INDIAN JOURNAL
OF
METEOROLOGY AND GEOPHYSICS

VOL. 6 | OCTOBER 1955 | NO. 4

92 (Einstein)

Albert Einstein (1879-1955)

Prof. MEGHNAD SAHA

Director, Institute of Nuclear Physics, Calcutta

(Received 15 August 1955)

1. Introduction

On 17 July 1955, a large number of distinguished physicists of the world assembled at Berne, the capital city of Switzerland, to celebrate the fiftieth anniversary of the publication in 1905 of '*Zur Elektro-dynamik der bewegten Körper*'* —by Albert Einstein; then a name quite unknown to science. This paper ushered a new age in science: the Age of Relativity.

Einstein lived long enough to see the fruition of this great work and of other great scientific works which flowed from his brain and compelled rightful homage from the whole world. To the great regret of the scientific world, he had passed away a few months before the celebrations.

It will appear paradoxical to the modern generation to be told that the merits of the paper were not immediately recognized.

It is said that this paper had been previously submitted for the doctorate degree of the Zürich University, but was *not* approved by the Faculty, because it contained phrases like '*Die Einführung des Lichtäthers wird sich als überflüssig sein*'—*the introduction of a light äther will be shown to be superfluous*—which were quite unpalatable to orthodox physical thought of those times. "Young man, write something more sensible". With these words, young Einstein, then 25 years of age, was dismissed by the sages of the Faculty.

Somewhat discouraged, Einstein sent the paper to the leading German journal on physics '*Annalen der Physik*', where it was published in July, 1905.

In the meantime, he worked on Brownian Movement, and sent for publication several papers to learned journals. On the strength of these works, he was admitted to the doctorate degree.

* On Electrodynamics of moving bodies

By this time his paper on '*Relativity*' had seen the light of the day, and immediately attracted the attention of the foremost leaders of thought in the physical science like Max Planck in Berlin, and H. Poincaré and Madame Curie in Paris, who wrote to him congratulatory letters which were very flattering to a young man still unknown to fame. From 1906, he suddenly burst into scientific fame, which later became world-wide after confirmation of the predictions from his Generalised Theory of Relativity published in 1915. The halo round him had not diminished in lustre till his death a few months ago.

2. Why is the theory of Special Relativity considered Revolutionary and how had the ideas contained in this paper shocked the older orthodox physicists?

Since the time of Galileo and Newton, the science of physics had been built on three fundamental conceptions, *viz.*, those of mass, time and space. Each one of these conceptions is fundamental and defies definition. We sometimes say: mass is the quantity of matter; time is universal flux, and space is what we measure by measuring rods. These are not definitions, but attempts at clearing our confusions.

The laws of dynamics make use of these concepts, and in the form

$$Mass \times acceleration = force$$

enunciated first by Galileo (1570—1642) or its various refinements, have been shown to account for the laws of planetary motion (Newton, 1642—1727) and innumerable phenomena in physics. But doubts began to be expressed about the correctness of these ideas with the rise of electrodynamics (1880) and discovery of the electron in 1897.

It was found impossible to define the aether, the all-pervading medium which was supposed to be the seat of all electromagnetic phenomena, including light, *vide* for example the failure of Michelson-Morley experiments, and a number of other experiments. The mass of the electron was experimentally found to vary with velocity, thus knocking down one of the fundamental concepts of classical dynamics, in which *'mass' is regarded as invariable.*

Voigt and Lorentz tried methods of finding out transformations in space and time-coordinates which would account for these anomalies. In fact what are known as '*Lorentz-Einstein transformations*' were first given by Voigt of Göttingen in 1887, on purely mathematical grounds.

But these contributions, ingenuous as they were, remained unnoticed on account of their highly artificial nature. It was only in 1905, when working as a clerk in the Swiss Patent Office at Berne, that Einstein was able to give simple physical deductions of the '*Lorentz-Einstein transformations*' by making use of the concept of simultaneity, and the constancy of the velocity of light when observed from any frame of reference. His '*Elektro-dynamik der bewegten Korper*' remains a classic in the history of science*.

This paper and others which followed brought out a lot of revolutionary ideas, which could be put to experimental test, the ultimate court of appeal of all theories. Some results may be mentioned;

---

* It is said that at a war bond rally in Kansas, a manuscript copy of this paper was sold for six million dollars, see *Einstein, Philosopher and Scientist*, p. 695.

The mass of a particle is not invariant, but varies with its velocity v according to the law $m = m_0/\sqrt{1 - v^2/c^2}$ where m_0 = rest-mass. This deduction was neatly verified in the laboratory up to velocities approaching that of light.

Mass and energy are equivalent, $E=mc^2$, so that if we have a measuring system in which the velocity of light is unity, m should equal E.

This law was verified by Lord Rutherford and his co-workers in the nuclear experiments carried out about 1919. It forms the corner-stone of nuclear physics. The theory of special relativity thus knocks down the classical ideas on mass, time and space, and demands a new formulation of dynamics.

3. Einstein's early years

Albert Einstein was born in a small Swabian Jewish community at Ulm, Württemberg, on 14 March 1879. He spent his boyhood at Munich where his father had temporarily settled to pursue his business interests in some electro-chemical works. Here he attended the Humanistische Gymnasium.

In 1894, his family migrated to Italy, but young Albert was sent to a cantonal school at Aarau in Switzerland. We learn from his autobiographical notes that he was attracted to mathematics at quite an early age and had mastered, between the ages 12—16, most of the elements of mathematics, including differential and integral calculus, basic ideas of analytical geometry, infinite series etc. His interest in natural sciences was roused by his reading of Bernstein's *People's Books on Natural Science*, a work of 5 or 6 volumes, which he read over and over again 'with breathless attention'.

From Aarau, Einstein went to Zürich and studied at the Federal Institute of Technology, where he attended the mathematical lectures of Hermann Minkowski, who later in 1908 applied the ideas of four dimensional geometry to the special theory of relativity, and put the results in a very elegant mathematical form. Sommerfeld tells us that, strangely enough no personal contacts developed between Minkowski and Einstein; and when Minkowski in 1908 developed his '*World Geometry*', now a classic in the special theory of relativity, Einstein is reported to have once remarked "Since the mathematicians have invaded the theory of relativity, I do not understand it myself any more." Later on, however, when Einstein took upon himself the problem of working out the general theory of relativity, he readily acknowledged the indispensibility of Minkowski's four-dimensional scheme.

At the Federal Institute of Technology, Einstein found greater interest in physics and spent more time in the physical laboratories. He also got interested in the works of Kirchhoff, Helmoltz and Hertz and studied their papers at leisure hours.

Einstein left the Federal Institute of Technology in 1900 and spent a year as a tutor at Schaffhausen. He used to spend his leisure hours at the library of the Patent Office, poring over papers and books on mathematics and physics. Here he attracted the attention of the Director, on whose recommendation, the impecunious youth as he was then, was appointed examiner of patents at the Federal Patent Office in Berne, a position which he held till 1909. At this time he also registered himself as a Swiss citizen. These seven or eight years that he spent at Berne as an examiner of patents were the most fruitful and productive in his scientific career. A spate of papers, all of the highest order from the point of view of originality and some of them of profound fundamental importance, appeared in quick succession, mostly in *Annalen der Physik*, on a wide range of subjects—statistical mechanics and thermodynamics, kinetic theory, quantum mechanics and relativity. In one single fruitful year, 1905, he published papers on

(i) *The photo-electric equation,*
(ii) *Brownian movement,*
(iii) *The special theory of relativity,* and
(iv) *A new determination of molecular dimensions*

The following year appeared his famous theory of specific heat in which he successfully applied Planck's quantum ideas to explain the anomalies in the value of specific heat discovered by Nernst and his co-workers.

The photo-electric effect, that is the emission of electrons from illuminated metal plates, was discovered by Hertz in 1887. The fact that electrons are emitted only when the frequency of the incident light exceeds a certain threshold frequency resisted all attempts at explanation on the basis of the classical electromagnetic theory of light. Einstein who had been following Planck's theory of black body radiation with great interest found the answer by adopting a far bolder view that emission and absorption both take place in quanta and that radiation itself has a quantum or corpuscular-like structure. On the basis of this revolutionary concept of light-quanta, he was immediately able to deduce his famous photo-electric equation. In the citation on the Nobel Prize award (1921) to him, only the photo-electric equation is mentioned, so that it appears that *even* by 1921, the dispensers of this great prize were not able to make up their mind regarding the merits of his contributions to Relativity.

In 1905, Einstein worked out the complete theory of Brownian motion and expressed the displacement of the particles in the following equation:

$$\bar{x}^2 = 2KUtT$$

where $\bar{x}^2$ is the average of the squares of displacements of particles, K the Boltzmann constant, t the time, T the temperature and U a constant containing the viscosity co-efficient of the liquid medium. The Avogadro number was determined by using this equation and measuring the displacements of particles under a microscope agreed with the values obtained by Perrin. The equation gave a complete theoretical basis of this puzzling phenomenon.

4. Einstein at Berlin (1913—1933)

The scientific world was quick to recognize the great originality and even the revolutionary character of Einstein's contributions. In 1909 he was appointed an associate professor of theoretical physics at the Zürich University. Two years later he was offered the chair of physics at Prague which he accepted only to return to the Federal Institute of Technology at Zürich as a full professor of theoretical physics the same year. Offers also came from Germany. In 1913, the famous physical chemist Nernst who recognized Einstein's merit from his contributions to specific heat theory, a subject which was Nernst's own child, succeeded in getting him to accept a professorship of the Berlin University, specially created for him and the Directorship of the Kaiser-Wilhelm Physical Institute in Berlin.

His friendship with the great German scientists—Planck, Nernst, Sommerfeld, von Laue, and others remained unshaken through the dramatic vicissitudes of his own career till the rise of Hitler.

He was also elected a member of the Royal Prussian Academy of Sciences and given a stipend sufficient to enable him to devote all his time to research without any routine duties. This was an ideal situation for Einstein, for he never liked delivering lectures. At Zürich he was obliged to deliver lectures to students much to his dislike. He never had any orderly lecture-manuscripts; whatever he managed to prepare generally got lost by the time he had to deliver them. At Berlin he was free from these obligations, although he could freely choose to deliver lectures at the University. Sommerfeld tells us that the completion of his general theory of relativity was in no small way due to the leisure he enjoyed in Berlin.

Einstein was soon elected member of many scientific academies and societies in and outside Germany, for example, of the Bavarian, Amsterdam and Copenhagen Academies. He was elected a foreign member of the Royal Society of London in 1921. A number of Universities—Geneva, Manchester, Rostock and Princeton, had also conferred honorary degrees upon him. He was awarded Nobel Prize in physics for his work on the photo-electric phenomena in 1921. The Copley Medal of the Royal Society and the Gold Medal of the Royal Astronomical Society of London were awarded to him in 1925 and 1926 respectively in recognition of his theory of relativity.

The political troubles in which Einstein got involved after World War I, which reached a climax during Hitler's regime, are well known. He was already marked for his leftist views. When the repression of the Jews began, he found conditions of living in Germany almost intolerable for him. During the 'relativity-rumpus' which occasionally sank to the level of anti-semitic mass meetings and demonstrations, he seriously considered leaving Berlin and it was only the persuasive powers of Max Planck, for whom he had great respect that he repeatedly revised his decision. Matters came to a head in 1933 shortly after Hitler came to power. For a number of his statements which appeared in the French and the American press, he was charged of participation in atrocity-mongering in foreign countries and of giving a convenient handle to the enemies of Germany.

He was obliged to withdraw his membership of the Prussian Academy of Science. The same year (1933) while he was on a lecture tour in England and America, he was deprived of his Berlin professorship and his post as Director of the Kaiser-Wilhelm Physical Institute. Even his personal possessions were confiscated.

5. Scientific life at Berlin : The Generalized Theory of Relativity

The Berlin period (1913—33), saw the most fruitful years of Einstein's life—the period when he gave out to the world '*The Generalized Theory of Relativity*'. He had, during these years, the congenial company of a great many giants in physics in the German capital city—Planck, Nernst, Haber, von Laue, and a host of younger workers who attained great reputation later and who had a genuine appreciation and understanding of his greatness. To this group, may also be added Sommerfeld, though he lived at Munich, and Born though he lived at Göttingen. He was a regular visitor to the physical colloquium held once weekly at the *Physikalische Institute* of the University, and listened very carefully to the discussions, but seldom spoke. The World War I, which intervened, does not appear to have much effect on his scientific work.

Here in 1915, he presented before the Royal Prussian Academy of Sciences, a report of his work on the Generalized Theory of Relativity published later as *Die Grundlage der Allgemeinen Relativitäts—theorie* in the *Annalen der Physik*, **49,** 1916. But the ideas appear to have been present in his mind since 1911, when he contributed a paper to the *Annalen* on interpretation of Eötvös's experiments on the equivalence of inertial and gravitational masses.

In this and other series of papers which were to follow, Einstein set to himself the following fundamental question:—Physics recognises the principle of inertia as the keystone of physics, and the experiments by von Eötvös had shown that the inertial mass was equal to the gravitational mass. For enunciating the principles of inertia, we have to conceive a system of reference (the Galilean system) which is supposed to have an absolute space connotation; and after the rise of the special theory of relativity, the space connotation should be changed to the absolute space-time framework connotation. But it is contrary to the mode of thinking in science to conceive of a thing which acts itself, but cannot be acted upon. The space-time continuum itself, therefore, should be modified by the gravitational field. The special theory of relativity concerns itself with the invariancy of the physical laws in two systems of reference one of which is moving with uniform velocity relatively to the other. This uniform motion is a restriction, that is why it is often called as the restricted theory of relativity. Einstein's *general* theory of relativity removes this restriction, the relative motion of the two systems need not be *uniform* but is *accelerated*. Let us consider an observer stationed inside an elevator which falls freely from the top of a sky scraper. If he places his watch in the mid air of the elevator, it would not fall to the bottom but remain stationary there. Newton's law of inertia which states that every material body continues its state of rest or uniform motion until disturbed by external force is valid within the elevator that falls freely; whereas an observer stationed on the earth finds that all bodies when left in the air fall to the ground because of the gravitation. We have here two systems of reference in relative accelerated motion, the system in the elevator may be called the inertial system because in it the force of gravity has been wiped out and as such the law of inertia is valid; whereas in the other system, to the observer stationed on the earth the force of gravity exists. So when we consider the two systems of reference moving relative to each other with accelerated motion, a transition from one system to another involves the presence or absence of the force of gravitation. So the force of gravitation becomes linked up with the geometrical description of the events in the system of reference. The next logical step is to formulate the laws of nature in such a way that they are valid in any of the systems. Einstein solves the problem by incorporating the force of gravitation within the geometry of the system and by an invariant formulation of physical laws valid for any arbitrary system. The space-time continuum of the inertial system is Euclidean, whereas for any other system in which the force of gravitation exists he takes the four-dimensional continuum to be non-Euclidean*.

* The mathematical apparatus in which Einstein expressed his ideas were given about a century earlier by Riemann and put into an elegant mathematical form by Schwarz and Christofell, which Einstein followed.

So the geometry of the world and the force of gravitation become synonymous; the presence of mass deforms the surrounding space-time continuum. The square of the distance between two adjacent world-points is given by

$$ds^2 = g_{\mu\nu} . dx^{\mu} . dx^{\nu}$$

when $g_{\mu\nu}$ is the metric tensor (symmetric) and depends on the distribution of the masses and their motions in the four dimensional continuum. In the absence of the masses the metric tensor reduces to

$$g_{11} = g_{22} = g_{33} = 1, \quad g_{44} = -1, \; g_{\mu\nu} = 0, \; \mu \neq \nu$$

We then have the flat Euclidean space. Further Einstein discarded the Newtonian concept of action-at-a-distance which implies that if a new star is born out of nothing, it exerts force instantaneously all around the universe, Einstein's formulation of the gravitational action is a field theory in line with the electromagnetic field theory of Maxwell. So the gravitational influence according to the field concept spreads with finite velocity from the source to other bodies, the field quantities that describe the gravitational action vary with position and time in accordance with the field equations of Einstein which in an empty space take the simple form $R_{\mu\nu} = 0$ where $R_{\mu\nu}$ is the contracted Riemann-Christoffel tensor and is a function of the $g_{\mu\nu}$'s.

The salient points of the general theory of relativity are: (1) The formulation of the field equations that describe how the gravitational field varies in space-time continuum and the equations of motion of a particle in such a field; (2) The above equations are valid in any arbitrary system of reference; (3) The geometry of space-time deformation replaces the concept of the gravitational force.

6. Consequences of the General Relativity Theory

Now we shall state some of the consequences of the general relativity theory.

In the first approximation the theory gives the same result as the Newtonian theory of gravitation, but when higher approximations are taken we have the following results which were worked out by Einstein and given as predictions to be verified*. They are:

(a) *Light passing past a field of gravitation will suffer deflection which can be calculated*

This can be verified only during a total solar eclipse by photographing the field of stars about the sun. The deflection, according to G.R. Theory, would be 1.74″ for a star just beyond the solar disc, while according to the Newtonian theory, *i.e.*, taking a light particle to possess a mass of $h\nu/c^2$, it would be just half, *viz.*, .87″. These predictions were made in 1915, in the midst of the first World War; but they happened to leak through the blockade to the outer world, and received attention from the Royal Astronomical Society of Great Britain. On the initiative of the Society, eclipse expenditions were organized by the observatories of Greenwich and Cambridge, who obtained for the deflection the values

* The considered view of the scientists who assembled at the Jubilee of Relativity Theory at Berne is that the deductions of the General Theory of Relativity needs careful re-analysis in the light of recent interpretations of the experimental results

$1.98'' \pm .12''$, and $1.61'' \pm .30''$. This confirmed Einstein's prediction that the gravitational deflection of light on the surface of the sun was $\simeq 1.74''$, *i.e.*, twice that of the Newtonian deflection of $.87''$.

N.B.—Since 1919, many eclipse expeditions were organized to obtain the correct value of the gravitational shift. It will be out of place to discuss them here.

(b) *The wavelength of monochromatic radiation emitted by a stellar body will be increased in direct proportion to the value of the gravitation potential on the surface of the stellar body*

On the sun, this amounts to a velocity effect to the red of .65 km per cm giving for a wavelength of 3883 Å.U. the shift of .008 Å.U.

It is extraordinarily difficult to measure such a small deviation correctly, as wavelengths of lines on the sun are subject to many other influences, *e.g.*, pressure shift, Döppler effect etc. Many celebrated workers like St. John and Evershed, have claimed to have shown the shift on the solar surface to be nearly .008 A.U. but the results have not appeared convincing to most readers.

But a confirmation of this prediction came from a very unexpected quarter. The bright star Sirius, has a faint Companion which had puzzled astronomers for a long time. While Sirius has a mass of 4 times the solar mass, the Companion has about a mass nearly equalling the solar mass, though it is 6000 times fainter than Sirius. This might be due to two facts—

(1) that the temperature of the Companion is much smaller than that of Sirius. This probability is excluded by an examination of the spectrum of the Companion which shows it to be of the F-class ($\theta = 8500°$A) while that of Sirius is of (A-class) is ($\theta = 10{,}000°$A).

So we turn to the second possibility.

(2) the surface of the Companion is extremely small, compared to that of Sirius.

This second deduction, from which there is no escape, enables us to calculate the density of the Companion which reaches the extraordinary value of $\simeq$ 50,000, *i.e.*, a rupee on the Companion will weigh a ton as Eddington graphically put it. This conclusion was arrived at by Böttlinger and Eddington, and the latter pointed out that it will render the gravitational potential on the surface of the Companion extraordinarily high and the relativity shift would be .30 A.U. instead of the puny amount of .008 A.U. on the sun.

On putting the matter to test, Adams at Mt. Wilson found the shift of H-lines on the Companion to be .32 A.U.

Thus the G.R. theory is responsible for the discovery to Astronomy of a remarkable class of stars, the *white dwarfs*, which probably would have otherwise taken an indefinite period to be discovered.

(c) *Motion of the perihelion of planets*

Since about fifty years from the time of the astronomer Le Verrier, it has been known that the perihelion of the planet mercury has a motion of 43″ per century.

This could not be accounted for by Newton's theory of gravitation and was an outstanding problem in theoretical astronomy. Einstein explained it from the G.R. theory, and gave the expression

$$\delta \text{ (in radians)} = \frac{24\,\pi^3 a^2}{(1-e^2)\, c^2 T^2}$$

a = semi major axis
T = period of revolution in seconds
e = eccentricity of the orbit

This completely accounted for the perihelion motion of mercury.

Verifications of these predictions greatly enhanced the prestige of Einstein, and he became the recipient of honours from many scientific societies and academies. At the same time he became deservedly a world figure—the only scientist whose name became familiar to the man in the street all over the world.

But his socialistic views which were well-known, made him a *béte noir* amongst the extreme sections of German nationalists, though the rank and file of German scientists claimed his achievement as a great triumph for German science. In non-German countries, however, his Germanic origin was scarcely referred to. His achievements were regarded as triumphs for a cool thinking Jewish savant, who could achieve such a great feat because he stood aloof from the sabre-rattling of extreme German nationalists. Speaking of these polemics, Einstein remarked with a dry humour "Had my predictions been not verified, the opinions would have been just reversed. The non-German world would have denounced me as a metaphysical German, and the Germans as a pedantic Jew".

7. Cosmology

We have seen that presence of masses make the space-time continuum non-Euclidean or curved—to put it crudely. When the space-time is curved, the question arises whether it is closed or not. The former will make space-time expanse finite and the latter infinite. What do we mean by saying that the space-time expanse is finite? When it is finite, a light signal sent from any point would return back to that point after lapse of time. It is difficult to conceive things in a four-dimensional space, so for simplicity we consider the two dimensional surface of a three dimensional space, say an ant crawling straight forward on the surface of a tennis ball will always come back to the starting point after some time. The size of the universe would depend on the degree of curvature of the space which, in its turn, depends on the distribution of masses in the universe. We shall see what data the giant telescopes reveal about the distribution of masses. Einstein in a paper to the Proceedings of the Prussian Academy of Sciences (1917) set us thinking on the cosmological consequences of the general theory of relativity. The conclusion of the paper was wrong because of an error in the calculation but the idea and the method of approach was taken up by de Sitter, Friedmann, Lemaitre and Robertson.

The entire universe consists of islands of matter in an otherwise sea of almost* complete emptiness. We call these islands of matter as nebulae; the

* Almost because the internebular space contains matter, to a density of about 10^{-30} gm per cm^3

solar system together with the nearest stars constitute one such nebula which is our galaxy. Our scale of distance in the universe is the light-year—a distance that light travels in one year. The average diameter of a nebula is about 20,000 light-years and the average distance of separation between them is 3,000,000 light-years. The nebula farthest from us is at a distance of half-a-billion light-years. Within the range of two billion light-years, as a 200-inch telescope can reach, there are something like a billion nebulae according to Hubble. That gives an idea how sparsely populated the universe is with nebulae.

There is another important feature about the nebulae, their spectra show a red shift (Döppler effect) which means the nebulae are running away from us. Moreover, it was found by the Mount Wilson astronomers, Hubble and others that the degree of red-shift increases with the distance, the more distant the nebula is from us, the greater is the speed of the running nebula.

The cosmologists assume that the universe is uniform with respect to the distribution of the nebulae and further that the nebulae are not only running away from us but also running away from each other. The proposed cosmological models are based on the principle of uniformity and the consequence of the red-shifts.

We maintain that the whole matter of the universe was concentrated in a very small volume—as electrons, protons and neutrons, then something happens and the fragments of matter start flying apart from each other, the distances these fragments have travelled depend on their speed, that explains why the speed of a nebula is in proportion to its distance from us. So far it is all right. But the velocity of recession appears to be too large, making the age of the universe to be too small. It makes the universe expand from a highly concentrated mass about five billions of years ago, while the age of archean and prearchean rocks on the earth, from well-documented experiments is found to reach the value of at least three, and according to some authorities six billion years. Thus we arrive at the paradox: *the child is older than the parent.* There have not been enthusiasts wanting who would sacrifice the evidence of ages of rocks in favour of the deductions from the relativity theory, but Einstein himself, as expected, does not favour this view. He expresses the difficulty in the following words:

"The situation becomes complicated by the fact that the entire duration of the expansion of space to the present, based on the equations in their simplest form, turns out *smaller* than appears credible in view of the reliably known age of terrestrial minerals. But the introduction of the '*cosmological constant*' offers absolutely no natural escape from the difficulty. This latter difficulty is given by way of the numerical value of Hubble's expansion—constant and the age-measurement of minerals, completely independent of any cosmological theory, provided that one interprets the Hubble effect as Döppler-effect."

8. Contributions to Quantum Physics

The Berlin period also saw the phenomenal rise of the quantum theory, and of wave-mechanics which, taken together, have thrown a flood of light on radiation and atomic phenomena. Though in the midst of these great discoveries, Einstein appears to have been little attracted to them, except on two occasions.

The first occasion was in 1917 when, poring over the implications of the Bohr-atom, he wrote a paper on Einstein A and B-coefficients, the A-coefficients denoting the spontaneous transition probability of excited states to lower ones, the B-coefficients denoting the transitions to higher and lower states under the effect of radiation. These contributions are rightly regarded as fundamental to atom-physics.

It was these considerations which led to a collaboration between Einstein and Ehrenfest under the title "*Quanten theorie des Strahlungsgleichgewichts*" in the *Zeitschrift f. Physik,* Vol. 19, pp. 301—306. While the author of this note was studying this paper together with S. N. Bose in 1924, the latter was led to a very ingenuous deduction of the Planck law of radiation. He showed that the number of cells A in a phase space can be determined by the expression

$$A = \frac{1}{h^3} \int\int \ldots dp_r \, dq_r$$

the integration extending over the whole phase-space covered by the particles.

One can then proceed to fill up the phase-space by the number of quanta available, by using combination with repetition, (a device already taken by Debye), and thus get the Planck law in a very simple manner. This is in fact what was done by S. N. Bose.

Bose's paper, published in the *Zeitschrift f. Physik,* Vol. 26, 1924 attracted the attention of Einstein (in fact, he translated it into German) and he made a very ingenious application of it to explain *'Gas-degeneration',* a phenomenon with which he had become acquainted in course of his visits to the laboratory of his friend Prof. W. Nernst, in the *Physicalische Chemische Institute of the Berlin University* (Sitzungsber d Preuss. Akademie, 1924 and 1925). Einstein showed that Bose's method of calculating the number of phase-cells could be extended to a statistical system representing a gas, and the most probable state of the gas can be worked out by using permutation with repetition. He thus worked out a theory of gaseous matter at low temperature, and tried to explain the deviations from the perfect gas law discovered by Nernst and his co-workers. Fermi on the other hand used combination *without* repetition and worked out what is known as Fermi—Dirac Statistics. It is now recognised that while the Fermi-Dirac theory correctly represents the statistics of particles with spin $\frac{1}{2}$, the Einstein-Bose theory correctly represents statistics of particles with spin zero, or an integral number. It was later shown from wave-mechanics, that the two modes represent the two different ways of combining wave functions representing particles, *viz.,* the symmetrical and the antisymmetrical ways.

9. Einstein in the U.S.A.

After his expulsion from Germany, Einstein received requests from a number of countries to become their citizen. He finally decided in favour of U.S.A. and settled at Princeton, whose famous Institute for Advanced Studies offered him the kind of quiet atmosphere for study and thinking he liked. For the remaining 22 years of his life, Princeton remained Einstein's home.

The important part played by Einstein in persuading the government of President Roosevelt to take interest in the development of military application of atomic energy is now well-known. Many scientists from Europe, Jewish as well as non-Jewish, had taken refuge in the U.S.A. to escape from the anti-semitic orgies of Hitler and Mussolini. They included, *e.g.*, men like Fermi, Szilard, Wigner and a host of others who were notable nuclear scientists.

World War II broke out in September 1939, and the years 1939, 1940 and 1941 were years of great anxiety for the whole world. It appeared that the Nazi hosts were going to overrun the whole world, and impose their rule over the major parts of the world. Public opinion in the U.S.A. was thoroughly alarmed, and everybody began to think how the defeat of the Nazis could be achieved.

Nuclear fission had been discovered, early in 1939, in Germany by Otto Hahn, and many scientists of different countries had foreseen its potentialities. In fact, Joliot-Curie and Halban in France, Fermi, Amaldi and their group in Italy, Flügge and others in Germany had already thought of turning nuclear energy to useful work by making use of the fission process, and they had independently thought of the reactor. The foreign scientists who had escaped from Nazi oppression in Europe, notably Fermi, Szilard and Wigner had much clearer ideas about the possibilities of developing military use of nuclear energy than most American scientists, but they recognized that it required effort on a huge scale which only the State could afford. In the year 1939-40, Szilard and Wigner persuaded Einstein to write to President Roosevelt about the military possibilities of atomic energy and the desirability of embarking upon an intensive programme of nuclear research and development to that end. A suggestion from Einstein could not be ignored and Roosevelt immediately appointed an Advisory Committee under the Chairmanship of Lyman Briggs, the Director of the National Bureau of Standards. This Committee reported unfavourably on the subject, but the matter was again referred to Prof. A. H. Compton who, along with his students had done some work on nuclear fission. Compton reported favourably and work (the Manhattan project) went on with mounting enthusiasm and suspense, culminating in the first atomic explosion at Alamogordo in the desert of New Mexico on 16 July 1945 that ushered in human history a new age, *the Atomic Age*. To be true, the Atomic Age had really begun with Einstein in 1905 when from his special theory of relativity he deduced his famous mass-energy equivalence law $E=m_0c^2$, the basic principle of any atomic energy development.

Einstein had later to regret his decision for having advised President Roosevelt to start 'Atomic Energy Work'. For the Atom-Bomb was used on two Japanese cities without warning, killing nearly 3,00,000 innocent people within the twinkling of the eye, and unleashing the cold atomic war. Einstein foresaw the horrors of the atomic war, returned to its denunciation with all the authority associated with his great name, but without the slightest effect on protagonists of war. He realized that a Frankenstein monster has been created, which was about to devour its own creators! He died a deeply disappointed man, full of gloomy forebodings for the future! His last legacy was a touching letter to the philosopher, Lord Bertrand Russell, advocating disarmament, banning of atomic weapons, and universal peace.

10. Epilogue

Einstein was easily the greatest scientific figure of his age, which was one of the greatest in science, and he was one of the giants of all times. He lived in the midst of science, yet apart from its routine. Picking up 'pearls' from an amorphous mass of matter was his speciality, and in this, he was eminently successful.

His was essentially an *'one-track mind'*. He was always working, his mind would be full of the work he had in hand and any attempt to deflect him away from the problem which occupied his mind turned out to be rarely successful. It is said that one of the professors of the Princeton University had some difficulty with the theories of specific heat, and fixed up an appointment with Einstein, who asked him, when the latter presented himself, what was the specific purpose for which he had chosen to call on him. He said that he wanted to discuss with him some difficulties he had in the quantum theory of specific heat. "But I have never worked on that subject." "Why", said the astonished professor "yours was the pioneering contribution to this subject". "Really, but I cannot recall when I worked on it", said Einstein, and it required some effort on the part of the bewildered professor to convince Einstein that he had really made the first contribution to the modern theory of specific heat!

Unlike many other great scientific men, he was entirely free from jealousy of his contemporaries. He was singularly free from personal jealousy from which many eminent workers suffer, *e.g.*, Newton and Leibnitz, Newton and Hooke, and many others.

Unlike many other scientific men, he was ready to admit his mistakes and shortcomings. He conceived the idea of proving the existence of *"molecular magnets"*, and devised the experiment now known as the 'Gyromagnetic Effect', which enables one to show that electrons are responsible for the magnetism of metals. The method enables one to find out the ratio between magnetic moment and angular momentum of electrons, which comes out to be $e/2mc$ when magnetism is wholly ascribed to the orbital motion of electrons. In 1916, Einstein and de Hass performed this experiment the only experiment Einstein performed in his life using the ingenious method of resonance, and found the experimental value to be almost exactly ($e/2mc$). Later this experiment was repeated by E. Beck in the Zürich Institute of Technology who found the ratio to be more nearer e/mc. When Einstein repaired to Zürich, Beck showed him his experiments and explained his hesitation at publishing a result which contradicted Einstein's. Einstein carefully went through the experiments and remarked *"Perhaps you are right, for you have performed the experiment much more carefully than we had done! You should not hesitate to publish the result."* It is now known that Beck was correct, for the magnetism in metals investigated by Einstein and de Hass, and Beck is mostly due to the spin of electron, for which the ratio is e/mc. But at this time, there was no idea of rotating electrons, and Einstein and de Hass's result appeared to be iron-clad. But still Einstein had the magnanimity to acknowledge the superior experimental technique of Beck*.

We can thus divide Einstein's scientific life into three periods:

(1) The Swiss period	1900—1913
(2) The German period	1913—1933
(3) The American period	1933—1955

* *Heard the story from Beck himself*

Of these the first two periods were the most fruitful creative years of his life. The Swiss period saw the blossoming of his genius, the German period its full ripening and maturity. Probably he could achieve so much because he stood on the shoulders of the great workers who passed before him—Voigt and Lorentz, Michelson and Morley, Eötvös and Riemann. The American period has not been so productive, not because his powers were declining, but more probably because the stimulus given by his genius had not fully worked out its course on the sciences of astronomy and physics.

Strangely enough, though taking interest in wave mechanics which has enriched the physical sciences beyond recognition since 1926, he did not believe in many of its philosophical implications. "I cannot believe", he remarked to the present writer in course of a conversation in 1927, that "the dear God has made the α-particle a wave".

Later he said "I am, in fact, firmly convinced that the essentially statistical character of contemporary quantum theory is solely to be ascribed to the fact that this theory operates with an incomplete description of physical systems".

It is this belief which kept him 'from falling in line with the opinion of almost all contemporary theoretical physicists'.