Arthur Eddington

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Arthur Stanley Eddington (1882–1944)

Sir Arthur Stanley Eddington, OM, FRS[1] (28 December 1882 – 22 November 1944) was a British astrophysicist of the early 20th century. The Eddington limit, the natural limit to the luminosity of stars, or the radiation generated by accretion onto a compact object, is named in his honour.

He is famous for his work regarding the Theory of Relativity. Eddington wrote a number of articles which announced and explained Einstein's theory of general relativity to the Englishspeaking world. World War I severed many lines of scientific communication and new developments in German science were not well known in England. He also conducted an expedition to observe the Solar eclipse of 29 May 1919 that provided one of the earliest confirmations of relativity, and he became known for his popular expositions and interpretations of the theory.

Biography

Early Years

Eddington was born in Kendal, Cumbria, England, son of Quaker parents, Arthur Henry Eddington and Sarah Ann Shout. His father taught at a Quaker training college in Lancashire before moving to Kendal to become headmaster of Stramongate School. He died in the typhoid epidemic which swept England in 1884. When his father died, his mother was left to bring up her two children with relatively little income. The family moved to Weston-super-Mare where at first Stanley (as his mother and sister always called Eddington) was educated at home before spending three years at a preparatory school.

In 1893 Stanley entered Brynmelyn School. He proved to be a most capable scholar particularly in mathematics and English literature. His performance earned him a scholarship to Owens College, Manchester (what was later to become the University of Manchester) in 1898, which he was able to attend, having turned 16 that year. He spent the first year in a general course, but turned to physics for the next three years. Eddington was greatly influenced by his physics and mathematics teachers, Arthur Schuster and Horace Lamb. At Manchester, Eddington lived at Dalton Hall, where he came under the lasting influence of the Quaker mathematician J.W. Graham. His progress was rapid, winning him several scholarships and he graduated with a B.Sc. in physics with First Class Honours in 1902.

Based on his performance at Owens College, he was awarded a scholarship to the University of Cambridge (Trinity College) in 1902. His tutor at Cambridge was the distinguished mathematician R.A. Herman and in 1904 Eddington became the first ever second-year student to be placed as Senior Wrangler. After receiving his M.A. in 1905, he began research on thermionic emission in the Cavendish Laboratory. This did not go well, and meanwhile he spent time teaching mathematics to first year engineering students. This hiatus was brief.

Astronomy

In January 1906, Eddington was nominated to the post of chief assistant to the Astronomer Royal at the Royal Greenwich Observatory. He left Cambridge for Greenwich the following month. He was put to work on a detailed analysis of the parallax of 433 Eros on photographic plates that had started in 1900. He developed a new statistical method based on the apparent drift of two background stars, winning him the Smith's Prize in 1907. The prize won him a Fellowship of

Trinity College, Cambridge. In December 1912 George Darwin, son of Charles Darwin, died suddenly and Eddington was promoted to his chair as the Plumian Professor of Astronomy and Experimental Philosophy in early 1913. Later that year, Robert Ball, holder of the theoretical Lowndean chair also died, and Eddington was named the director of the entire Cambridge Observatory the next year. In May, 1914 he was elected a Fellow of the Royal Society and won their Royal Medal in 1918 and delivered their Bakerian Lecture in 1926.[2]

Eddington also investigated the interior of stars through theory, and developed the first true understanding of stellar processes. He began this in 1916 with investigations of possible physical explanations for Cepheid variables. He began by extending Karl Schwarzschild's earlier work on radiation pressure in Emden polytropic models. These models treated a star as a sphere of gas held up against gravity by internal thermal pressure, and one of Eddington's chief additions was to show that radiation pressure was necessary to prevent collapse of the sphere. He developed his model despite knowingly lacking firm foundations for understanding opacity and energy generation in the stellar interior. However, his results allowed for calculation of temperature, density and pressure at all points inside a star, and Eddington argued that his theory was so useful for further astrophysical investigation that it should be retained despite not being based on completely accepted physics. James Jeans contributed the important suggestion that stellar matter would certainly be ionized, but that was the end of any collaboration between the pair, who became famous for their lively debates.

Eddington defended his method by pointing to the utility of his results, particularly his important mass-luminosity relation. This had the unexpected result of showing that virtually all stars, including giants and dwarfs, behaved as ideal gases. In the process of developing his stellar models, he sought to overturn current thinking about the sources of stellar energy. Jeans and others defended the Kelvin–Helmholtz mechanism, which was based on classical mechanics, while Eddington speculated broadly about the qualitative and quantitative consequences of possible proton-electron annihilation and nuclear fusion processes.

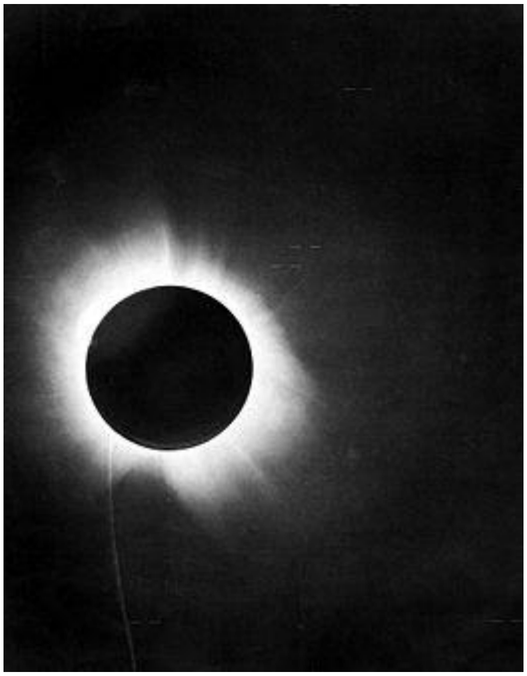
With these assumptions, he demonstrated that the interior temperature of stars must be millions of degrees. In 1924, he discovered the mass-luminosity relation for stars (see Lecchini in #External links and references). Despite some disagreement, Eddington's models were eventually accepted as a powerful tool for further investigation, particularly in issues of stellar evolution. The confirmation of his estimated stellar diameters by Michelson in 1920 proved crucial in convincing astronomers unused to Eddington's intuitive, exploratory style. Eddington's theory appeared in mature form in 1926 as *The Internal Constitution of the Stars*, which became an important text for training an entire generation of astrophysicists.

During World War I Eddington became embroiled in controversy within the British astronomical and scientific communities. Many astronomers, chief among them H.H. Turner, argued that scientific relations with all of the Central Powers should be permanently ended due to their conduct in the war. Eddington, a Quaker pacifist, struggled to keep wartime bitterness out of astronomy. He repeatedly called for British scientists to preserve their pre-war friendships and collegiality with German scientists. Eddington's pacifism caused severe difficulties during the war, especially when he was called up for conscription in 1918. He claimed conscientious objector status, a position recognized by the law, if somewhat despised by the public. In 1918 the government sought to revoke this deferment, and only the timely intervention of the Astronomer Royal and other high profile figures kept Eddington out of prison.

Eddington's work in astrophysics in the late 1920s and the 1930s continued his work in stellar structure, and precipitated further clashes with Jeans and Edward Arthur Milne. An important topic was the extension of his models to take advantage of developments in quantum physics, including the use of degeneracy physics in describing dwarf stars. This precipitated his famous dispute with Subrahmanyan Chandrasekhar, who was then a student at Cambridge. Chandrasekhar's work presaged the existence of black holes, which at the time seemed so absurdly non-physical that Eddington refused to believe that Chandrasekhar's purely mathematical derivation had consequences for the real world. Chandrasekhar's narrative of this incident, in which his work is harshly rejected, portrays Eddington as rather cruel and dogmatic, and is at variance with Eddington's character as described by other contemporaries. Eddington's criticism seems to have been based on a suspicion that a purely mathematical derivation from quantum theory was not enough to explain the daunting physical paradoxes that were apparently part of degenerate stars.[3]

Relativity

During World War I Eddington was Secretary of the Royal Astronomical Society, which meant he was the first to receive a series of letters and papers from Willem de Sitter regarding Einstein’s theory of general relativity. Eddington was fortunate in being not only one of the few astronomers with the mathematical skills to understand general relativity, but (owing to his internationalist and pacifist views) one of the few at the time who was still interested in pursuing a theory developed by a German physicist. He quickly became the chief supporter and expositor of relativity in Britain. He and Astronomer Royal Frank Watson Dyson organized two expeditions to observe a solar eclipse in 1919 to make the first empirical test of Einstein’s theory: the measurement of the deflection of light by the sun's gravitational field. In fact, it was Dyson’s argument for the indispensability of Eddington’s expertise in this test that allowed him to escape prison during the war.



One of Eddington's photographs of the total solar eclipse of 29 May 1919, presented in his 1920 paper announcing its success, confirming Einstein's theory that light "bends"

After the war, Eddington travelled to the island of Príncipe near Africa to watch the solar eclipse of 29 May 1919. During the eclipse, he took pictures of the stars in the region around the Sun. According to the theory of general relativity, stars with light rays that passed near the Sun would appear to have been slightly shifted because their light had been curved by its gravitational field. This effect is noticeable only during eclipses, since otherwise the Sun's brightness obscures the affected stars. Eddington showed that Newtonian gravitation could be interpreted to predict half the shift predicted by Einstein. (Somewhat confusingly, this same half-shift was initially predicted by Einstein with an incomplete version of general relativity. By the time of the 1919 eclipse Einstein had corrected his calculations.)

Eddington's observations published the next year[4] confirmed Einstein's theory, and were hailed at the time as a conclusive proof of general relativity over the Newtonian model. The news was reported in newspapers all over the world as a major story. Afterward, Eddington embarked on a campaign to popularize relativity and the expedition as landmarks both in scientific development and international scientific relations.

It has been claimed that Eddington's observations were of poor quality and he had unjustly discounted simultaneous observations at Sobral, Brazil which appeared closer to the Newtonian model.[5] The quality of the 1919 results was indeed poor compared to later observations, but was sufficient to persuade contemporary astronomers. The rejection of the results from the Brazil expedition was due to a defect in the telescopes used which, again, was completely accepted and well-understood by contemporary astronomers.[6]

Throughout this period Eddington lectured on relativity, and was particularly well known for his ability to explain the concepts in lay terms as well as scientific. He collected many of these into the *Mathematical Theory of Relativity* in 1923, which Albert Einstein suggested was "the finest presentation of the subject in any language." He was an early advocate of Einstein's General Relativity, and an interesting anecdote well illustrates his humour and personal intellectual investment: Ludwig Silberstein, a physicist who thought of himself as an expert on relativity, approached Eddington at the Royal Society's (6 November) 1919 meeting where he had defended Einstein's Relativity with his Brazil-Principe Solar Eclipse calculations with some degree of scepticism and ruefully charged Arthur as one who claimed to be one of three men who actually understood the theory (Silberstein, of course, was including himself and Einstein as the other two). When Eddington refrained from replying, he insisted Arthur not be "so shy", whereupon Eddington replied, "Oh, no! I was wondering who the third one might be!"[7]

Popular and philosophical writings

During the 1920s and 30s Eddington gave innumerable lectures, interviews, and radio broadcasts on relativity (in addition to his textbook *The Mathematical Theory of Relativity*), and later, quantum mechanics. Many of these were gathered into books, including *The Nature of the Physical World* and *New Pathways in Science*. His skillful use of literary allusions and humor helped make these famously difficult subjects quite accessible.

Eddington's books and lectures were immensely popular with the public, not only because of Eddington's clear and entertaining exposition, but also for his willingness to discuss the philosophical and religious implications of the new physics. He argued for a deeply-rooted philosophical harmony between scientific investigation and religious mysticism, and also that the positivist nature of modern physics (i.e., relativity and quantum physics) provided new room for personal religious experience and free will. Unlike many other spiritual scientists, he rejected the idea that science could provide proof of religious propositions. He promoted the infinite monkey theorem in his 1928 book *The Nature of the Physical World*, with the phrase "If an army of monkeys were strumming on typewriters, they might write all the books in the British Museum". His popular writings made him, quite literally, a household name in Great Britain between the world wars.

Philosophy

Idealism

Sir Arthur Eddington wrote in his book *The Nature of the Physical World* that "The stuff of the world is mind-stuff."

The mind-stuff of the world is, of course, something more general than our individual conscious minds…. The mind-stuff is not spread in space and time; these are part of the cyclic scheme ultimately derived out of it…. It is necessary to keep reminding ourselves that all knowledge of our environment from which the world of physics is constructed, has entered in the form of messages transmitted along the nerves to the seat of consciousness…. Consciousness is not sharply defined, but fades into subconsciousness; and beyond that we must postulate something

indefinite but yet continuous with our mental nature…. It is difficult for the matter-of-fact physicist to accept the view that the substratum of everything is of mental character. But no one can deny that mind is the first and most direct thing in our experience, and all else is remote inference."
—Eddington, *The Nature of the Physical World*, 276-81.

The idealist conclusion was not integral to his epistemology but was based on two main arguments.

The first derives directly from current physical theory. Briefly, mechanical theories of the ether and of the behavior of fundamental particles have been discarded in both relativity and quantum physics. From this Eddington inferred that a materialistic metaphysics was outmoded and that, in consequence—the disjunction of materialism or idealism being assumed exhaustive—an idealistic metaphysics is required. The second and more interesting argument was based on Eddington's epistemology and may be regarded as consisting of two parts. First, all we know of the objective world is its structure, and the structure of the objective world is precisely mirrored in our own consciousness. We therefore have no reason to doubt that the objective world, too, is "mind-stuff." Dualistic metaphysics, then, cannot be evidentially supported. (The conclusion appears to be a valid deduction from its premises.)

But, second, not only can we not know that the objective world is nonmentalistic, we also cannot intelligibly suppose that it could be material. To conceive of a dualism entails attributing material properties to the objective world. However, this presupposes that we could observe that the objective world has material properties. But this is absurd, for whatever is observed must ultimately be the content of our own consciousness and, consequently, nonmaterial.

Ian Barbour in his book Issues in Science and Religion (1966), p. 133, cites Arthur Eddington's The Nature of the Physical World (1928) for a text that argues The Heisenberg Uncertainty Principles provides a scientific basis for "the defense of the idea of human freedom" and his Science and the Unseen World (1929) for support of philosophical idealism "the thesis that reality is basically mental".

Charles De Koninck points out that Eddington believed in objective reality existing apart from our minds, but was using the phrase "mind-stuff" to highlight the inherent intelligibility of the world: that our minds and the physical world are made of the same "stuff" and that our minds are the inescapable connection to the world.[8] As De Koninck quotes Eddington,

There is a doctrine well known to philosophers that the moon ceases to exist when no one is looking at it. I will not discuss the doctrine since I have not the least idea what is the meaning of the word existence when used in this connection. At any rate the science of astronomy has not been based on this spasmodic kind of moon. In the scientific world (which has to fulfill functions less vague than merely existing) there is a moon which appeared on the scene before the astronomer; it reflects sunlight when no one sees it; it has mass when no one is measuring the mass; it is distant 240,000 miles from the earth when no one is surveying the distance; and it will eclipse the sun in 1999 even if the human race has succeeded in killing itself off before that date.
—Eddington, *The Nature of the Physical World*, 226

Indeterminism

See also: Indeterminism and Indeterminism in Science

Against Albert Einstein and others who advocated determinism, indeterminism—championed by Eddington[8]—says that a physical object has an ontologically undetermined component that is not due to the epistemological limitations of physicists' understanding. The Uncertainty Principle in quantum mechanics, then, would not necessarily be due to hidden variables but to an indeterminism in nature itself.

Cosmology

Eddington was also heavily involved with the development of the first generation of general relativistic cosmological models. He had been investigating the instability of the Einstein universe when he learned of both Lemaitre's 1927 paper postulating an expanding or contracting universe and Hubble's work on the recession on the spiral nebulae. He felt the cosmological constant must have played the crucial role in the universe's evolution from an Einsteinian steady state to its current expanding state, and most of his cosmological investigations focused on the constant's significance and characteristics.

Fundamental theory

During the 1920s until his death, he increasingly concentrated on what he called "fundamental theory" which was intended to be a unification of quantum theory, relativity and gravitation. At first he progressed along "traditional" lines, but turned increasingly to an almost numerological analysis of the dimensionless ratios of fundamental constants.

His basic approach was to combine several fundamental constants in order to produce a dimensionless number. In many cases these would result in numbers close to 10^{40}, its square, or its square root. He was convinced that the mass of the proton and the charge of the electron were a *natural and complete specification for constructing a Universe* and that their values were not accidental. One of the discoverers of quantum mechanics, Paul Dirac, also pursued this line of investigation, which has become known as the Dirac large numbers hypothesis, and some scientists even today believe it has something to it.

A somewhat damaging statement in his defence of these concepts involved the fine structure constant, α. At the time it was measured to be very close to 1/136, and he argued that the value should in fact be exactly 1/136 for epistemological reasons. Later measurements placed the value much closer to 1/137, at which point he switched his line of reasoning to argue that one more should be added to the degrees of freedom, so that the value should in fact be exactly 1/137, the Eddington number. Wags at the time started calling him "Arthur Adding-one"[*citation needed*]. The current measured value is estimated at 1/137.035999679(94).

Eddington believed he had identified an algebraic basis for fundamental physics, which he termed "E-frames" (representing a certain group – a Clifford algebra). While his theory has long been neglected by the general physics community, similar algebraic notions underlie many modern attempts at a grand unified theory. Moreover, Eddington's emphasis on the values of the fundamental constants, and specifically upon dimensionless numbers derived from them, is nowadays a central concern of physics.

He did not complete this line of research before his death in 1944, and his book entitled *Fundamental Theory* was published posthumously in 1948. Eddington died in Cambridge, England and is buried at the Parish of the Ascension Burial Ground in Cambridge.

Eddington number (cycling)

Eddington is credited with devising a measure of a cyclist's long distance riding achievements. The Eddington Number in this context is defined as E, the number of days a cyclist has cycled more than E miles. For example an Eddington Number of 70 would imply that a cyclist has cycled more than 70 miles in a day on 70 occasions. Achieving a high Eddington number is difficult since moving from, say, 70 to 75 will probably require more than five new long distance rides since any rides shorter than 75 miles will no longer be included in the reckoning.

The construct of the Eddington Number for cycling is identical to the ***h*-index** that quantifies both the actual scientific productivity and the apparent scientific impact of a scientist.