe spherical in the spatial co-ordinates with the uniform distribution of matter in exact equilibrium. This is generally called the *Einstein universe*. The departure from Euclidian metric is measured by the radius of curvature R_0 of the spherical space, and this is connected with the total mass M of the particles constituting the universe by the equation

$$\gamma M/c^2 = \tfrac{1}{4}\pi R_0,$$

where γ denotes the Newtonian constant of gravitation. The total volume of this universe is $2\pi^2 R_0^3$. The cosmological problem when the λ-term is not introduced was discussed in 1931.

A further development of the theory of relativity was initiated in 1918 by Weyl, who attempted to represent electromagnetic forces as well as gravitational forces as aspects of the pure geometry of space and time. The enlargement of geometrical ideas thus achieved by Weyl was followed in 1921 by a still wider extension due to Eddington which is based on an analysis of the notion of teleparallelism in curved space. Eddington's theory was further developed by Einstein, and in fact it is probably true to say that the main interest of Einstein's later years was the construction of a number of unified field theories in which an atom is made to represent both gravitational and electromagnetic phenomena in terms of the geometry of certain non-Riemannian manifolds. The equations so obtained are extremely complicated and it has proved difficult to submit them to any decisive experimental test.

The obituary notice of Einstein in the *Biographical Memoirs of Fellows of the Royal Society* contains a bibliography of 197 papers. To summarise and appraise such a wealth of fundamental research is an impossible task, but the three great contributions which Einstein made to physics may perhaps be described as

(1) the evidence for the existence of molecules from the Brownian movement,

(2) the evidence for the existence of photons from the nature of black body radiation and the photo-electric effect,

and, to conclude with a paradox,

(3) the evidence for the existence of the aether as manifested in the gravitational distortion of space time.

I am indebted to the late Sir Edmund Whittaker, F.R.S., and to the Council of the Royal Society for permission to draw freely on the obituary notice which he wrote for the Royal Society (*Biographical Memoirs of Fellows of the Royal Society*, Volume 1, 1955).