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In Memoriam: Sir Arthur Stanley Eddington, O.M.

With the death of Sir Arthur Eddington on November 21, 1944, a very great man has passed through the portals into the unseen world.

Born in Kendal in 1882, he attended school there and then entered Owens College, that famous training ground of potential scholars. Proceeding to the University of Cambridge he trod the courts and corridors where the spirit of Newton lingers, where brilliant mathematicians had been or were making advances in pure mathematics and in its applications to physical problems and to astronomy -- Airey, Cayley, Stokes, John Couch Adams, Larmor, J.J. Thomson, George Darwin. Here he won the distinction of Senior Wrangler in 1904 and became Smith's Prizeman and Fellow of Trinity in 1907.

As Chief Assistant at Greenwich Observatory from about that time until 1913, Eddington rose to prominence with his investigations of stellar movements and the structure of the Universe, which formed the subject matter and title of his first book, published in 1914. In this year he was made a Fellow of the Royal Society and in the previous year, at the age of thirty he was elected Plumian professor of astronomy in the University of Cambridge. This chair he held, and the directorship of the Observatory, with steadily increasing honour and international recognition, to the end of his life.

In memory I see him in his classroom off Bene't Street. From my seat beneath the tablet to ~~the Lucasian professors~~, Cayley and Stokes, I watch a master-mind at work. A slight man of average height, in academic gown, reserved almost to the point of shyness, he rarely looks at his class. His keen eyes look at or through the side wall as he half turns from the blackboard and seems to think aloud the significance of the tensors which he has just written on the board. The mathematical theory of relativity is developed ab initio before our eyes and the symbols are made to live and take on meaning. I see his face in profile and hear his low voice as he says as though in soliloquy -- "The real three-dimensional world is obsolete, and

must be replaced by the four-dimensional space-time with non-Euclidean properties . . . But the four-dimensional world is no mere illustration; it is the real world of physics, arrived at in the recognized way by which physics has always (rightly or wrongly) sought for reality." Remember that this was only 1922. Einstein's ~~complete~~ general theory had only been known in England for some five years; de Sitter's and Weyl's contributions were as yet scarcely understood; and Eddington's Report on the Relativity Theory of Gravitation for the Physical Society of London and his less mathematical Space, Time and Gravitation were not two years old. The thrill of seeing physical science on the march in a new direction, the sense of something stirring, of new adventure, held us tensely expectant even though we might but half comprehend it -- and before us slowly, deliberately, quietly, alternately thinking aloud in symbols and in words, was one of the few men, one of perhaps ~~twelve~~ a dozen men, who at that time had the insight and vision to see whither it was leading.

The scene changes to the Cavendish Laboratory where Sir Ernest Rutherford is presiding at a meeting of the ~~Physical~~ Cavendish Society and Professor Eddington is the speaker. He has given an exposition of his recent theoretical work on ~~the radiating and absorbing properties of stellar gases~~ electron capture in giant stars in his usual quiet, reasoned, restrained manner. Again one must remember that this is 1922 and physicists are not very familiar with the behaviour of matter at temperatures ranging from 3000° C. to several million degrees, nor with the opacity resulting from extremely high ionization. A dozen questions are put to the speaker like rapid rapier thrusts, and quietly parried. Then Rutherford rises with lust for battle in his eyes and as with a mighty broadsword delivers what he obviously thinks is a final deadly blow. Fire suddenly springs into Eddington's eyes, and steel meets steel with sparks flying. Criticisms based on a physicist's discharge tubes are shown to be inapplicable as applied to the stellar conditions. The attacker becomes the attacked and retires from

the field with a growl.

Another picture is conjured up by memory. It is Eddington's study. A door at one side gives access to the Observatory library, a door in the opposite wall opens into the corridor of the Director's residence. A not very self-confident student is shown into the study by a maid who closes the door and goes to inform the Professor. A chesterfield in the centre of the room faces a wall of books. Across the end of the chesterfield is a large table which is obviously the Professor's combined desk and work table. More book shelves are on the other walls. There is a patter of feet and a rustling —the door from the residence opens gently and in trots a little black dog with silky hair and long ears, followed by Professor Eddington, friendly but very reserved. We sit down on the sofa and I show him what progress I have made in a problem relating to the proper motions of certain groups of stars and their spectroscopic parallaxes. The dog jumps up beside its master and he fondles its ears with his left hand while he holds the calculations in his right. I have run up against accidental errors which have led to systematic errors and I have no notion how to proceed. In silence he studies the page, in silence he gets up and goes to his desk, in silence he works away, consults a book from the side wall and then resumes his writing. After perhaps fifteen minutes during which no word has been spoken but the dog has relieved my tenseness by submitting to be patted, Professor Eddington comes back to the sofa, sits down and shows me a beautiful bit of integral calculus which he has just done, resolving the difficulty by indicating the correction that must be applied to counter balance the systematic error which has crept in. Here is a born teacher, clear in exposition, patient and encouraging. Mutual interest in the investigation gradually breaks down our earlier stiffness, and by the time the next phase of the work is planned out, the atmosphere is one of unstrained kindly friendliness. He comes with me to the door, holds back his dog while I mount my bicycle to ride the mile or so back to the town along

the Madingly Road, my mind filled with marvel at the way a master mathematician wields his tools and with zest to get on with the work.

Other scenes from this period rise before my eyes. Eight or ten students are with him around the Sheepshanks telescope and a lunar eclipse is in progress. We ply him with questions about recent reports of observations and speculations from across the Atlantic and he tells us his own views on these and kindred topics. Humour, anecdote, and wisdom enrich the occasion.

In a lecture room at Emmanuel College an undergraduate group interested in the relationship of science, religion and philosophy, has invited Professor Eddington to address an open meeting. We listen with intensest concentration as new ideas or fresh approaches to familiar problems are put before us--thoughts and ideas which he later incorporated in Chapters XII to XIV of The Nature of the Physical World and in portions of his Swarthmore Lecture — the closed cycle of physics, and the way out. The impression made by that address on some of his hearers has deepened with the passing of the years.

I can almost see and hear him at the meeting of the Royal Astronomical Society at Burlington House, when as President he presented the gold medal of the Society to James Hopwood Jeans, and outlined with brilliant competence the scientific achievements of the Medallist. Referring to the series of papers on problems of stellar constitution in which he and Jeans had hurled mathematical missiles at one another over a period of several years, he paused to remark that "the ~~spectators must feel certain that some corpse lies upon the field, but that our Medallist and I will differ as to whose corpse it is~~ onlooker will perhaps conclude that someone was badly annihilated but it is possible that Jeans and I may still have a difference of opinion — as to precisely whose corpse lies stricken on the field."

Few men of science have a record of achievement comparable to that of Eddington. His papers on stellar structure led him into many fields. Fundamental was his recognition of the part played by radiation pressure, which with gravitational attraction and gas pressure account for the stability of stars and their limited range in the mass. This led to papers on the deep interiors of stars, calculation of central temperatures, of sources of energy,

of atomic and electronic states, of pressures and densities, of variable stars and Cepheid pulsation, of stellar diameters, of masses and luminosities, of the densities of white dwarf stars, of diffuse interstellar gases. Who that was following astrophysics in those years will ever forget the excitement produced by his paper of March 1924, on the mass-luminosity relation and the papers which it evoked from J.H. Jeans in the November following and from R.H. Fowler about two years later, this last showing how the statistical mechanics of a degenerate gas was applicable to the white dwarfs. Much of this has proved the starting point of many researches by men of many nations. He was in due course brought together in his Internal Constitution of the Stars and the subsequent Halley Lecture and many other papers carried these researches farther.

Epoch making in more ways than one, were the verifications of some of Eddington's predictions. With Michelson's stellar interferometer attached to the 100-inch reflector at Mount Wilson Observatory, Pease in 1920 found the angular diameter of the giant red stars to be in agreement with Eddington's calculations. In 1925 W.S. Adams succeeded in measuring the red shift in the spectrum lines of the white dwarf companion of Sirius, thus verifying both the Einstein relativity theory and Eddington's theoretical calculation of the immense density of stars of this class.

Eddington has been the outstanding exponent in the English language of relativity theory. It was he who first interpreted the ideas of Einstein, de Sitter and Weyl. It was he who realized the importance of testing Einstein's theory on its prediction that rays of light passing close to a body like the sun would be deflected in the gravitational field and that this might be accomplished during the total solar eclipse of May 29, 1919. War notwithstanding, the plans were pushed ahead and when the eventful day arrived even though the Treaty of Versailles had not yet been signed, two British expeditions were in

readiness to take the crucial photographs and Eddington at Principe Island obtained the plates which gave a first measure of confirmation to the new theory. It was Eddington who interpreted Lemaitre to the English-speaking world and for fifteen years he has upheld the theory of the expanding universe, modifying the original approach of Lemaitre by starting from an 'Einstein universe'. The goal of his endeavours has been the formulation of a satisfactory theory combining both relativity and quantum theories. During the last few years he has published several papers attempting to make this very synthesis—how successfully cannot be said until the few mathematicians competent to judge have examined it in every detail. Its consequences upon the time scale of the Universe are to lengthen the "age" beyond that of previous theories. This was the subject of his last contribution to the Royal astronomical society.

Insert this para on p. 7. *

My thoughts go to a conversation with Dr. de Sitter in 1931 when I asked him the result of a controversy between himself and Sir Arthur over the effect of space expansion upon our own galaxy. Eddington had maintained that the dimensions of the galaxy would be unaltered, de Sitter had eventually been obliged to agree, and he said to me, shaking his patriarchial head ruefully -- "Eddington was right. Eddington is always right." Not everyone has thought this in regard to his most speculative and debatable researches, those on the theoretical determination of cosmological and physical constants.

The numbers 136, 137, 256 will awaken, in the minds of many, memories of a kindled interest, of perplexity, doubt, expectation and perhaps of moments of great thrill, as they think back over the last fifteen years. One name alone stands central amongst these memories—that of Sir A.S. Eddington. This has been his playground pre-eminently. Some of us have stood fascinated at the edge of the field watching this illusive game played patiently, skillfully, brilliantly by one man, a master juggler with the elements of the theory of groups, with quantum mechanics, and with the basic units of measurement, producing, as from the proverbial hat, physical constants both atomic and astronomical. Some there have been who paused to watch briefly, to smile or even ridicule the Aristotelian tour de force. But steadily and doggedly the

theory has been pushed forward, ~~several papers having appeared in the last three years~~ until now the evidence seems overwhelming that, with no observational data other than three basic constants, namely, the velocity of light and the Rydberg and Faraday constants for hydrogen, it is possible to calculate theoretically the following thirteen physical constants: charge e; Planck's constant; masses of electron, proton, hydrogen atom; gravitation constant; fine structure constant; nuclear range-constant; nuclear energy-constant; mass of universe; number of particles in universe; Einstein radius of space; nebular speed. This is a striking achievement. In his book Relativity Theory of Protons and Electrons the foundations of this theory are set forth.

* ----------→ Dingle has been a consistent opponent of Eddington's Aristotelianism as found in these researches. In reviewing Born's recent book, Experiment and Theory in Physics, Dingle says, "Like others, Professor Born has not succeeded in understanding the essential parts of Eddington's theory connecting the constants of quantum theory with those of cosmology. That is not to say that there is nothing of great value in the theory." His final comment is perhaps the wisest that has yet been made on this subject: 'I am far from attacking Eddington's theories or from doubting his results. If they should turn out to be right I shall rejoice. But I shall not attribute this (possible) success to Eddington's philosophy, as a doctrine which could be followed by others, but to his personal genius and intuition'." The world may have to wait a long time for another man with 'personal genius and intuition' comparable to Sir Arthur's. This entire investigation must surely rank as one of the great adventures of the human mind.

Insert para from p.6.

Eddington's excursions into philosophy and metaphysics are to be found mainly in three books. The Nature of the Physical World, 1928, comprises his Gifford Lectures of the previous year. New Pathways of Science contains the Messenger Lectures delivered at Cornell in 1934, and The Philosophy of Physical Science arose from the Tarner Lectures in Cambridge in 1938. These books are a source of sheer delight to readers trained in the mathematical

sciences. To many who have only a very meagre knowledge in these fields, large parts of each book can be enjoyed with profit. To philosophers in general they are illuminating and provocative, and to a few stern logicians they are a source of severe irritation. Much of the writing is brilliant exposition. With the aid of simile and metaphor, and ofttimes pungent wit, some of the most abstruse mathematical subjects are put in words so that the layman can at least get some idea of the way science is going, ~~the opinions of the leading investigators, results,~~ relativity, quantum theory, probability, wave mechanics, indeterminism, speculations, and outstanding problems. He develops his philosophy of physical science, regarding the result as partaking of the nature of both Selective subjectivism and Structuralism, and then proceeds to "a general philosophical outlook which a scientist can accept without inconsistency."

He is Platonic in his insistence upon the intrinsic part played by mind in the picture of the universe which man constructs for himself. He stresses the purely symbolic character of the world built up by the measurements of the physicists and astronomers. The underlying reality is untouched by these methods of approach. His own world-building as also that of Einstein, de Sitter, Weyl or Lemaitre, is not to be thought of as the making of a model but rather as map-making, a partial representation only. "Symbolic" knowledge, the result of physical measurements, can be put into this map, but "intimate" knowledge, the essential contribution of the mind, cannot be introduced. "Realization that physical knowledge is concerned only with structure points the way by which the conception of man as an element in a moral and spiritual order can be dovetailed into the conception of man as the plaything of the forces of the material world."

Being a Quaker with sincere mystical insight, Eddington lays great stress on recognition of the unseen world. His approach is through intimate knowledge: "The desire for truth, ...the reaching out of the spirit from its isolation to something beyond, a response to beauty in nature and art, an Inner Light of conviction and guidance -- are these as much a part of our

being as our sensitivity to sense-impressions? .....Who does not prize these moments that reveal to us the poetry of existence? .....We do not ask whether philosophy can justify such an outlook ....rather our system of philosophy is itself on trial; it must stand or fall according as it is broad enough to find room for this experience as an element of life. The sense of values within us recognizes that this is a test to be passed; it is as essential that our philosophy should survive this test as that it should survive the experimental tests supplied by science. .....We all know that there are regions of the human spirit untrammelled by the world of physics. .....There are some to whom the sense of a divine presence irradiating the soul is one of the most obvious things of experience."

Eddington was very careful never to lend support to a rather widespread proclivity on the part of too many religious teachers to grasp some bit of scientific knowledge and distort it into evidence for faith in spiritual values and beliefs. Herman Weyl has written "Modern science, in so far as I am familiar with it through my own scientific work, mathematics and physics [and cosmology] makes the world appear more and more an open one, as a world not closed but pointing beyond itself. .....science can do no more than show us this open horizon...." Eddington, in one of his writings, quotes this passage and endorses it thus: "He who views mysticism from the standpoint of scientific philosophy may be compared to a man looking down on a city from a height....It is something that from the present peak of science, the clouds have so far rolled away that we seem able to make out the site of the city....But the domain thus revealed ought to be known from within. To join in this knowledge we must surrender our scientific vantage point, and enter the way by which man has from the earliest times entered into the things of the spirit."

In the closing section of his last book, The Philosophy of Physical Science, we find these sentences: "Even in science we realize that knowledge is not the only thing that counts. We allow ourselves to speak of the spirit

of science. Deeper than any 'form of thought' is a faith that creative activity signifies more than the thing it creates.....In the age of science, faith yet remains supreme; for reason is one of the articles of faith.....A scientist should recognize in his philosophy -- as he already recognizes in his propaganda -- that for the ultimate justification of his activity it is necessary to look away from the knowledge itself, to a striving in man's nature, not to be justified of science or reason, for it is itself the justification of science, of reason, of art, of conduct."

Eddington was essentially a man of happy nature, fond of sports, of his pipe and fireside, and of his associations with astronomers and other scientists the world over. In a letter from Cambridge written in December 1943 he says, "We get on pretty well here though things are a bit difficult in various ways. One misses very much the stimulus of research students." His powerful, restless mind found satisfaction not only in the results but in the actual struggle of hard thinking. In his Swarthmore Lecture he had said: "You will understand the true spirit neither of science nor of religion unless seeking is placed in the forefront.

The happiness which he derived from his work was both intellectual and aesthetic. In his last book he contrasts the Pythagorean arithmetic of counting with the assignment of numbers to systems where the process of counting is logically ruled out--and of this latter he says "it is impossible not to admire the devastating beauty of quantum arithmetic." These words remind one of a ~~young~~ astronomer of three hundred years earlier, John Kepler, for whom Tycho Brahe's records of planetary observations had "the fragrance of ambrosia." These are the reactions of great rounded characters--no cold materialistic philosophy will explain the divine fire. "Verily it is by Beauty that we come at Wisdom, yet not by reason at Beauty."

Sir Arthur Eddington took the universe from atoms to stellar galaxies and likewise the world unseen save by "the eye of the soul" as his hunting

grounds, and there in imagination and reason went forth "in uncurbed glory." Now, this giant among thinking men, 'The gentle Knight,' has gone forth upon a new adventure and the astronomical simile from the Book of Daniel seems wholly fitting -- They that be wise shall shine as the firmament of heaven and ..... as the stars for ever and ever.

R.W.D.

1944 Dec. 3.