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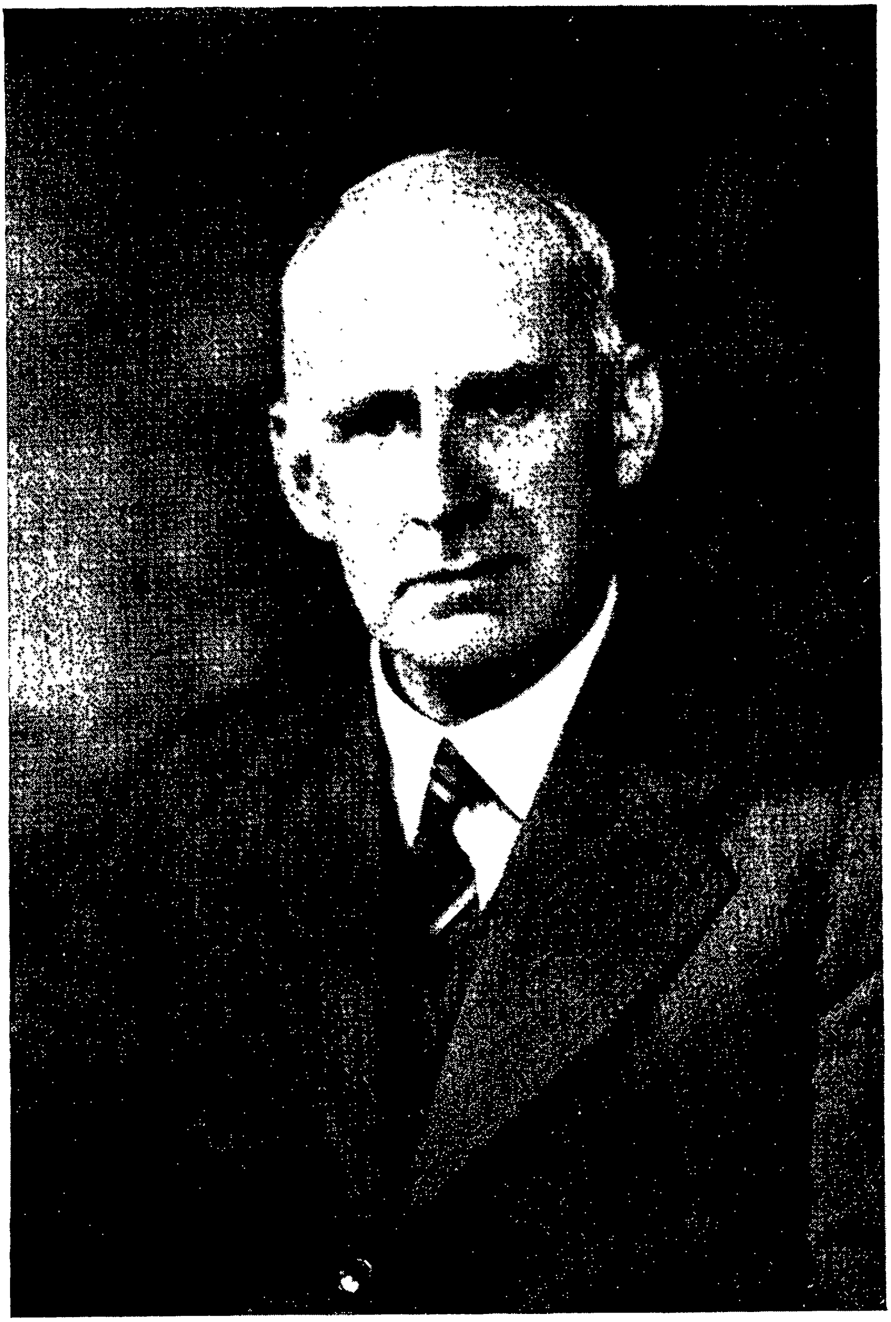
SIR ARTHUR STANLEY EDDINGTON, O.M., F.R.S.

EDDINGTON : THE ASTRONOMER.

The death of Sir Arthur Eddington, which occurred after an operation at a nursing-home in Cambridge on 1944 November 22, has come as a great shock to the whole scientific world. Not quite 62, he was still at the height of his powers and still in the van of astronomical achievements. An hour or two before he left for the nursing-home he was able to put the finishing touches to the manuscript of his last book without deciding, however, on a title.

Arthur Stanley Eddington was born on 1882 December 28 at Kendal, Westmorland, the only son and second child of Arthur H. Eddington, headmaster of the Friends' School in that town. At a very early age the young Eddington had already shown unmistakable signs of the road his genius was to follow; in his first mathematical research he embarked on the bold undertaking of counting the words of the Bible, and a little later, having acquired a one-inch telescope, he began his astronomical career as an observer of the celestial bodies whose secrets became, in his mature years, the chief object of his investigations. Eddington's father died at an early age; the family removed to Weston-super-Mare, and there, at Bryn Melyn School, Eddington received his early education. Then, after a brilliant career at Owens College, Manchester, he proceeded in 1902 to Trinity College, Cambridge, with an entrance scholarship in Natural Science. In 1904 he was Senior Wrangler in Part I. of the Mathematical Tripos, and a year later he obtained the highest distinction in Part II. The Smith's Prize followed in 1907, and in the same year he was elected a Fellow of Trinity. Eddington had spent the Michaelmas Term of 1905 in the Cavendish Laboratory researching on "Thermionic Emission," and it is evident that in those days he intended to make Physics his principal life-study. But, fortunately for Astronomy, a vacancy occurred at the beginning of 1906 at the Royal Observatory, Greenwich, due to the late Sir Frank Dyson's transference from Greenwich to Edinburgh as Astronomer Royal for Scotland; and Eddington was enabled to return to his first love, as Chief Assistant under the then Astronomer Royal, Sir W. H. M. Christie.



A. S. Eddington

Then followed seven years at Greenwich, during which he took his share in routine observations, his principal work being the planning and carrying out of the observations with the Cookson Floating Zenith Telescope for determining the constant of aberration and the variation of latitude. In addition, he began there his masterly researches in stellar kinematics and stellar dynamics which brought him right to the forefront of contemporary scientists, and to which we shall refer more fully in a moment.

In 1913 Eddington succeeded Sir George Darwin at Cambridge as Plumian Professor of Astronomy and Experimental Philosophy, and in the following year he succeeded Sir Robert Ball as Director of the University Observatory, where he resided until his death.

To those who only knew Eddington in his later years as a rather shy and reserved scientist, apparently engrossed in his work to the exclusion of all other interests, it may come as a surprise to learn that at Greenwich he was a keen member of the Observatory Hockey team. Actually, he was interested in every kind of sport, mainly, it is true, as a spectator, although after he returned to Cambridge as Plumian Professor he played golf fairly regularly on the Gog Magog course, not however—it must be confessed—with very conspicuous success ; also, he was a very good swimmer, and on most summer afternoons he was to be seen disporting himself in the waters of the Cam.

In 1904 Kapteyn announced his discovery of the two star-streams. Hitherto it had been assumed that the individual space-velocities of the stars were entirely random. The observed motions, however, included the effects of the solar motion, and from the time of Sir William Herschel the main object of astronomers dealing with stellar proper motions consisted in deriving the constants of the solar motion, *i. e.*, the direction in the sky towards which the Sun was moving, and, when radial velocities became available, the Sun's speed. It was only when Kapteyn began to investigate the hypothesis of random motion that he was led to the discovery that the stars could, apparently, be divided into two groups (or streams), for each of which the idea of the random distribution of velocities, in direction and magnitude, appeared to be applicable. If we consider a small area of the sky and construct a polar diagram showing the number of stars with proper motions in the different position angles from 0° to 360°, the curve would, in the absence of solar motion and on the hypothesis of random motions for all the stars concerned, be a circle, ideally. The effect of the solar motion is to transform the circle into an oval curve, the direction of the longest axis being directly related to the projection of the solar motion on the area of the sky considered. If this is done for different areas, the various directions of the longest axes of the oval curves, when plotted on a sphere, would all, in theory, converge to two antipodal points, one of which gives the direction in the sky (the solar apex) towards which the Sun is travelling. Kapteyn found that his polar curves were not the simple ovals as described, but were bi-lobed, suggesting that the observed stellar motions could be represented as the combined effect of two random-velocity distributions formed by the superposition of two simple oval curves, each oval having its own characteristics of shape, direction of the principal axis and the number of stars involved. It was at this point in 1906 that Eddington came on the scene with a precise definition of the random distribution of velocities (assumed to be Maxwellian in character), a clear account of the mathematical consequences, and a convincing application to the proper motions of the Groombridge stars. There was now no doubt as to the main features of Kapteyn's discovery; further, Eddington was able to derive the constants of each stream. In later papers he showed that the stars belonging to the two streams were intermingled in space, and in 1910 he analysed the proper motions of the stars in Boss's *Preliminary General Catalogue*, with results in most respects similar to those derived from the Groombridge stars. In 1907, Schwarzschild had shown that the observed features of star-streaming could be equally well represented in terms of a modified Maxwellian law embracing all the stars concerned—the so-called ellipsoidal hypothesis. Thereafter, investigators of the systematic motions of the stars have had alternative methods of dealing with the problem, the choice being generally dictated by the character of the particular research undertaken.

Eddington's first book, *Stellar Movements and the Structure of the Universe*, appeared in 1914; it gave an account of his own researches, and those of others, on stellar kinematics. As a synthesis of contemporary knowledge in this new field of investigation it exercised a profound influence in astronomical research. It should not be forgotten that the last chapter of the book—" On the Dynamics of the Stellar System "—may be regarded as the beginning of a vast new subject, Stellar Dynamics, in which Eddington pointed the way for future developments. The apparent analogy of the stellar system with a gaseous system of molecules suggested by the kinetic theory of gases, was rejected and the fundamental law of stellar dynamics was stated to be :—the stars describe paths under the general attraction of the stellar system without interfering with one another. In the second of two papers in *Monthly Notices* (vol. **75**, 1915) Eddington succeeded, on the basis of the ellipsoidal law of velocities, in solving the problem of a globular stellar cluster in a steady state, the solution specifying the stellar density and the distribution of velocities at any point; in a third paper (vol. **76**, 1916) he attacked the more difficult problem of oblate systems, with its application to our own Galaxy clearly in view.

Eddington's interests were now to be directed into two very different and diverse channels—relativity and stellar interiors. In 1915 Einstein's theory of general relativity appeared; by the end of 1917 Professor W. de Sitter, of Leiden, had contributed three papers to *Monthly Notices* with the three astronomical consequences of the theory in view, and at the beginning of that year Eddington had contributed a Council Note. At the time Eddington was, almost certainly, the only scientist in this country with any knowledge of the new developments in our ideas of space and time, and he forthwith became our leading authority, writing in 1918 for the Physical Society his *Report on the Relativity Theory of Gravitation*, which so effectively introduced the subject to the main body of scientists at that time, and later becoming a substantial contributor to the further development of the subject. The new theory had explained successfully the outstanding anomaly in planetary motions relating to the advance of the perihelion of Mercury. The second astronomical test—the deflection of light at the Sun's limb by 1¾ seconds of arc—could only be carried out at the time of a total eclipse of the Sun, and then only if there were a sufficient number of bright stars close to the eclipsed Sun. The eclipse of 1919 May 29 was peculiarly favourable, and it was eventually found possible to send two expeditions from this country to make the necessary observations: one to Brazil and the other to Principe, a small island off the west coast of Africa. Eddington and the late E. T. Cottingham were the observers at Principe. The Brazil observers had a clear sky, but Eddington was not so fortunate, light cloud persisting throughout most of totality. The results of the two expeditions—which, incidentally, aroused an immense popular interest—confirmed the theory handsomely. Of the 16 eclipse plates taken at Principe only two, secured in a relatively clear sky, had sufficiently good images of stars for the purpose in hand, and these, between them, had measurable images of only six stars; Eddington's result, $1''\cdot61 \pm 0''\cdot30$, for the deflection of light at the Sun's limb, in surprisingly good accordance with the theoretical value, must be mentioned. It may be added that Eddington had never the slightest doubt in his own mind as to the genuineness of the confirmation of Einstein's theory by the 1919 expeditions.

In 1920 Eddington's *Space, Time and Gravitation* appeared, followed in 1923 by *The Mathematical Theory of Relativity*; the former was essentially a descriptive account of the new theory and is still the best introduction to the recondite treatment given in the second book. I leave to a more able pen than mine (see p. 7) the adequate assessment of Eddington's achievements in relativity, quantum and cosmological theory.

In 1916 Eddington began his famous researches on the internal constitution of the stars. In earlier investigations on the physical constitution of the stars it had been assumed that the maintenance of a star's expenditure of heat and light was ensured by means of convection currents carrying heat from the inner and hotter regions to the stellar boundary. With the progress of physical theory, mainly in thermodynamics, it came to be realised that the main factor in transporting heat from the inner to the outer regions was radiation. Eddington was the first to apply this new principle to stellar interiors. His earlier researches were definitely concerned with giant stars, for which the gas-laws were assumed to be applicable. The formulation of the problem involved the following ideas. The pressure at any point supporting the weight of outer gas consisted of gas-pressure and radiation-pressure; a mean molecular weight had to be assumed, and, on the assumption that the gases were wholly or almost wholly ionised, this must be approximately 2—as he eventually realised—unless the star was largely composed of hydrogen; the restraining power of the stellar gas on the outward passage of radiation had to be taken into account, this feature being represented by the opacity coefficient; finally, it had to be recognised that the maintenance of outflow of heat and light involved the conversion of sub-atomic energy into the energy of radiation. Such were the main features of the problem, the solution of which Eddington successfully achieved. His principal result at this stage was that the luminosity of a giant star depended mainly on its mass (the mass-luminosity relation), and that for the range of stellar masses between one-tenth and a hundred times the Sun's mass the radiation and gas pressures were comparable; with the further implication that for much greater masses the radiation pressure, being now all-powerful, would presumably endanger the stability of the star. In a sense—I think he expressed it in this way himself—his theory predicted the existence of globes of gas with the characteristics of mass and luminosity observed in the giant stars. It is to be remembered that the problem related specifically at first to gaseous stars—that is, the diffuse giant stars—dense stars such as the Sun, with densities comparable with the density of water, being outside the orbit of the theory. Eddington then set himself to discover to what extent dense stars, for which accurate details were known, deviated from the theory, and he was astonished to find that they fitted the theory as satisfactorily as the diffuse stars. There could only be one explanation: the Sun and the dense stars must be in the state of a perfect gas, a fact which he then realised must be due to the high ionisation of the stellar atoms. Thus all the familiar stars—the white dwarfs excepted—obeyed the mass-luminosity relation; in other words, the mass of a star essentially determines its luminosity.

The general applicability of the mass-luminosity relation had a significant influence on the theory of stellar evolution. The current theory supposed that a star evolved by passing through the stages represented by the giant and dwarf branches of the Hertzsprung-Russell diagram, and the explanations of how this process operated were now seen to be invalid. The crux of the problem, according to Eddington, was the method whereby energy was generated within the star. Evolution in the sense described was possible if the star maintained its output of radiation by the progressive annihilation of its mass, and in this event a time-scale of 10^{14} years was necessary. Alternatively, the Hertzsprung-Russell scheme of evolution was impossible if the time-scale is very much shorter—say, of the order 10^{10} years—some sub-atomic process of releasing energy being essential. Other considerations point to the short time-scale, and thermo-nuclear reactions now provide the mechanism for the release of energy within the star.

Eddington must frequently have had the joy of the discoverer adventuring into untrodden paths of human thought, and I well remember his excitement in February 1924 when he came into the Observatory library to tell me that he had just completed the last of the calculations which finally established the general applicability of the mass-luminosity relation beyond any possibility of doubt.

Concurrently with the researches just described, Eddington had also been tackling, with a great measure of success, the difficult problem of the pulsations of a star with reference to Cepheid variables, following the suggestion of H. Shapley and H. C. Plummer as to the cause of variability of these stars. *The Internal Constitution of the Stars* appeared in 1926, followed in 1927 by the delightfully written *Stars and Atoms.*

The year 1925 may be taken as the time of Eddington's entrance into the field of philosophy with an article on "The Domain of Physical

Science" in a composite work on *Science, Religion and Reality*. This was followed in 1928 by his Gifford Lectures at Edinburgh on *The Nature of the Physical World*, in 1929 by *Science and the Unseen World*, in 1935 by *New Pathways in Science*, and in 1939 by *The Philosophy of Physical Science*.

Eddington's duties as Director of an observatory—a small one, it is true, but at any rate a live and active one—were not onerous, but at almost any minute of the day he was cheerfully ready to discuss any matter of detail or any fresh discovery wherever made. He gave every encouragement to an extensive programme on proper motions, taking a keen and critical interest in the results as they came along. In the early days of photo-electric photometry he recognised the suitability of the Sheepshanks telescope for pioneering work in the photometry of the brighter variable stars, and he was an expert—in the real sense of the term—in his practical grasp of everything connected with the various equipments installed from time to time on the telescope. When he went to the Observatory in 1914, work on the Zodiacal Catalogue was still incomplete, and in the last year or two of the first Great War he finished off all the outstanding transit observations single-handed.

Equipped with superb mathematical powers and with an invaluable training in practical astronomy, Eddington's outlook on science was primarily and fundamentally that of the physicist—the universe was his laboratory and the stars his crucibles. He succeeded in keeping abreast, as few can, of the multitudinous advances in astronomy and physics, and was ever ready to share his expert knowledge with all who required guidance or enlightenment. Readers of his popular books recognised a master of English prose and a lucid and entertaining expositor of the most difficult subjects. Eddington's knowledge of English literature was extensive. He wrote verses—for his own amusement and never, I think, for publication—which had considerable merit according to those privileged to read them and competent to assess their value. At school he showed great distinction in the classical languages. Intellectually he was endowed richly. Socially, he was shy and reserved, but once the ice was broken he could be informative and entertaining on a large variety of subjects. Perhaps he was at his best in his own study with two or three home or foreign astronomers talking shop; or on informal occasions during conferences at home or abroad.

Eddington was Secretary of the Royal Astronomical Society from 1912 to 1916, President from 1921 to 1923 and Foreign Secretary from 1933 to his death; he was awarded the Gold Medal of the Society in 1924. He was elected a Fellow of the Royal Society in 1914, receiving a Royal Medal in 1928. The Bruce Medal of the Astronomical Society of the Pacific was awarded to him in 1924. He was President of the Physical Society from 1930 to 1932, and in 1938 he became President of the International Astronomical Union. He held Honorary Doctorates in about a dozen Universities at home and abroad, and was an Honorary Member of several foreign academies and societies. He was created a Knight Bachelor in 1930, and his highest honour, the Order of Merit, came to him in 1938. He was unmarried and his only sister, Miss Winifred Eddington, survives him. W. M. Smart.

EDDINGTON : MATHEMATICAL PHYSICIST AND PHILOSOPHER.

Since the year 1917, in which he received from de Sitter a copy of Einstein's famous paper on the general theory of relativity, Eddington devoted his energies with a steadily increasing intensity first to relativity, secondly to quantum theory, and lastly to general speculations on the philosophy of physics. Both in relativity and in quantum theory he viewed current expositions with a severely critical eye and did not hesitate to re-organise the entire theoretical structure with a view to obtaining better internal consistency and a more satisfactory agreement with his extremely individualistic philosophy.

Relativity Theory.

Eddington's investigations into relativity theory opened with the famous *Report* which he prepared for the Physical Society and which, for some time, was the only authoritative exposition of the subject in English. This has now been supplemented by his well-known work, *The Mathematical Theory of Relativity*, which includes an account of later developments both by himself and by other workers, and which concludes with a prophetic passage referring to the great region of unexplored problems of the atomicity of matter and of energy.

Eddington's part in organising the 1919 eclipse expedition to obtain observational evidence for Einstein's theory has been reported above (see p. 4). On the theoretical side, his investigations centred around Einstein's law of gravitation,

$$G_{\alpha\beta}-\tfrac{1}{2}Gg_{\alpha\beta}+\lambda g_{\alpha\beta}=-(8\pi\gamma/c^4)\,.\,T_{\alpha\beta},$$

in which $g_{\alpha\beta}$ are the coefficients of the fundamental quadratic form for the "interval" ds in space-time, $G_{\alpha\beta}$ is the contracted Riemann tensor, $T_{\alpha\beta}$ is the momentum-energy tensor, while λ, γ and c are the cosmological constant, the constant of gravitation, and the speed of light *in vacuo*.

At the time when Einstein first put forward his theory, the most that could be said for this law was that in empty space it was the only law which was

(1) covariant for all transformations of the space-time co-ordinates,
and (2) involved only the tensor $g_{\alpha\beta}$ and its first and second derivatives (apart from the much too restricted condition of the vanishing of the Riemann-Christoffel tensor, which leads to flat space-time).

The readiness with which this law was accepted was due to the fact that to a first approximation it agreed with Newton's law of gravitation in Euclidean space, while to a second approximation it successfully accounted for an outstanding small discrepancy between observation and planetary theory, and also successfully predicted gravitational influences on light.

The general form of Einstein's law, including the matter-tensor $T_{\alpha\beta}$, had also the great advantage that the curvature tensor on the left-hand side had a divergence which vanished identically. Eddington insisted strongly on this feature, and indeed at times he spoke as if a tensor with zero divergence was a satisfying substitute for gross matter. At the same time, he was among the first to prove that the Einstein tensor is by no means the only space-time tensor with this property, which is, in fact, shared by any tensor obtained by Hamiltonian differentiation of an invariant integral over a region of space-time.

In the attempt to construct a more satisfying theoretical support for Einstein's law of gravitation, and if possible to incorporate electromagnetism, Eddington devised a wide generalisation of Weyl's unified field theory, based on the concept of parallel displacement around a closed circuit. In this research he independently invented non-Riemannian geometry and obtained a remarkable interpretation of Einstein's equations in empty space as the " self-gauging " characteristic of an electron. The original object of this research—the inclusion of the electromagnetic field—was never attained in a really satisfactory way, and, with the subsequent development of Eddington's views on quantum theory, it was abandoned. But the new interpretation of Einstein's law remained as a continued inspiration in Eddington's later work in quantum theory.

Quantum Theory.

Eddington's researches in quantum theory (apart from an earlier discussion of Planck's radiation law) started with the study of Dirac's relativistic wave equation for an electron. This led him to formulate the theory that electric interactions were fundamentally a manifestation of the Pauli exclusion principle. In developing this principle he introduced the momentum operators corresponding to the ignorable coordinates θ which increase by π when two identical particles are interchanged. The enumeration of the number of " freedoms " in the space in which these operators were effective was a matter of some difficulty, but it was extremely encouraging that the answer seemed to be either 136 or 137, while the fine structure constant was about 1/137 and the " packing fraction " of the nucleus was about 136/137.

By a closer study of the 136 rotations in the space of the identity operators and of the 10 rotations in the space-time of relativity, Eddington developed a theory of the masses of the proton and electron which issued in the remarkable quadratic equation,

$$10x^2-136x+1=0,$$

for these masses expressed in " natural " units. This equation yields a value of 1847·60 for the ratio of proton-mass to electron-mass, in startling agreement with experimental results. Subsequent refinements of this theory have yielded a result accurate to 1 part in 10,000. Further extensions of these methods—expounded in his *Relativity Theory of Protons and Electrons*—seemed to offer an explanation of the curious 5/2 factor in the experimental value of the spin of the proton.

The theory of almost all of the subsequent investigations is the single particle viewed against the background of the whole universe—a situation recalling the self-gauging electron of relativity theory. Although Eddington's investigations here (and elsewhere) in quantum theory have been received with considerable reservations by mathematical physicists, there can be no doubt of the value and the correctness of his main contention that no problem of quantum theory is rightly formulated unless the " background " is specified and taken into account. The theory of this background—which he later came to call the " uranoid "—

is a blend of Einstein's space-time and of Dirac's world of almost completely filled negative energy levels in positron theory. The enumeration of the stationary states in the uranoid led Eddington to propose a definite value for the total number of protons and electrons in the universe, and also to give precise values for such quasi-observational constants as the radius of an Einstein universe, its rate of expansion and the mean density of matter. In estimating these cosmological constants Eddington was as successful as he was with the physical constants connected with the masses and charges of elementary particles.

All these researches were concerned with what Eddington called the "spin" extension of relativity. In 1943 he opened another line of investigation into the "statistical" relativity theory, in which he analysed the consequences of a systematic application of the principle of uncertainty both to the system observed and to the frame of reference. This theory is, perhaps, reported too briefly in his Dublin lectures to carry complete conviction, but some of the results are so striking that the reader cannot but wish them to be true. In particular there stand out the theory of the non-Coulombian interaction energy and the theory of the equivalence of space-time curvature and of probability effects in the uranoid.

Philosophy of Physical Science.

Eddington's views on general philosophical questions related to physical science were given in his lectures on "The Nature of the Physical World" and on "The Philosophy of Physical Science." His most devoted admirers must confess that both in these official utterances and in his private conversation he left us some very hard sayings. The idea which seemed to dominate his work was that a great part of physics was simply the mode of interpretation which the physicist had imposed on observation, and that this part of physics was, therefore, deducible by pure reason from our knowledge of the psychology of physicists, independently of any experiment. Indeed, at times he spoke as if nature was a wild welter of chance on which human reason imposed the laws of physics, much as a glass prism resolves white light into a regular spectrum of colours.

My personal opinion is that these professions of subjectivism or solipsism were semi-jocular exaggerations, intended to direct attention to the new ideas advanced in his theories and to combat by over-emphasis the self-satisfied simplicity of current physical philosophy. The ideas which were really effective in his work were that the multiplicity of principles invoked in relativity and in quantum theory—such as gauge-invariance, Lorentz invariance, uncertainty principle, exclusion principle, electric interaction—are reducible to a much smaller number of principles when they are systematically analysed; and that when they are developed completely and consistently they determine quite definitely all the natural constants of the world—such as the number of dimensions of space-time, the number of particles in the uranoid, the relations between γ, c, e, h, m, M, etc., in the now familiar notation.

It would be premature and impertinent to conclude this brief and very inadequate notice with any attempt at a final judgement on Eddington's work. The man was ever greater than his work, but *that* was always stimulating and suggestive, opening up new perspectives of future progress. The detailed answers which he gave to the problems sketched above were avowedly incomplete, regarded as pieces of deductive reasoning, and were subject to continual slight revision. But it was in the formulation of the great series of questions which lay behind the magnificent series of his papers that he gave his best gift to his fellow workers. These questions form, as it were, a great series of signposts leading to a Promised Land which perhaps he never quite attained in this life. We who come after him may, in time, see further than he did, but only because we are like pygmies standing on the shoulders of a giant. G. TEMPLE.

EDDINGTON AND ASTRONOMY.

Astronomy is under a great debt to Sir William Christie for his selection in 1906 of Eddington to fill the vacant post of Chief Assistant at the Royal Observatory, Greenwich. Eddington would have made his mark in any field of research that captured his interest. How fortunate it was that astronomy became his first interest! The calibre of the man was shown in his earliest book, *Stellar Motions and the Structure of the Universe*, a model of what such a book should be. The largest distance mentioned in that book was 10,000 parsecs. This serves as a reminder of how great the advances in astronomy have been during the past 30 years. Many of the important developments of these years were due to Eddington himself or were directly stimulated by his work. The theory of the radiative equilibrium of the stars; the mass-luminosity relationship, obeyed by both giant and dwarf stars; the conception of the main sequence; the nature of the white dwarf stars; the problems of Cepheid pulsations; the nature of the interstellar clouds; the chemical constitution of stellar interiors; any one of these would have been sufficient to establish firmly the reputation of a lesser man. His combination of great mathematical powers, keen physical intuition, appreciation of the problems of observation, and the ability to write of abstruse problems so lucidly and charmingly was unique. He was a master and a genius; and he was always ready to help and encourage those who sought his assistance. He was a true friend and, we may say in the words of Chaucer, "He was a verray parfit gentle knight."

H. SPENCER JONES.

EDDINGTON AND PHYSICS.

Although Sir Arthur Eddington first made his name by work on a purely astronomical problem, that of star streams, and although throughout his life he was a working astronomer in charge of an observatory, his greatest achievements were essentially bound up with modern physics, and his death is deeply deplored by all physicists as a great blow to their science. The way in which he seized upon the essential features of the modern theory of the structure of the atom, and applied them to fundamental problems of stellar constitution and stellar evolution, extended the scope of physical theory and gave a striking demonstration of the powers of bold scientific imagination when allied to technical ability of the most accomplished kind. His early work on relativity was likewise of great service to physics, and his masterly *Report on the Relativity Theory of Gravitation*, prepared for the Physical Society, did much to spread knowledge of the new problems with which it dealt and to instigate enquiry. If some of his more daring and difficult speculations were beyond the comprehension of many, all recognised in them the grappling of a master mind with problems of the most fundamental nature.

Eddington showed his interest in general physics by serving as President of the Physical Society from 1930 to 1932. His carefully constructed presidential address on " The Expanding Universe " was a compliment to the Society, and he was a regular attendant at its meetings during his time of office.

Even such a brief tribute as this must make reference to the charm of his more popular writings, which showed that facility in the most abstract technical branches of a science need not necessarily be a bar to an understanding of the mental needs of ordinary men, and demonstrated that clear and elegant prose is not the prerogative of professional literary men alone. Eddington was one of the great figures in British science, and his sudden and unexpected passing leaves a gap which it will take long to fill. E. N. da C. Andrade.

Eddington and Stellar Structure.

The influence of the investigations of Sir Arthur Eddington in the field of stellar structure is overwhelming. His writings during the decade 1915–25 set a pattern, a notation and an objective which workers since him have done little other than follow. Previous to him there had been the pioneer work of Homer Lane, Ritter, Kelvin and Emden, but much of this was merely formal. It was Eddington who brought it all to life, infusing it with his sense of real physics and endowing it with aspects of splendid beauty. Schwarzschild, indeed (Eddington's spiritual forerunner), had dealt with some features of radiative transfer. But Eddington combined the radiative transfer of energy, the mechanical effects of radiation pressure and the absolute value of the absorption coefficient of stellar material in masterly fashion ; he inaugurated the astronomical determination of constants of pure physics ; he first recognised the importance of ionisation in stellar interiors, and by simple methods evaluated the mean molecular weight of stellar material ; he discovered the mass-luminosity law. The amazing power and vividness he displayed in his justly famous work, *The Internal Constitution of the Stars*, and the persuasiveness with which he urged his conclusions, have even (to my mind) been a danger to the subject, in that they have all but inhibited independent lines of approach to these questions ; for there is no doubt that it is possible reasonably to adopt a different attitude to some of them. But of Eddington's supreme capacity to create interest, to sweep away the cobwebs of formalism, to substitute real stars for mere " Gaskugeln ", there can be and will be no two views : Eddington will always be our incomparable pioneer. E. A. Milne.

EDDINGTON AND PHILOSOPHY.

Most scientists entertain a mild contempt for philosophy; a few recognise the importance of what they call " the philosophy of science "; a very, very few understand that philosophy is a matrix indispensable for the development of science. Of these last, Eddington was an outstanding example. He aimed at formulating the philosophy to which men of science " stand committed by their practice "—the phrase is his own. That he should have died before completing his work is an inestimable calamity.

Two obstacles faced him. Scientists, who were best equipped to understand his philosophy, had but a pallid interest in it, while philosophers lacked the requisite scientific knowledge. Eddington saw that the deepest division in philosophy was not between the real and the ideal, but between the rational and the empirical, and recent physical thought has inescapable epistemological implications of which he was clearly aware. Uninitiated philosophers missed the essential truth of his ideas and gave excessive attention to minor defects of expression. Secondly, Eddington's philosophy was largely shaped by his own scientific work, and this he did not succeed in making generally understood. Not for lack of expository power; his account exhibits the same confidence and certainty as his exposition of familiar knowledge. But he could not appreciate his readers' difficulties. His replies left critics as bewildered as before. The clue to his work lies in the background of thought which to him was so natural that he could not realise that it was being questioned. HERBERT DINGLE.

EDDINGTON: AN AMERICAN VIEW.

The death of Sir Arthur Eddington is a calamity. A great master is gone, and a master in many fields, but most of all in astrophysics. He was distinguished by a remarkable physical insight, which led him to the solution of many major problems. The internal constitution of the stars, the relation between mass and luminosity, the pulsations of Cepheids and the reflection effect in eclipsing variables; and the physical state of interstellar gas may serve as examples. All these presented difficult problems which had been unsuccessfully attacked by others; but Eddington's results were presented with such lucidity that they were immediately convincing.

Further theoretical structures have often been built upon the foundations which he laid, but very rarely has reconstruction of these foundations been required. This sound judgement, and his masterly presentation, reach a climax in *The Internal Constitution of the Stars*, which, after eighteen years, is still essential reading for any student.

Beyond and above this his loss will be keenly felt by many friends all over the world. He contributed greatly to the cause of international co-operation in science, not only by his participation in congresses and meetings, great and small, but by his quiet, cordial relations with those who, on both sides of the Atlantic, appreciated him equally as a host and as a guest. We have lost an inspiration in science, and a guide in philosophy; what is more, we have lost a friend. H. N. RUSSELL.