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*ESSAY*

# A Most Rare Vision: Eddington's Thinking on the Relation between Science and Religion[1]

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**Abstract —** It is argued that Eddington's religious beliefs as a lifelong Quaker were directly related to his philosophy of physical science and his quest for a 'fundamental theory' of the most basic relationships in the physical world. He was trying to reconcile, or even to unite, the two most important things in his life: the excitement of scientific research and the profundity of his own mystical experience. In each realm alike, he saw himself as a seeker led by an 'Inner Light'. In neither did he claim to have reached the goal. The reactions of philosophers and theologians contemporary with Eddington is examined, and some attempt is made to assess the value of his ideas today.

## 1. Introduction

Arthur Stanley Eddington (1882-1944) has been described as "the most distinguished astrophysicist of his time" (Chandrasekhar, 1983) and few, if any, would dissent from that assessment. After an outstanding student career at the Universities of Manchester and Cambridge, he was appointed early in 1906 to the post of Chief Assistant at the Royal Observatory in Greenwich. He returned to Cambridge in 1913 as Plumian Professor and (a year later) Director of the Observatory – posts that he held until his death, 50 years ago. Eddington's principal occupation at Greenwich was the study of stellar proper motions and star streaming, which led to the publication of his first book (Eddington, 1914). He was among the first people in the English-speaking world to appreciate the importance of the theory of relativity, of which he became the interpreter through a report commissioned by the Physical Society of London (Eddington, 1918). This directed his attention to fundamental problems of physics, which became his dominant interest and led to a series of books (Ed-

'Editor's Note: An apparently unbridgeable chasm is nowadays thought to exist between the scientific perspective that the material world constitutes the sole or primary reality, and the metaphysical perspective that, on the contrary, a spiritual reality is primary. The latter view is widely assumed to be scientifically preposterous. Arguably the two most prominent astrophysicists of the first half of the twentieth century were Sir Arthur Eddington and Sir James Jeans. Both held the view that material reality was a creation of spiritual forces and wrote eloquently on this topic. This article, which originally appeared in the Quarterly Journal of the Royal Astronomical Society, Vol. 35, pp. 249-270, 1994, is reprinted here (with permission) to shed light upon this apparent conflict of scientific versus metaphysical perspectives.

dington, 1923, 1936, 1946) that established him as one of the pioneers of modem theoretical cosmology and of what would now be called unified field theory. (I am indebted to the referees for emphasizing that Eddington's attempts in this latter area preceded those of Einstein.) At the same time, he was laying the foundations of our knowledge of stellar structure and published a classic book (Eddington, 1926) from which the present writer learned the fundamentals of the subject over a quarter of a century later, and which is still a useful introduction today.

Eddington's colleagues recognized his abilities early by electing him to fellowship of the Royal Society in 1914, before his 32nd birthday, and again in 1922-23, when he was elected President of the Royal Astronomical Society. The wider public probably first learned of him as the leader of the successful eclipse expedition to Principe at which the bending of light rays passing near the Sun, predicted by Einstein's general theory of relativity, was first measured in 1919. He then realized that others, besides his professional colleagues, wanted to understand the new developments of relativity and quantum theory, and he embarked on a career as a writer of popular and semi-popular books. The first was *Space, Time and Gravitation* (Eddington, 1921) but the main group (to be cited below) was published between 1928 and 1939. At least two generations in the English-speaking world learned whatever astronomy they knew either from these books (which were also translated) or those of Sir James Jeans, and many who became professional astronomers were first introduced to serious astronomy through these works. The knighthood awarded to Eddington in 1930, and the Order of Merit (in 1938) probably reflect his standing as an interpreter of science as much as that as a practitioner; but in 1938 also his colleagues endorsed these other honors by electing him President of the International Astronomical Union, a position that, because of the Second World War, he held until his death.

Eddington, a lifelong Quaker, was a deeply religious man and it is hard to determine from his writings whether his scientific work or his religious experience was more important to him. As a man of integrity, he examined carefully whether there was, or needed to be, any conflict between the two. His popular books, especially the Swarthmore lecture *Science and the Unseen World* (Eddington,1929), contain some of the results of his examination. Writing in areas in which he was not an expert, he found that even his great scientific reputation could not save him from criticism. Professional philosophers of the day almost lined up to take shots at both Eddington and Jeans (who began popular writing at about the same time), taking aim at the conclusion that ultimate reality was 'spiritual' (Eddington's word) or 'mental' (Jeans' word). By our standards, the sales of these two men's books may seem modest, but they were unprecedented for books of their type. One measure of their widespread popularity may be that Dorothy Sayers (1939) felt able to incorporate some of Eddington's ideas in a short story about Lord Peter Wimsey. We could, perhaps, form some idea of the stir that they caused, if we were to imagine that today's

two best-known popularizers, Stephen Hawking and Carl Sagan, had published similar conclusions. Eddington supported his ideas of the nature of reality by developing his own philosophy of physical science, which was subjected to devastating, and at least party justified, criticism by philosophers, who seemed, however, to overlook its relation to his individualistic religious beliefs. I shall argue that, however poor it may be as metaphysics, Eddington's philosophy was an honest attempt to relate his religious experience and his scientific work, and that the former throws light not only on his philosophy, but on his increasing preoccupation – so often seen as quixotic – in the last years of his life with the work eventually published posthumously as *Fundamental Theory* (Eddington,1946).

## 2. The Quakers: Eddington's Religious Beliefs

The Society of Friends, commonly known as the Quakers, originated in the middle of the seventeenth century. The founder, George Fox, an itinerant preacher in the 1640s, began a clearly identifiable separate movement in 1652 when, preaching near Kendal (Eddington's birthplace), he won over most of the members of a group called 'Seekers', whose ways and ideas had much in common with his. The name 'Quaker' was first applied by a judge before whom Fox appeared (unlicensed preaching being an offense) and was clearly intended as an insult. All Quakers I have met, however, use the name with pride, and I shall use this shorter more familiar term. Fox insisted that everyone had something of God in him or her and that each person should follow this Inner Light. To this end, Quakers are not required to subscribe to any credal statement: they have no paid clergy and no fixed order of service. They are free, within very broad limits to follow their own consciences, and in this way are still 'Seekers'. Nevertheless, certain beliefs are characteristic: for example, pacifism and (unusually for a seventeenth-century dissenting group) a strong belief in human free-will. Eddington shared fully in both of these. Quakers are also strongly linked with social activity and reform: this element is less obvious in Eddington's life and work. Both Eddington's parents came from traditional Quaker families, and his mother could trace her ancestry back to people associated with Fox himself (Douglas, 1956, p.1). Eddington's own religious attitudes were strongly permeated by Quaker ideas. He was, in spirit, a Seeker and argued that in science, as well as in religion, one should follow the Inner Light (Eddington, 1929, p. 90). One of his most famous (and, I believe, most profound) remarks on the subject was "You will understand the true spirit neither of science nor of religion unless seeking is placed in the forefront." (Eddington, 1929, p. 88). In accordance with the Quakers' lack of concern for credal statements, he wrote little about specific Christian doctrines (I suspect that he was, in the technical sense, a unitarian), about the miraculous element in Christianity, or the literal interpretation of the Bible. I imagine that Eddington, with his love of poetry, had no difficulty in interpreting much of the Bible in a poetic sense. He did express a belief in a personal God (Eddington,

1929, p. 49), but cautiously, aware of how easily such a statement might be misunderstood as crude anthropomorphism. He says little about the survival of the human personality after death, although I think that a belief in some form of survival is implicit in his writing. In short, his writing on religion is non-theological, even occasionally anti-theological, except that it reflects his very strong concern with human free-will.

Overriding Eddington's specifically Quaker ideas, however, was the high value he placed on 'mystical religion' — he had, he told us, "no impulse to defend any other" (Eddington, 1928, p. 339). The word 'mysticism' (together with its derivatives) is often used loosely by modern scientists, either as a synonym for 'pseudo-science' or as a euphemism for sheer muddle-headedness. For students of religion, however, it is a precise technical term. Eddington's own definition (Eddington, 1928, p. 321) may not completely satisfy such specialists, but it serves to fix our ideas of what he was talking about:

> If I were to try to put into words the essential truth revealed in the mystic experience, it would be that our minds are not apart from the world; and the feelings we have of gladness and melancholy and our yet deeper feelings are not of ourselves alone, but are glimpses of a reality transcending the narrow limits of our particular consciousness — that the harmony and beauty of the face of Nature is at the root one with the gladness that transfigures the face of man.

Eddington must have written this from first-hand knowledge, and it is the closest he got to claiming to be a mystic or to describing his own religious experience. While Quakerism may be particularly hospitable to this kind of mysticism, Eddington was describing something that is found in religions as diverse as Christianity (in all its forms) and Hinduism. However much some may wish to argue about the interpretation, the experience cannot be denied; and it cannot be explained away, for Eddington at least, as a result of mental instability, drugs or excessive asceticism. It is, perhaps, as unwise for those of us who have not had the experience to attempt to interpret it, as it would be for a tone-deaf person to describe a symphony concert, or a color-blind one to set up as an art critic. The only alternative is to accept accounts like Eddington's at their face value.

### 3. Eddington's Philosophy of Science

In philosophy, as in science and religion, Eddington was a seeker following his own Inner Light. One reason for the philosophers' criticisms was that they took as a complete metaphysical system what Eddington intended as a tentative outline of ideas. Unity and consistency, he said, are ideals to be reached by convergence (Eddington, 1935, p. 291) and he regarded seeking (in science, religion and philosophy) as more important than finding. He said so explicitly in *Science and the Unseen World* (p. 23):

We seek the truth; but if some voice told us that a few years more would see the end of our journey, that the clouds of uncertainty would be dispersed, and that we should perceive the whole truth about the physical Universe, the tidings would be by no means joyful. In science as in religion the truth shines ahead as a beacon showing us the path; we do not ask to attain it; it is better far that we be permitted to seek.

Another cause of misunderstandings with philosophers was that Eddington presented his ideas in popular and semi-popular books (Eddington, 1921, 1925, 1928, 1935, 1939) without the degree of intellectual rigor required for a proper judgment or their value; but the philosophers' criticisms that his ideas were confused are not entirely without foundation. I think that, with care, those ideas could be presented in such a way as to avoid many of the criticisms that were leveled, and Eddington himself tried to do so in his later books; but it was *The Nature of the Physical World* that had the biggest impact and to which most of the critics responded. In the Introduction to that book, Eddington presented the 'two tables' that so annoyed Stebbing (1937, pp. 45ff). He pointed to the paradox of an apparently firm impenetrable table-top consisting mostly of empty space in which tiny, rapidly moving electric charges supported his paper and his arms by buffeting against them like a swarm of flies. He apparently did mean to suggest that there were two tables (see Eddington, 1939, p. viii) — the scientific one and the everyday one — which were components of two distinct worlds. In a later book (1935) he modified this to talk of two accounts of one world. This is perhaps the better form of expression; it is undoubtedly a convenient shorthand to talk of 'two worlds', but doing so was the source of some of the confusion that philosophers criticized. Eddington wanted to make clear that the scientific and everyday worlds (or descriptions) were different, and to argue that neither was the ultimate reality. With the first statement, I imagine, no scientists and few philosophers would disagree; with the second, most scientists and many philosophers certainly did. Reality, Eddington maintained, was inscrutable, and ultimately spiritual in nature. If this be granted, it follows that both the everyday and the scientific descriptions are in some sense the creation of spirit (or mind) and this is the source of Eddington's belief that the laws of nature, and particularly the fundamental constants (or dimensionless ratios of them) could be found non-empirically by studying the way in which the mind works. Or course, particular facts, such as the distance of the Earth from the Sun, or the size of the Galaxy, could be found only by making the appropriate measurements.

Since science began as an effort to understand more precisely how the objects around us behave, to speak of 'scientific' and 'everyday' objects (or even descriptions) may seem paradoxical. Even Newton's laws are not commonsense, however, and the predictions of relativity and quantum theories are often counter-intuitive. We learn about the objects around us through our senses and by reasoning from past experience. We recognize that our senses can deceive us and that our reasoning is fallible, so, like Eddington, we accept that objects around us may not be, in all respects, what they appear. In scien-

tific study, we refine our senses by using carefully calibrated instruments, and our reasoning by applying mathematics. Most scientists are satisfied that in so doing they have removed the obvious sources of illusion and error: many even deny reality to anything that cannot be studied in those ways. Eddington, however, stressed that by using instruments all observational facts were reduced to pointer readings, and that to translate these into objective properties always required inference — sometimes a very long train of it. He further maintained that analysis of pointer readings, and of the relations between them, depended on the structure of our minds. Just as a fisherman with a coarse net might come to believe that a law of nature set a minimum size for fish (Eddington, 1939, p. 16), so we interpret observed relationships as laws of nature, because of the structure of our minds. On p. 57 of the book just cited, Eddington wrote (with the emphasis shown):

> ... all the laws of nature that are usually classed as fundamental can be foreseen wholly from epistemological considerations. They correspond to a ***priori*** *knowledge,* and are therefore *wholly* subjective.

The detailed working out of this idea, as far as Eddington could complete it before his death, is in the posthumous book *Fundamental Theory* (1946), but the vast majority of scientists has not accepted his reasoning. Most of them see the world of our scientific description as being, in some sense, the 'real world'. Eddington's view that electrons, quanta, etc. are only manifestations in the scientific world of some deeper reality of which we can, at most, know only the structure, has been largely rejected. That view, however, left room in reality for non-material entities, which were important to Eddington. I venture to suggest that his mystical experience had given him "a most rare vision" of the 'real world' and that the rather complex metaphysics that he tried to construct was an attempt to reconcile these glimpses of reality with his scientific knowledge, without doing violence to either.

### 4. Human Free-Will

Whether or not human beings have free-will is a perennial question that can be debated in scientific, philosophical, or theological contexts. During much of the nineteenth century, the scientific arguments dominated and Newtonian physics was seen as implying strict mechanical determinism. Stebbing (1937, Chap. VII), borrowing partly from T. H. Huxley, called this belief "the nineteenth-century nightmare." Laplace (1814) set the tone of the nightmare by imagining a super-intelligence that knew the positions and velocities of every particle in the Universe, at a given instant, and could calculate all their past and future configurations. Such an intelligence, he said, would find past and future alike "present to its eyes." The nightmare even permeated the literature of the period, and Eddington found a succinct summary in Fitzgerald's (1859) version of the Rubaiyat of *Omar Khayyam:*

With Earth's first Clay they did the last Man's knead,
And then of the last Harvest sow'd the Seed:
Yea, the first Morning of Creation wrote
What the last Dawn of Reckoning shall read.

Fitzgerald readily admitted that his translation was free (Graves & Ali-Shah, 1967) and this stanza may reflect the European nightmare as much as Islamic teaching or the opinions of that eleventh-century Persian who, like Eddington, was both astronomer and mystic.

In retrospect, the first signs of waking from the nightmare may have been the discovery of the statistical laws of thermodynamics, but at the time those laws were seen merely as a computing device needed precisely because, even with our modern computing powers that would have astounded him, we are not the sort of super-intelligences that Laplace envisaged. Later, radioactivity and quantum theory led to the idea that individual particles might behave unpredictably. Heisenberg's (1927) uncertainty principle, stating that a fundamental particle's position and velocity could not simultaneously be known with complete precision, brought the final waking. Eddington' was among those who were convinced that the uncertainty lay in the particle itself. He sharply criticized fellow scientists (including both Planck and Einstein: Eddington, 1935, pp. 295-303) who argued that the uncertainty is only in our knowledge and that atomic and sub-atomic events were completely determined. It was in this context that Bertrand Russell (Russell, 1931, p. 112) wrote his famous epigram:

Sir Arthur Eddington deduces religion from the fact that atoms do not obey the laws of mathematics. Sir James Jeans deduces it from the fact that they do.

Eddington felt that Russell had misrepresented him here: he had no difficulty in showing that he had *never* tried to deduce religious belief or the existence of God from any specific result and had, indeed, "strongly opposed" (Eddington, 1935, p. 306) all attempts to do so. The most telling self-quotation came from *The Nature* of *the Physical World* (p. 353):

The religious reader may well be content that I have not offered him a God revealed by the quantum theory, and therefore liable to be swept away in the next scientific revolution.

Eddington went on to maintain that Russell had confused his views on religion with those on free-will, and insisted (Eddington, 1935, p. 306):

I have not suggested that either religion or free-will can be deduced from modern physics; I have limited myself to showing that certain difficulties in reconciling them have been removed.

Nevertheless, Eddington often juxtaposed religion and free-will, which latter — judging from the space that he devoted to it — was very important to him. Russell can be partly forgiven for the confusion, but his 1931 book, The Scientific Outlook, is not one of his best. My impression is that the book was written hurriedly, and a letter that Russell later published (Russell, 1968, p. 290) supports this. Russell (p. 110) maintained that, at that time, it was not known whether or not the behavior of atoms was capricious. He severely criticized Eddington's arguments, particularly one that he saw as an oversimplified deduction of free-will from Heisenberg's principle. I am not sure that Eddington's arguments were as naive as Russell (p. 108) believed, but they might seem so on a hasty reading. Heisenberg published his principle after Eddington had delivered his Gifford Lectures, but before The Nature of the Physical World was published. Eddington rewrote parts of Chapter X to discuss the new development: his first thoughts on the subject may not have been expressed with his usual clarity. He suggested, however, that consciousness could correlate the behavior of individual particles, amplifying the small uncertainty and leading to genuine acts of volition. Both Russell and Jeans criticized this as Cartesian dualism. I am not sure that it is a good argument for human free-will, but it is a scientific one and could, in principle at least, be settled by experiment, rather than by philosophical reasoning. Eddington himself emphasized that his suggestions were tentative, remarking (Eddington, 1935, p. 87) in a metaphor later employed by Jeans (1942, p. 216):

> Although the door of human freedom is open, it is not flung wide open: only a chink of daylight appears.

Eddington also recognized that the arguments for or against determinism at the mechanical, biological, psychological, and even theological levels are all distinct; but he rightly saw mechanical determinism as basic. If the motions of our bodies are determined by all that has gone before, the questions of whether we are determined by our genes, our upbringing and environment, or even the grace of God, are all academic.

## 5. Cosmology

Cosmology is one of those areas of scientific investigation that necessarily raises philosophical and religious questions. Eddington (1939, p. 7) mildly criticized Einstein for his supposed reply to a question from the then Archbishop of Canterbury, concerning the significance for religion of the theory of relativity. Einstein is said to have answered somewhat hastily that relativity was a purely scientific theory and had nothing at all to do with religion. Eddington expressed some sympathy with Einstein's probable motives for this reply, but pointed out that Darwin could have responded similarly to the Archbishop of his day, although many Christians then (and now) thought that the theory of

evolution had a great deal to do with their beliefs. Great scientific syntheses so affect our view of the world that they are bound to affect the way we think about religious questions — whether we react by rejecting traditional formulations or by rethinking them.

Eddington was among the first to accept that the red-shifts detected in the spectra of extra-galactic nebulae were genuine evidence of the expansion of the Universe. Even Hubble (1937, Chap. III) himself was more hesitant. Acceptance of the expansion of the Universe naturally leads to questions about its origin. Gamow's (1946) paper is usually regarded as the first scientific statement of the theory now known as the 'Big Bang', but the idea was anticipated in Eddington's lifetime, notably by Friedmann and Lemaître. Eddington was more directly influenced by the latter, who coined the term 'fireworks theory' (Lemaître, 1935') for his own idea of the origin of the Universe. Einstein (1917), believing that the small relative velocities of stars in our own Galaxy were characteristic of the whole Universe, showed that a Universe containing matter could remain indefinitely in a quasi-stable state, if a cosmical repulsion were assumed. Lemaître (1931) showed that very small instabilities would grow into expansion, but he also suggested that the Universe was created with a built-in tendency to expand — in a fireworks explosion. Shortly after Eddington's death, Lemaître (1945) elaborated his theory of the primeval atom, now superseded by Gamow's form of the Big Bang and modern ideas of nucleosynthesis.

Eddington was much impressed by Lemaître's work on stability, but he did not like the fireworks theory. This was, partly, because of a time-scale problem which, ironically, is threatening to emerge again today: the oldest objects in the Universe seemed to be older than the Universe itself. A prolonged phase of unstable equilibrium, provided galaxies and stars were able to exist during it, offered a way out of that paradox. But Eddington was quite frank that his chief reason for rejecting an explosive origin for the Universe was an aesthetic one. He was reluctant to accept an abrupt beginning for the Universe (Eddington, 1933, p. 56). Earlier (Eddington, 1928, p. 85) he had made a similar point in discussing the heat-death predicted for the Universe by the second law of thermodynamics. Here it was clearer that his 'aesthetic' objection was basically religious. The corollary of 'heat-death', or running-down of the Universe, was that at some definite time in the past, the Universe was 'wound up'. Eddington wrote:

> As a scientist I simply do not believe that the Universe began with a bang; unscientifically I feel equally unwilling to accept the implied discontinuity in the divine nature. But I can make no suggestions to avoid the deadlock.

[2]This is the earliest paper readily available to me in which I can find the words *feu d'artifice*. I believe Lemaitre used the term even earlier. I have much sympathy with those who believe that the term 'Big Bang' trivializes an event that would have seemed awe-insipiring beyond our powers of imagination, would we have observed it. I am not sanguine, however, that the astronomical community can be persuaded to change its usage.

His religious motivation is even clearer in a famous passage from *Science and the Unseen World* (Eddington, 1929, p. 25):

> Probably most astronomers, if they were to speak frankly, would confess to some chafing when they are reminded of the psalm 'The heavens declare the glory of God.' It is so often rubbed into us with implications far beyond the simple poetic thought awakened by the splendor of the star-clad sky. There is another passage from the Old Testament that comes nearer to my own sympathies:
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> "And behold the Lord passed by, and a great and strong wind rent the mountains, and brake the rocks before the Lord; but the Lord was not in the wind: and after the wind an earthquake; but the Lord was not in the earthquake: and after the earthquake a fire; but the Lord was not in the fire: and after the fire a still small voice... And behold there came a voice unto him, and said, What doest thou here, Elijah?"
>
> Wind, earthquake, fire — meteorology, seismology, physics — pass in review...; the Lord was not in them. Afterwards, a stirring, an awakening in the organ of the brain, a voice which asks 'What doest thou here?'

Because Eddington believed in a God who spoke in a still small voice, it seemed simply ridiculous to him that such a God should start the world with a bang. He was not the first cosmologist to make scientific decisions on aesthetic, or even religious, grounds: the tradition goes back at least to Kepler. Had Eddington lived only a few years longer, he probably would also have expressed aesthetic objections to the steady-state theory, as the following quotation (Eddington, 1929, p. 86) shows:

> At present we can see no way in which an attack on the second law of thermodynamics could possibly succeed, and I confess that personally I have no great desire that it should succeed in averting the final running-down of the Universe. I am no Phoenix worshipper. This is a topic on which science is silent, and all that one can say is prejudice. But since prejudice in favor of a never-ending cycle of rebirth is often vocal, I may perhaps give voice to the opposite prejudice. I would feel more content that the Universe should accomplish some great scheme of evolution and, having achieved whatever may be achieved, lapse back into chaotic changelessness, than that its purpose should be banalized by continual repetition. I am an Evolutionist, not a Multiplicationist. It seems rather stupid to keep doing the same thing over and over again.

It is tempting, but probably pointless, to speculate how Eddington might have reacted to the arguments for primordial helium abundance and the discovery of the cosmic background radiation. He would, or course, have appreciated their significance as evidence for the Big Bang, but he often showed a healthy skepticism toward observational results (see especially Eddington, 1933, p. 17). Chandrasekhar (1983, p. 25) recounts that, left to himself, Eddington would not have troubled to verify the relativistic displacement of stars at the 1919 eclipse, since he was already convinced to the correctness of the

theory. If he had felt impelled to accept the Big Bang theory, he would, I believe, have done so only with the greatest of reluctance.

Eddington was also among the first to see the connection between cosmology and particle physics. This, of course, was closely connected with his philosophy of physics and his fundamental theory. The book of that name has, I believe, been found difficult by all who have read it. Having only dipped into it myself I do not claim to understand it, but I have found a summary by Whittaker (1949, pp. 185-204), who edited Eddington's book for publication, and a companion volume by Slater (1957) to be helpful. I think it safe to say that, even if Eddington was right in principle, his attempts to construct a fundamental theory were premature in practice. Our ideas about fundamental particles have changed immeasurably since his time. Eddington sometimes illustrated the world of nuclear physics by quotations from Lewis Carroll's Jabberwocky (Eddington, 1928, p. 291; 1936, p. 255) but perhaps he did not read James Joyce, for he never mentioned quarks! Today's cosmologists would probably have been more impressed had he found a value for Hubble's constant somewhere in the range of modem empirical determinations, rather than the best value then known — between five and ten times greater than currently believed values (but see Slater 1954). Although the numerical coincidences between the observed values of natural constants and Eddington's calculated values are impressive, many have believed that some of the empirical values were implicitly introduced into the theoretical calculations, and that Eddington did not really prove his point. Nevertheless, a comment applied by Whittaker (1937) to one of Eddington's earlier books might also be applied to Fundamental *Theory:*

> ...if it contributes little to the day-to-day progress of physics, it may enlighten generations yet to come.

## 6. Reactions of Eddington's Contemporaries

### 6.1 Eddington and Jeans

The impact of the popular writings of both Eddington and Jeans was undoubtedly strengthened by the coincidence that the two men ventured into popular exposition at about the same time. Readers were impressed by the similarity of the conclusions drawn from the latest developments in physics and astronomy by Britain's two best-known astronomers. Most were probably unaware of the rivalry — usually friendly but sometimes bitter (Jeans, 1926) — between these two in the field of stellar structure, or even in the difference of emphasis in their philosophical conclusions. What came across was that both believed scientific discovery to be less inimical to belief in God than had appeared in the late nineteenth century. Their approaches were different, however, and neither author was above taking pot shots at the other as successive books appeared. Jeans turned to popular writing as he felt his powers of origi-

nal mathematical investigation beginning to wane (Milne, 1952b, p. 73) and his early popular books, at least, tended to concentrate on specific results. Eddington continued original research to within weeks of his death (Douglas, 1956, p. 183) and usually preferred to explain principles (but see *Stars and Atoms,* 1927). His books have lasted better: one can read *The Expanding Universe* today and be amazed at the author's insight, even prescience, while *The Mysterious Universe* (Jeans, 1930) distracts, or even irritates, the modem reader by its many purported factual statements that now appear quite wrong. In his last chapter, however, Jeans did try to interpret the significance of the astronomical discoveries of his day, and it was this chapter, together with Eddington's Gifford Lectures (Eddington, 1928) that coupled the two men firmly together in the public mind.

Jeans agreed with Eddington that the material objects around us do not constitute the ultimate reality, and that we cannot know the nature of that reality. He differed in regarding the 'scientific world' as that part of the 'real world' accessible to sensory experience. He described the ultimate reality as 'mental'; Eddington preferred the term 'spiritual', but I suspect that they meant the same thing. Jeans identified his philosophical outlook with Berkeley's idealism; Eddington was reluctant to identify with any of the great philosophers of history, but considered himself (Eddington, 1939, p. 188) to be closest to Kant. Indeed, Kantian influences on Eddington's thought can be seen in the latter's belief in the possibility of *a priori* knowledge, in the impossibility of knowing things in themselves and in the mind's imposition of its own categories on the physical Universe.

Jean's statement "it begins to appear that thc Great Architect of the Universe is a pure mathematician" attracted much attention. Eddington, in ironical vein, had made a similar suggestion (Eddington, 1928, pp. 104, 209), but he made clear (Eddington, 1935, pp. 323-3; 1939, p. 137) his disagreement with Jeans. He tried to show, in Chapter IX of *The Philosophy of Physical Science,* that "the mathematics is not there till we put it there," but this seems to me one of the weaker chapters of the book. Jeans was much impressed by Plato's famous metaphor of people in a cave, able to see only the shadows of beings in the real world outside. He thought that we were in that position, and had developed mathematics as a game, only to find that it was just what was needed to study the real world — as if the creatures in the cave had invented the game of chess and then found that the shadows were playing the same game. He concluded that the mind behind the shadows, the Creator, and the human mind had something in common — namely, mathematics.

I believe that Jeans was thinking of, for example, non-Euclidean geometry, tensor calculus, and group theory — all developed as parts of pure mathematics without thought of their possible applications, and each needed in either relativity or quantum theory. I believe also that Eddington, despite his disagreement with Jeans, understood him in that sense. Bertrand Russell (1931, p. 113) confused the issue, however, and apparently believed that Jeans was

inferring a mathematician God from his own researches on stellar structure. Russell (p. 116) accused Jeans of having confused pure and applied mathematics — an extraordinary charge for one mathematician to lay against another fully as competent. (Russell was Seventh Wrangler in 1904.) Russell must have known better; in the same book (Russell, 1931, p. 61) he had himself pointed out that non-Euclidean geometry was developed nearly a century before it was needed in the theory of relativity — further evidence that he wrote *The Scientific Outlook* in a hurry. Had the book come from the pen of a lesser writer, it could have been ignored, but Russell influenced other critics of Jeans; Stebbing (1937, p. 26) repeated Russell's words almost *verbatim*, although I doubt if she would have made that criticism on her own authority. Perhaps more justifiably, Stebbing (p. 15) also accused Jeans of creating God in his own image — as a sort of Super-president of the Royal Society, worthy to be a colleague of Jeans himself!

Jeans and Eddington also disagreed about fundamental theory. Jeans did not believe that the constants of nature could be computed theoretically. His arguments, being scientific, probably seem more convincing to most scientists than do many of the philosophical criticisms. He discussed Eddington's work explicitly in a later book, *Physics and Philosophy* (Jeans, 1942, pp. 72-81). Eddington had a chance to see the relevant parts in proof, so he presumably accepted the criticism as fair. Jeans emphasized the empirical nature of science and pointed out that Eddington had not deduced any known scientific law from pure theory. The constants that Eddington claimed to have derived, Jeans said, were not properly defined. For example, Eddington computed a mass-ratio of 1847:1, but did not show conclusively that it referred to the proton and electron. This seems to me to be true, at least of one of Eddington's popular accounts of the matter (Eddington, 1935, pp. 243-7).

The two men also differed about free-will, which was less important to Jeans than to Eddington. Jeans considered the matter mainly in the context of moral choices; Eddington in that of the mind acting on the body to produce our 'voluntary' actions. The two are related: there is no genuine freedom of moral choice if we cannot act on our choices by, for example, standing firm in the face of physical danger. Nevertheless, the difference of emphasis rather suggests that Eddington was deliberately choosing the court in which his case would be most difficult to argue. If our bodily movements are determined, whether by mechanical, genetic or psychological laws, then arguments for free-will must be worded very carefully. Jeans even questioned the concept, pointing out that when we thought we were choosing freely, we were constrained by the choices that we had made throughout out lives, which had to some extent formed our characters.

### *6.2 The Philosophers*

British professional philosophers of the day were united in criticizing both Eddington and Jeans. Among the most distinguished were Braithwaite (1929,

1940), Broad (indirectly, 1938), Joad (1932), Stace (1934), Stebbing (1937) and Russell (*loc. cit.*). All found inconsistencies, obscurities, or even flaws in the arguments of the two astronomers. Jeans, particularly, was criticized for his ignorance of philosophy (which he readily admitted). While some forms of idealist philosophy had been fashionable in Britain when Jeans and Eddington were students, the dominant school at the time they wrote was realist (Russell, 1928 — here, I think, reliable). Joad's principal criticism was that the two men were, philosophically speaking, a generation out of date. Reading the philosophers has convinced me that there are genuine flaws in the arguments of both Eddington and Jeans, even though I find much in the thought of both men that is congenial. I cannot help wondering, however, if similar flaws would have been overlooked had the astronomers drawn realist, or even materialist, conclusions from their science. Some, at least, of the fury of the philosophers could be explained by chagrin at seeing ideas that they had imbibed as students, and then reacted against, advanced in widely read books by two eminent scientists. The Philosophy *of* Physical Science and Philosophy and Physics each seem to me to be better argued than earlier books by their respective authors, but these books were criticized too, and the debate might have raged much longer if the Second World War had not diverted the energies of the academic community.

I believe Joad was the most cogent of the philosopher critics, although my (admittedly hazy) recollections of him as a radio personality did not predispose me to this opinion — which was, nevertheless, Eddington's own (Eddington, 1935, p. 288). Joad was certainly one of the most courteous of the critics, and was at pains to state the positions of both Eddington and Jeans as clearly as he could, before criticizing. As noted, his chief criticism was that both men were out-of-date in their philosophy, and had not understood that the new realists had rejected nineteenth-century idealism for good reasons. He saw Eddington and Jeans as the most prominent examples of a general trend, and welcomed the greater openness of scientists (in the 1920s and 1930s) to philosophical and theological ideas. Joad committed some elementary scientific errors which, though surprising, are not very important to his arguments. In criticizing Jean's 'pure-mathematician God' he seems to me to confuse 'mathematical' with 'numerical', which is perhaps more important. The most serious fault in his argument, as I understand it, is that he apparently equates the propositions 'Mind created the Universe' and 'my mind created the Universe'. Whether the first be true or false, it is clearly distinct from the second, which is nothing but solipsism and absurd.

Stebbing's (1937) Philosophy and the Physicists is probably, however, the best-known critique of the early views of Eddington and Jeans, and she was equally critical of Jean's Physics and Philosophy (Stebbing, 1943). She had a lively style of her own and chose not to mince matters. She was, indeed, the least courteous of the critics listed above, her favorite adjectives for the philosophical ideas of the astronomers being "confused" and "absurd" — despite

repeated protestations of respect for their scientific work. In a book of nearly 300 pages, she disposed of Jeans in 40 — requiring the remainder to deal with "the greater subtlety of Eddington's argument" (Stebbing, p. 21). Much of her criticism centered on the loose use of words, so that she sometimes sounded like a schoolteacher marking the essays of two promising, but decidedly immature, sixth-formers. In particular, she attacked the many metaphors and illustrations that make Eddington's books such a pleasure to read. She was aware that this would expose her to the criticism of taking literally passages that were never so intended, and defended herself by claiming that Eddington often got carried away by his own metaphors, and took over some loose analogy into what was meant to be a more precise argument. She may sometimes have been right, but the context of some of the metaphors she criticized leaves room for doubt. For example, Eddington twice makes a humorous comparison between the reactions of a scientist and of an ordinary person when stepping through a doorway. The scientist hesitates, recalling the insubstantial atoms that make the floorboards, the velocity at which the doorway is hurtling around the Sun — and so on: the ordinary person walks through. Stebbing (pp. 48ff) criticizes this at length, but in one context (Eddington, 1925, p. 187) the illustration is an attention-getting introduction, and in the other (Eddington, 1928, p. 342) it is the end of the main part of the text. Neither time did Eddington draw significant conclusions from it.

If Eddington sometimes confused metaphorical and metaphysical argument, Stebbing often confused her roles. At times, she affected to speak for the 'common reader', but she herself was a very uncommon reader — highly intelligent, highly critical (I mean that as a compliment), articulate, with strong philosophical opinions of her own and the professional competence to back them up. At other times she undoubtedly spoke for professional philosophers in general, and pointed out genuine errors in reasoning. Much of the time, however, she seems to me to have been speaking on behalf of a particular school of philosophers, attacking arguments because she did not like the conclusions drawn from them. A good example is provided by the apparently trivial question of whether or not roses are really red. It is not as trivial as it seems, because Eddington's 'selective subjectivism' does not stand a chance if a property like color — notorious for the disagreements it creates between different observers — is fully objective. Unless I misunderstand her, Stebbing (pp. 64 and 130) did believe that roses are red. Her colleague Stace (1934) certainly wrote:

> Chairs and tables and stars do really exist. They are exactly what they appear to be, colored spatial resounding objects. Moreover this familiar world is the only real world, the only world that really exists.

In the same article, Stace argued that atoms, electrons and stars (his inconsistency) were fictitious objects, apparently failing to realize that he was thereby

strengthening Eddington's claim that the laws controlling them are subjective. Let us return, however, to the redness of roses, with which both Jeans and Eddington dealt in later books. On this occasion, Jeans (1942, p. 96) was the more succinct and compelling, and I believe that most scientists will agree with his analysis. Disdaining even to cite Stebbing, Jeans argued that at least three things are needed to create the impression of a red rose: light of a certain wavelength range in the source of illumination, the capacity of reflecting light of these wavelengths in the rose, and an observer of 'normal' color sensitivity (e.g. not color-blind or jaundiced). This argument seems to me sufficient to defeat extreme forms of realism (apply it to a white rose that we can make to appear any color we choose) but British realist philosophers of the inter-war years apparently did not accept it. On Jean's view, the redness of a red rose does correspond to some objective property — presumably we would say to the molecular structure of the pigment — but that property is not itself redness. Eddington would probably have seen this identification of the objective property with structure as a vindication of his own views.

An important part of Stebbing's book, however, is the four chapters (7 to 10) that she devotes to a discussion of human free-will and its relation to physical determinism. Here she does not just criticize Eddington, but helps to clarify the issue. She argues (Stebbing, p. 217) that our conviction that we are responsible is part of the data that we must take into account in the discussion. Our freedom of action is certainly limited by physical, genetic and other trains of causation, but that does not destroy our responsibility. It is, indeed, responsibility that she emphasizes, rather than freedom, and she insists that causation is not compulsion. I may be compelled by someone physically stronger than myself to do something that I believe to be wrong, but in such circumstances I am not responsible. On the other hand, if a friend persuades me to a course of action by rational argument, although he is in some sense a cause of my acts, he did not compel me and I remain responsible. Stebbing believed that, under the influence of classical physics, we had all confused causation and compulsion. She did not think that quantum uncertainty had any direct bearing on human free-will, but she did think that Heinsenberg's principle helped us to extricate ourselves from the confusion into which we had fallen.

I am unsure whether Dingle, whose writings display a somewhat ambivalent attitude towards Eddington, should be accounted a philosophical or scientific critic. He did not much concern himself with Jeans, but his review (Dingle, 1940) of The Philosophy of Physical Science was distinctly hostile. Earlier, Dingle (1937) had attacked Eddington and Dirac [whose note on large-number coincidences (Dirac, 1937) had just appeared, inspired by Eddington's work]. Dingle argued that they were "new Aristotelians," turning their backs on the experimental method introduced into modern science by Galileo, and returning to the kind of argument used by Galileo's opponents. Even the inverted commas around "Aristotelian" did not save Dingle from reproof by W. McEntegart, a good Thomist, who pointed out that Aristotle's biology, at least, was

empirically based. The article generated so much correspondence, including replies from Eddington and Dirac, that *Nature* consolidated it in a supplement (*Nature*, Vol. 139, pp. 997-1012. 1937), to which the interested reader is referred.

Some may be surprised at my failure so far even to mention A. N. Whitehead, probably the most profound of all the mathematician-philosophers of the period, and the only one, I believe, who still commands a significant following among professional philosophers. Most of his philosophical writing was completed before Eddington and Jeans entered the field. Moreover, he made clear in a letter to Russell (1968, p. 96) that his ideas had been incubating a long time. He probably chose not to make last-minute references to philosophical ideas that he may well have considered superficial.

### *6.3 The Theologians*

In *The Scientific Outlook*, Russell (1931, p. 105) wrote that Eddington, Jeans, and the biologist Lloyd Morgan had attracted much public attention, and he claimed that the press had exaggerated the degree to which they had supported traditional Christian beliefs, so that may people received the impression that the science of the 1920s had all but proved the entire book of *Genesis*. Russell recognized that this was a misunderstanding, and to the extent that his own book helped to correct this false impression, it was useful; but he went on to criticize his own version of these writers' ideas, claiming that (unnamed) theologians were so desperate for any argument that would support belief in God, that they jumped at the chance to represent the science of the day as proving the existence of God.

It all sounds plausible, but it proves rather difficult to identify the theologians Russell had in mind. Perhaps he was thinking of articles in the popular press, that cannot be recovered without a lengthy file search that I am not at present in a position to make. Perhaps he relied on reports of friends on sermons that they had heard. No doubt, then, as now, bad sermons containing ill-digested results were preached, but Russell rarely, if ever, attended church and probably did not know that (unfortunately) many preachers are not very good theologians. Stebbing cited two books by members of the clergy, but one was published before *The Nature of the Physical World* and the other (not available to me) aimed primarily to reassure Calvinists that, whatever scientists said about free-will, they could continue to believe in predestination. Neither seems to be quite what Russell was talking about. At that time, a group of theologians often referred to as the 'Cambridge modernists' was influential. Scholars of very different backgrounds, they were united by their opposition to fundamentalist interpretations of Christianity and by a belief that modern knowledge, especially scientific knowledge, must be taken into account in the interpretation of Christian doctrines. Three senior Church-of-England clergy associated with this school, W. R. Inge, E. W. Barnes and C. E. Raven, different in many ways, particularly in their abilities to grasp Eddington's more ab-

stract mathematical reasoning, were amongst those most likely to be sympathetic to the openings offered by Eddington and Jeans, but in fact largely ignored them.

Of those three, Inge, then Dean of St. Paul's, had the most to say. In 1925, he contributed the closing chapter to a book edited by Joseph Needham, *Science, Religion and Reality,* to which Eddington contributed some of his earliest published remarks on the subject — anticipating ideas developed in *The Nature of the Physical World.* Inge (1925, p. 362) dismissed that chapter very briefly.

> In the last part of his book Aliotta discusses the influence of the new mathematical theories as shaking the foundations of a materialistic philosophy. I must leave this topic to those who are qualified to deal with it. It is the subject of Professor Eddington's essay which follows that of Professor Aliotta. I will only say that an outsider like myself feels a strong suspicion that the new instrument with which Einstein has presented the mathematicians is being put to uses for which it was never intended. I cannot see how a purely mathematical theory can either prove or disprove materialism. In fact, I am still unconvinced that it has much importance either for the metaphysician or the theologian.

After the appearance of *The Mysterious Universe* and *The Nature of the Physical World,* Inge (1933) published *God and the Astronomers,* a course of lecture-sermons. His own scholarly reputation rested on his studies of Plotinus, so we might suppose him to have been sympathetic towards the various forms of idealism, but he wasted little time on the astronomers' "not entirely happy incursions into metaphysics" (Inge, p. 44). His chief concern was a point on which Eddington and Jeans were in total agreement: the prediction of the heat-death of the Universe as a consequence of the second law of thermodynamics. Although, as Barrow & Tipler (1986, p. 168) point out, Inge believed that "modernist philosophy" with its doctrine of unlimited progress had more to fear from this prediction than Christianity did, I detect more subtlety, even ambivalence, in his thought than they suggest. He was, of course, committed to the belief that the Universe is dependent on God, who is not Himself dependent on anything, yet he apparently felt that God without a Universe would be in some sense incomplete, and he found it difficult to understand why God should destroy, or allow to be destroyed, something that He had created (Inge, 1933, p. 29). On p. 70, Inge asserted "Nothing that really is can ever perish." Unfortunately, E. A. Milne, the one mathematical physicist of note who, at that time, questioned the heat-death, suppressed his doubts — largely though the influence of Jeans — until they were published posthumously (Milne, 1952a, Chap. X; 1952b, pp. 164-6). Inge would, I think, have been open to modern discussions (Islam, 1977; Dyson, 1979; Barrow & Tiplet, 1986, Chap. X; Harrison, 1992) that envisage other possibilities for the 'end' of the Universe, including the indefinite continuation of intelligence. He did not share Eddington's dislike of eternal recurrence, and thought the "perpetual

continuance of the Universe" by some recurrent cycle "more in accordance with the will of God" (Inge, p. 64) than the "heat-death" would be. He also played with an idea suggested by Millikan (1931), but criticized by Jeans (1931a, b), that certain features in the energy spectrum of cosmic rays could be explained if, in remote parts of the Universe, energy could be converted back to hydrogen atoms. Inge's theology led him to consider these purely scientific ideas, and I suspect that Eddington's (1935, p. 59) quite reasonable question "Since when has the doctrine that heaven and earth shall pass away been ecclesiastically unorthodox?" was addressed to him.

If, on that point, the Quaker scientist was more orthodox than the Anglican divine, Inge might nowadays score better than Eddington on a test of scientific orthodoxy. He did not share Eddington's dislike of beginning with a bang (Inge, p. 244) and he did not believe that science could logically lead to a pure mentalist philosophy. By implication, Inge did not agree with Eddington's vision of the Universe achieving whatever could be achieved and then lapsing back into chaos, because he denied that the Universe had one infinite purpose (Inge, p. 12), although he thought that it might have a series of finite purposes. "There is, I think," Inge (p. 240) said "something derogatory to the Deity in supposing that He made this vast Universe for so paltry an end as the production of ourselves and our friends." Many people, when purpose in the Universe is discussed, jump to the conclusion that the appearance of humanity is the only conceivable purpose and (unconsciously) echo Inge's remarks. That several of today's leading cosmologists do so is testified by a number of recent published interviews (Lightman & Brawer, 1990), and some seem to regard the argument as a telling criticism of theism. Dean Inge said the same thing 60 years ago.

Eddington and E.W. Barnes present a contrast of style rather than content. Barnes was a somewhat controversial Bishop of Birmingham, remaining in that position until the early 1950s. I can recall him attracting headlines similar to those that recently surrounded the Bishop of Durham. Barnes' scholarship was not questioned, however, and it was wide-ranging, although originally he was a mathematician and had been one of Eddington's teachers at Cambridge (Douglas, 1956, p. 10). In the same year that Eddington gave his Gifford lectures at Edinburgh, Barnes began a similar course in Aberdeen, although his was not published until later (Barnes, 1933). The two books provide an amazing contrast: the eminent scientist went out of his way to make his as readable and comprehensible as possible, the Bishop made no concessions, sprinkling quite advanced mathematical formulae through the earlier part of his book. Recalling my own experience in a Gifford audience, I cannot help thinking that Barnes lost most of his. Although the book is replete with references to the scientific work of Eddington and Jeans, their philosophical speculations are not mentioned at all. This is partly a matter of timing, but the delay in publication of Barnes' book would have permitted the insertion of at least a footnote had he been as desperate for support in his apologetics as Russell would have

us believe. Moreover, Barnes (1931) had another opportunity to comment on Eddington's ideas when he contributed to a supplement of ***Nature*** (many papers in which are relevant here) devoted to a discussion of then current ideas in cosmology and their possible significance. Rather interestingly, Barnes rejected the Moulton-Chamberlain theory of the origin of the solar system by a close encounter of the Sun with another star, which Jeans espoused and Eddington thought probable, because it implied that planetary systems were very rare, and would make the appearance of mind in the physical Universe an accident. Unlike Inge, Barnes believed that there was a single purpose to the Universe — the emergence of beings capable of spiritual excellence. Barnes was careful, however, to point out that evolution might take many different courses in other planetary systems, and that human beings were not necessarily the only intelligent creatures in the Universe. He still failed to mention Eddington's arguments for the spiritual nature of ultimate reality.

The third theologian, C. E. Raven, was primarily noted for his New-Testament scholarship and his knowledge of the history of the early Church. As an amateur naturalist and ornithologist, however, he had a keen interest in biological science, studied genetics under Bateson (Dillistone, 1975, p. 54) and wrote scholarly works on the history of biology (e.g. Raven, 1942) which were the basis for the award to him of an honorary Manchester D.Sc. Like Eddington, he was interested in the relation between science and religion, and was a pacifist. Raven returned to Cambridge as Regius Professor of Divinity in 1931, and one might expect that the two men would engage in an active exchange of ideas until Eddington's death in 1944. Surprisingly, the biographer of neither mentions the other. In his own Gifford lectures, also delivered in Edinburgh, Raven (1953) cites Eddington only once in each volume, almost in passing. Raven argued that the traditional emphasis in the history of science on the development of physics, at the expense of any treatment of biology, distorted our understanding of the development of relations between science and religion (Raven, 1953, Vol. 1, pp. 7-9). In this respect Eddington was very traditionalist, at times almost equating 'science' with 'physical science'. This difference between the two men's approaches may have made contacts between them less fruitful than we would otherwise have expected. Again, however, Raven's silence about Eddington's philosophical ideas shows that he was no more desperate than Inge or Barnes for support for his beliefs.

## 7. A Modern Perspective

Eddington maintained his philosophical and religious positions until the end of his life, and his later books contain many spirited replies to his critics — although they are not always identified. Jeans retreated under pressure. *Physics and Philosophy* contains no reference to God as a pure mathematician; in that book Jeans favors belief in some sort of Hegelian Absolute Mind, rather than in a personal God. The intensity of his own religious experience closed that route to Eddington, although he was well aware that it was the natural conclu-

sion of his own arguments. I believe that his adventures into philosophy were largely an attempt to convince himself that he could do justice to both the religious and scientific sides of nature, while retaining his intellectual honesty. Those adventures led him to assert the primacy of mind or consciousness. He definitely did not hold what I understand to be the dominant modern view, that consciousness is a phenomenon that appears when matter is sufficiently highly organized — whether in an animal brain or a digital computer. If he were still alive, I believe that he would resist that view, but he was surprisingly open to the possibility of what we call artificial intelligence. The question he would have asked of a robot that was claimed to be human was (Eddington, 1935, p. 312): does seeking the truth matter to it as much as to human beings? If the answer were 'yes' he would have accepted the claim. Perhaps he believed that a positive answer would never be possible, but his attitude is reminiscent of Turing's (1950) test. Turing replaced the question 'can machines think?' with the question 'can a suitably disguised computer respond to a human questioner in such a way as to convince its interrogator that it, and not a second concealed respondent, was the human being?' Eddington was more specific about what the test question should be, and thus went to the heart of the matter. But Turing permitted the computer to 'lie', and I do not know how Eddington would have coped with that.

The problem of free-will still exercises us, and is related to the problem of the origin of the mind. It is difficult to escape the success of predictions based on scientific law, and many scientists have lapsed back into the nineteenth-century nightmare, and even seem to have a masochistic enjoyment in dreaming it. Few now see a foundation for human free-will in quantum indeterminacy; most emphasize the complete determinacy of the wave equation of a particle, pointing out that only the result of measurement is unpredictable. Even at the macroscopic level, however, motions are not so rigidly determined as Laplace, influenced by his investigations of the solar system, thought. His postulated super-intelligence could not know the past state of a closed container of gas in equilibrium, since, whatever that past state, the distribution of velocities must be Maxwellian. Chaos theory has also helped us to understand how very far-reaching the effects of very small perturbations can be, but, presumably, Laplace's super-intelligence would have been able to take this into account. Biology, however, has been transformed since Eddington's death, and he would now have to face the challenge of genetic determinism to his belief in free-will. I think he would take up the challenge, and might move in the direction suggested by Stebbing, as described in Section 6.2 above. He would face as much criticism on this topic today, however, as he did in his own time.

In some respects in fact, Eddington and Jeans might have to face even more strident criticism. Both Ingre and Joad commented that scientists were more open around 1930 (compared with, say, 1900) to philosophical and religious matters. Eddington and Jeans were apparently only the most prominent of many. Their eminence (not to mention Jean's complete financial indepen-

dence) enabled them to say things that, even then, younger people beginning their careers would have been wise not to say. The atmosphere is in some ways more hostile to such discussions today, although interest has grown in the borderline regions between science, philosophy and theology. There are now university departments and centers for the study of such interdisciplinary regions, and specialist journals to advance their interests. Systematic study of these areas that Jeans and Eddington pioneered in amateur fashion is good, but academics are all too easily tempted to talk just to each other, and the multiplication of sub-disciplines, such as 'science and religion' can also multiply the number of boundaries to be crossed. One of the refreshing things about the literature of the 1930s is its relative comprehensibility. Philosophers and theologians obviously found *Nature* of interest, and occasionally contributed to its pages. Nowadays, that journal, as it has itself documented (Hayes, 1992), is harder to understand. We need as much as ever people like Eddington and Jeans who are prepared to cross disciplinary boundaries, even at the risk of appearing foolish to experts. From the opposite side, both Inge and Barnes ventured criticisms of scientific theories for non-scientific reasons — and subsequent work has at least partly vindicated them, in that the theories they criticized (heat-death and the Moulton-Chamberlain theory of the origin of the solar system) now find much less support, even on scientific grounds. Nowadays we stress the autonomy of science and, reacting against fundamentalist criticisms, tend to reject all religiously based critiques of science. Because some churchmen have abused their privilege, however, it does not necessarily follow that scientists always have the last word about truth.

In recent years since Carter's (1974) anthropic principle re-opened discussion of ideas like Eddington's. Writers on this topic (e.g. Davies, 1982; Barrow & Tipler, 1986, pp. 224-228; Leslie 1992) fully acknowledge that Eddington's work on the fundamental constants was an important step on the road to anthropic arguments. I think that Eddington would have welcomed the recognition of the subjective elements in our knowledge of the Universe at large, but, with his strong inclination against basing belief in God on scientific theories, he would have been very cautious in what he would have tried to deduce from the anthropic principle.

Only after completing this article, did I have an opportunity to read Barrow's (1991) book *Theories of Everything: The Quest for Ultimate Explanation* which, incidentally, clearly sets Eddington's ideas in the context of modem thinking about the same issues. I note with interest that Barrow (p. 90) makes the suggestion that I have, independently, tried to substantiate, that Eddington's religious beliefs were directly related to what *he* regarded as his most important scientific work. If, indeed, Eddington's philosophical ideas and his fundamental theory were influenced by his religious experience, some will undoubtedly see that as a confirmation of the view that science and religion should not be mixed. The consensus now is that Eddington was wrong in basing free-will on quantum uncertainty, on the origin of the expansion of the

Universe, and about his fundamental theory. It almost looks as if his religion led him into scientific dead-ends. We should remember, however, that he was tackling problems, two generations ago, that are still occupying our best minds. If he saw indistinctly, it was because he was peering though the mists of time — and he may yet prove to have been more nearly right on some of these issues than even his modem critics. He knew the difficulty of conveying profound thought — whether religious or scientific — in human language, and the abbreviated quotation from Shakespeare (1600) with which he closed *The Expanding Universe* may indicate that he was as conscious as anyone of the imperfections of his attempts:

> I have had a most rare vision. I have had a dream, —past the wit of man to say what dream it was: man is but an ass, if he go about to expound this dream.... Methought I was, and methought I had, but man is but a patched fool, if he will offer to say what methought I had.... It shall be called Bottom's dream, because it hath no bottom.

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