THE SOURCES OF EDDINGTON'S PHILOSOPHY

BY

HERBERT DINGLE

D.Sc., A.R.C.S.

Professor of History & Philosophy of Science
University College, London

THE EIGHTH
ARTHUR STANLEY EDDINGTON
MEMORIAL LECTURE
2 November 1954

CAMBRIDGE
AT THE UNIVERSITY PRESS
1954

PUBLISHED BY
THE SYNDICS OF THE CAMBRIDGE UNIVERSITY PRESS

London Office: Bentley House, N.W. 1
American Branch: New York

Agents for Canada, India, and Pakistan: Macmillan

Printed in Great Britain at the University Press, Cambridge
(Brooke Crutchley, University Printer)

THE ARTHUR STANLEY EDDINGTON MEMORIAL LECTURESHIP

This Lectureship was instituted in 1947 with the intention of providing a fitting memorial to Sir Arthur Eddington, O.M., Plumian Professor of Astronomy in the University of Cambridge from 1913 to 1944.

The lectures are to deal with some aspect of contemporary scientific thought considered in its bearing on the philosophy of religion or on ethics. It is hoped that they will thus help to maintain and further Eddington's concern for relating the scientific, the philosophical and the religious methods of seeking truth and will be a means of developing that insight into the unity underlying these different methods which was his characteristic aim.

Man's rapidly increasing control over natural forces holds out prospects of material achievements that are dazzling; but unless this increased control of material power can be matched by a great moral and spiritual advance, it threatens the catastrophic breakdown of human civilization. Consequently, the need was never so urgent as now for a synthesis of the kind of understanding to be gained through various ways —scientific, philosophical and religious—of seeking truth.

The Lectureship is managed by a Board of four Trustees appointed by The Royal Society, Trinity College, Cambridge, and the Society of Friends.

LECTURES ON THIS FOUNDATION

1. Reflections on the Philosophy of Sir Arthur Eddington by A. D. RITCHIE
2. Sir Arthur Eddington: Man of Science and Mystic by L. P. JACKS
3. The Unity of Knowledge by GEORGE B. JEFFERY, F.R.S.
4. Creative Aspects of Natural Law by R. A. FISHER, F.R.S.
5. Eddington's Principle in the Philosophy of Science by Sir EDMUND WHITTAKER, F.R.S.
6. Time and Universe for the Scientific Conscience by MARTIN JOHNSON
7. Some Aspects of the Conflict between Science and Religion by H. H. PRICE
8. The Sources of Eddington's Philosophy by HERBERT DINGLE

THE SOURCES OF EDDINGTON'S PHILOSOPHY

It is all but ten years since the eponymous subject of this series of lectures laid down his labours and left to astronomy new foundations for research, to physics an enigma to solve, to philosophy a source of bewilderment and incredulity, and to the student of human mentality a fascinating field for reflexion. It is to the last two, and especially the last, of these bequests that I invite your attention this evening. As an astronomer Eddington's place is secure. Whatever the future may reveal of the constitution of the stars will be brought to our knowledge because of his pioneering efforts more than a generation ago. His fundamental physical theory, received during its gradual unfolding with an unhappy mixture of incomprehension and scepticism, is viewed with much the same feelings today, but we may be sure that the last word on this matter has not yet been said. On neither of these subjects is comment appropriate at this time, at any rate by me—in the former case because it is superfluous and in the latter because it is impossible. There remains the development of Eddington's general philosophy, and what

I hope to do is to throw what light I can on the circumstances that caused it to take the course it did.

I first made contact with the workings of Eddington's mind through his writings, and then through occasional lectures. My first meeting with him, I believe, was when as President he admitted me to Fellowship of the Royal Astronomical Society. Long afterwards I reminded him of this, and he excused himself on the ground that he didn't know what he was doing. This pleased me very much, because I had often told him that but he had never before been brought to confess it. I mention this little incident partly to show that, if we did not always see eye to eye, it was not through lack of frankness on both sides, but chiefly because I think in all seriousness that one of the most significant of Eddington's characteristics was that he didn't know what he was doing, that he had no idea—or, more correctly, a quite false idea—of what his work really implied. He was a creator of high originality, but he was a poor critic. He let his instinct guide him—and what an instinct it was!—but his attempts to rationalize it were either incomprehensible or clearly wrong. I am not going to discuss the age-old problem of the relative importance of creators and critics. You may, if you wish, call the critic

a creator *manqué* who could disappear not only with no loss to the world but with liberation of the creative spirit; or you may regard him as the interpreter who brings to the clear light of understanding what the creator achieves blindly, as the engineer comprehends the principles of which the spider, who alone can build the web, knows nothing. Let all that be as it may, the fact remains that Eddington's gift to the world consists in what he did, not in what he said he was doing. His failure to appreciate other people's achievements is evident enough in the few reviews which he reluctantly wrote when it was difficult to avoid doing so, and I believe that the same failure is no less evident in his estimate of his own work.

Why was this so? In the last resort, of course, it is useless to ask why minds are as they are. Let us accept them and be thankful, and leave to the distant future the ultimate problem of their origin and nature. But we can, I think, take a step towards a solution, and the thesis I wish to lay before you can be summarized as follows. Eddington had an exceptional capacity for understanding the background of his subject, which is very rare in those who lead its frontier activities. Consequently, when the theory of relativity burst upon the world he realized fully and with astonishing speed its profoundly revolutionary character. But he was also extremely precocious, and by the time that he realized the significance of relativity, which he tells us was in 1916, he was already thirty-four years old. His view of the nature of the scientific problem was by that time so firmly established in his mind that it was impossible, even for him, then to shake it off; and that view was incompatible with the implications of relativity. Hence all that he could do was to force the two incompatibles into an unnatural union in which the requirements of relativity, though fully accepted, were distorted to the form of a philosophy not flexible enough to receive them in their natural state. To use a metaphor which he adopted when he thought he was describing physicists in general but was really engaged in introspection, he fitted the organism of relativity into the Procrustean bed of his Victorian philosophy. In contemplating the spectacle one hardly knows which feeling prevails—sorrow at the torture or admiration at the achievement. We can imagine what the world would have gained had he been born fifteen years later, but he could hardly have accomplished a mightier work.

To make clear what I mean it is necessary to digress for a while and to consider the nature of the change which relativity demanded in our understanding of the scientific problem. And by relativity I mean what is often called the 'special'

theory of relativity, which Einstein published in 1905 but which did not impress itself on Eddington's mind until in 1916 de Sitter pointed out the astronomical consequences of the 'general' theory at which Einstein had then arrived. From a rather narrow mathematical or physical point of view the general theory is, in fact, a generalization of the special theory, for it removes from the consideration of motion the restriction to what is called 'uniformity', but so far as general principles are concerned it is the 'special' theory that contains the essence of the matter. When that theory is once understood and accepted, a generalization to motion of all kinds becomes inevitable, whether or not Einstein's happens to be the right generalization, and it is therefore to the 'special' theory that we must look for light on the fundamental change.

How fundamental that change was is still not generally realized. To the average mathematical physicist, relativity simply consists in substituting the Lorentz for the Galilean transformation of space and time measurements. The 'relativity correction' is a commonly used expression, as though it were simply a matter of putting in some small term that had previously been overlooked. But that is a very superficial view. It usually works for practical purposes, though no one has been more critical of its blind application than Eddington himself—'it is just muddle-headedness' he once complained to me, in objecting to the work of one of the leaders of theoretical physics. I am concerned now not with the question whether such blind applications are right or wrong, but only with the fact that they are blind. The simple substitution of one mathematical formula for another cannot satisfy the philosophy of science unless its necessary implications are understood; it is not sufficient merely to say that it works. Those who wish to understand the matter must ask themselves why it is the Lorentz and not the Galilean transformation that must be used, and that inevitably leads to the abandonment, not merely of the pre-relativity practices but of the pre-relativity presuppositions also.

To the Victorian physicist, as it is convenient to call him (though the source of his beliefs belongs to an earlier time), the object of science could be described very simply; it was the discovery of the nature of the external world. That world consisted obviously of pieces of matter moving about in time and space. The physicist watched its behaviour under conditions which he could control in his laboratory, and in particular he made measurements because he had learnt by experience that precise relations often existed between the results of measurements of various kinds which

were obscured when only the ordinary uncontrolled behaviour of bodies was observed. The measurements were regarded as determinations of the magnitudes of properties possessed by bodies. Thus, each piece of matter possessed a volume, a mass, a density and so on, and instruments, such as meter scales, balances, thermometers, were simply means by which the magnitudes of these properties could be ascertained. But the bodies, with their properties, existed whether you made any measurements or not. An iron bar, for instance, had a length, a mass, a temperature, a density, and many other properties before any measurement of their magnitudes had been made, and would have had them just the same if no one had ever thought of measuring them. The measurement was simply a way of finding out what was already there whether you tried to find it out or not.

The standpoint of relativity implied a complete reversal of all this. You didn't start with the iron rod complete with properties and then discover by measurement what the sizes of those properties were. You started with the measurements that you had made, and gave them names such as length, volume, mass and the rest. The difference may seem merely verbal; in fact it is vital, and goes to the very root of the philosophy of physical science.

For consider just one property—length—for simplicity. If this is an inherent property of the rod, you have simply to measure it once for all and then, provided that nothing happens to the rod, you know exactly what it is at any subsequent time. Scientists were all agreed about this; the physicist who looked on the rod as lying at rest in his laboratory, and the astronomer who looked on it as moving at $18\frac{1}{2}$ miles a second round the Sun, agreed that this length was whatever the measurement made it out to be. There was no need for each of them to measure it. The length was a property of the rod; it had nothing to do with their view of how the rod was moving.

But if you start with the measurement, and do not use the word 'length' until you have a measurement to bear it, the matter is different. The physicist has to measure the length of a stationary rod and the astronomer the length of a moving one. The recognized procedure for measuring length was quite satisfactory for the physicist, but not so clearly so for the astronomer. If his rod is moving along the measuring scale, he must be careful to read both ends of it at the same time. He has therefore to determine what positions the ends occupy at some single instant, and to his astonishment he found that by no means which he could devise could he do this. There always

remained a small measure of uncertainty. In short, there was no procedure known to physics by which the length of a moving rod could be measured.

This, of course, would not in itself have caused any dismay to the Victorian physicist. He could measure the length when the rod was regarded as stationary, and so he could know it; there was no need to repeat under difficult conditions what could be done under easy ones. But unfortunately his researches led him into a contradiction unless the length of a moving rod could be supposed to be less than that of the same stationary one. As we have seen, he could not make the measurement to check this, so he had to *assume* that it was so, that a rod which had a length l when stationary had a length smaller than l when it was moving in the direction of its length. And this he did. He could then still maintain his view that the length of the rod was a property of the world independent of the observer, but he had to suppose that it was not an invariable property, but a property whose magnitude depended on the motion of the rod.

Now this would have been all right if the motion of the rod also were a property of the world independent of the observer; that is to say, if the rod were definitely moving or stationary, quite independently of how you chose to regard it. Clearly there is no inconsistency in saying that one property of the external world depends on another. But this was impossible, for ever since the time of Galileo it had been recognized that if two bodies were in uniform relative motion, there was no objective difference at all between them which would enable you to say which was moving and which, if either, was at rest. This was fundamental to physics, to Victorian as well as twentieth-century physics, because it is enshrined in Newton's first law of motion on which the whole physical scheme is built. And, in fact, the difference between the physicist and the astronomer was not that one was contemplating a stationary and the other a relatively moving rod. They were both contemplating the same rod, in the same state, and the difference between them was simply that one wished to call that state a state of rest and the other wished to call it a state of motion. The assumption that the rod contracted when it moved therefore meant that the rod contracted when you chose to say that it moved, and if two people were in different minds the rod simultaneously had two different lengths.

This was the absurdity which relativity removed. I need not, of course, go into details here, but it will be clear, I think, that since, from the relativity point of view, you were justified in

speaking of the length of a stationary rod because you could measure it and so had something to which to give a name, so you could speak of the length of a moving rod if you defined a process of measuring it which could actually be carried out. And this definition the theory of relativity provided. It defined the length of a body *in terms of its motion*, so that it had a definite, ascertainable meaning whatever motion you supposed the body to have, and it was such that, if you supposed the body to have no motion at all, the length was just that which Victorian physics had ascribed to it as an absolute property. In that way the contradiction that had beset Victorian physics was removed.

But that meant, you see, that the whole Victorian view of physics had to be abandoned. I have spoken of length, but in fact not only length but every physical property that a body was supposed to possess had to be redefined so that its value depended on the motion which you were pleased to assign to the body.* The view that physics is the description of the character of an independent

* As special cases, a few properties (e.g. electric charge) happened to be independent of motion—invariant, as we say—but that must be regarded as irrelevant to the general point here discussed. The product of the mass and the volume of a body is invariant, but no one supposes that this has any special significance.

external world was simply no longer tenable. Physics became a description of the relations existing between the results of certain operations which you performed, and you chose for yourself what those operations should be. Physical quantities—that is to say, those things that were represented by symbols in physical equations—were not the magnitudes of objective features of the external world. They were the results of your own definitions, and only certain of the relations between them were free from your power to change them by changing your mind. This is not generally admitted even now,* yet it is inescapable by anyone who accepts the theory of relativity as genuine physics. The argument is too simple to be deniable. Every relativist will admit that if two rods, *A* and *B*, of equal length when relatively at rest, are in relative motion along their common direction, then *A* is longer or shorter than *B*, or equal to it, exactly as you please. It is therefore impossible to evade the conclusion that its length is not a property of either rod; and what is true of length is true of every other so-called physical property. Physics is therefore not the investigation of the nature of the external world.

Now Eddington saw all this with perfect clearness, and marvellously quickly. What it has taken others many years to grasp, he saw almost at once. In what I believe to be his earliest writing on the subject—his Report to the Physical Society on the new general relativity theory, which was published before the eclipse expeditions of 1919 made relativity red-hot news—he states quite clearly that length is not a property of the rod but something which we determine by a physical operation. In his semi-popular book, *Space, Time and Gravitation*, published in 1920, he states still more definitely that where the relativist differs fundamentally from the Victorian physicist is in the hypothesis that 'there is an absolute thing in nature corresponding to length' (p. 7),* and he goes on to say that 'any physical quantity, such as length, mass, force, etc., which is not a pure number, can only be defined as the result arrived at by conducting a physical experiment according to specified rules'. But the most revealing exposition of his view of the whole matter is contained in the Introduction to *The Mathematical Theory of Relativity*, first published in 1923.

I think that much of the bewilderment with which Eddington's later views were received would have been avoided if this Introduction

* E.g. see P. Epstein, *Amer. J. Phys.* **10**, 1, 203, 205 (1942), **11**, 228 (1943), and M. Born, *Phil. Quart.* **3**, 139 (1953).

* All references to Eddington's books are to the first editions.

had been studied with sufficient care, for it contains the germ from which all the rest developed. He asserts there (p. 3), and puts the statement in italics, that '*a physical quantity is defined by the series of operations and calculations of which it is the result*'. This is identical with Bridgman's outlook, expressed much later, which has become known as 'operationalism'. It contains also the essence of the contemporary 'logical positivist' thesis, although I think it is in the highest degree unlikely that Eddington had even heard of this school at that time. As is well known, the logical positivists classified all possible statements into three types: synthetic statements, that described the results of physical observations; analytic statements, which were in essence mathematical and tautological; and nonsensical statements. This same analysis, about which volumes have been written, is given in a sentence in Eddington's Introduction (p. 3), where he says that 'any attempt to describe a condition of the world otherwise [than by 'the study of physical quantities'] is either mathematical symbolism or meaningless jargon'. He did not, like the logical positivists, try to purchase precision at the cost of significance by attending only to the *language* of the description (even so, the goods have still not been delivered), but, so far as I know, no one has noticed that the root of

his philosophy is the same as that of the logical positivists.

All this is clear enough, but now comes the trouble. The logical consequence of this beginning would have been the inference that the Victorian external world could henceforth be ignored. The evidence for its existence had lain in physical observation; that would have been so obvious to a Victorian that he would hardly have thought of saying it unless questioned on the matter. If, then, the results of physical observation are not, after all, descriptions of the world but simply the consequences of performing certain operations, clearly the evidence for that world, as an object presented for study, vanishes and the only function left for the word 'world', if it is retained, is to denote the system of postulated entities that correlates the observations. In other words, the scientific problem, as seen by the Victorians, is reversed. Instead of starting with a given, unknown world and finding out its nature and character by observation, we start with observations and construct (or infer, if you prefer the word) a world to satisfy them.

But this was just the step that Eddington could not take. His Victorian conviction of the primacy of the external world was so deeply rooted that it survived the destruction of the evidence which alone could justify it. Such cases are by no means unknown in the history of science; Copernicus affords an outstanding example. If the stars move round the Earth, the fact that they all move together makes it impossible to doubt that they are fixed on a sphere, and centuries of belief in the sphere so deduced established its existence as a primary fact that could be taken as given. But if the motion of the stars is only the reflexion of the Earth's rotation, then they must *inevitably* appear to move together, and the sphere becomes a baseless hypothesis. Copernicus, although giving the motion to the Earth, nevertheless went on believing in the starry sphere because its existence was fixed so deeply in his mind that he was unaware that evidence was needed for it.

It was just the same with Eddington. Physical observation failed to reveal the world, but the world was there. What was it like? The answer could only be: we do not know; it is essentially mysterious. But he was loath to believe that there was no relation whatever between physical quantities and the world, so he made the only possible assumption; physical quantities *symbolize* the world in some way. Each of them represents a 'condition of the world'. We could, however, form no conception of the nature of any condition of the world from the corresponding physical

quantity or quantities. He gives as an illustration the two ways of expressing the remoteness of a star, by its distance and by its parallax—that is, roughly speaking, the apparent size of the Earth's orbit as seen from the star. These, he says, are alternative representations of the same condition of the world. But if you double the distance, the Earth's orbit will appear only half as great, so the parallax is halved. What, then, happens to the symbolized condition of the world; is it doubled or halved or changed in some quite different way? We do not know. The question is meaningless because the nature of the world is incomprehensible.

The situation, then, is this. Outside us is a world, which for consistency I will always call *the external world*, which is exposed to our observation. We can observe it in various ways, but they all fall into two broad classes, which we may distinguish as *metrical* and *non-metrical*. Physics is concerned only with metrical observations, i.e. with measurements, and it is, of course, only measurements that relativity has shown to be functions of our arbitrarily chosen assumption of movement. This seemed to Eddington to place them in a class apart, and it was only to metrical observations that he assigned a purely symbolical character; certain kinds of non-metrical observations he was willing to believe afforded a direct insight into the nature of the external world. He first expressed this distinction in the following terms: 'I venture to say that the division of the external world into a material world and a spiritual world is superficial, and that the deep line of cleavage is between the metrical and the non-metrical aspects of the world.'* This is a legitimate distinction, whether or not it is fundamental, but unfortunately, in a later work, he identified the realm of the metrical with science instead of with physics, and he wrote: 'The cleavage between the scientific and the extra-scientific domain of experience is, I believe, not a cleavage between the concrete and the transcendental but between the metrical and the non-metrical.'† This had the effect of placing most of biology and psychology outside science, and it has caused a great deal of unfortunate controversy. The question is merely a verbal one, it is true, but if one uses words in a way not normally accepted one must expect to be misunderstood. Some years later, when his book, *The Philosophy of Physical Science* (1939), was passing through the Press, he told me that the choice of that title in-

* *Science, Religion and Reality*, edited by J. Needham (1926), p. 200.

† *The Nature of the Physical World* (1928), p. 275.

stead of *The Philosophy of Science* was an attempt to keep me quiet. The attempt was unsuccessful, but I am glad to have rendered some slight service to the cause of clarity.

I shall return to the question of non-metrical observation of the world, but for the moment let us continue with Eddington's view of physics. Outside us, I repeat, is the inscrutable external world, and we make measurements which symbolize in some unknown way its 'conditions'. We can derive from our measurements the idea of a coherent system which at one time we would have called a description of the world but which now we must call a symbol, a metaphor, in which each element stands for, but in no way resembles, some element of the external world. On account of this detailed correspondence the physical description can be said to indicate the *structure* of the world, just as a map shows the structure of a country, though the graded intensity of colour has no resemblance at all to the variation of height as one crosses a mountain range, and a thin blue line is quite unlike the muddy liquid we may be unlucky enough to fall into. The physical description, which corresponds to the map, we may call the *physical world*, in contrast to the *external world* which is the unknown thing symbolized by it. Eddington does not always use these terms consistently,* and this is one source of his obscurity in spite of his great gift of clear expression. For instance, the word 'electron' is used indiscriminately for the physically defined entity and for its unknown counterpart in the external world. He speaks with confidence of the behaviour of electrons in his description of physical ideas—for example, in his illustration of the uncertainty principle†—and in the next breath tells us that the electron is '*something unknown...doing we don't know what*'.‡ In one case the 'electron' stands for the dot on the map, the constituent of the physical world, and in the other it stands for the populous city, the constituent of the external world.

At the risk of tediousness, let me try to make clear the distinction between a *physical quantity*, which, according to Eddington and I think quite properly, is defined by the operations of which it is the result, and what we may call a *physical object*, such as an electron. A physical quantity is anything that is represented by a symbol in a physical equation, and the symbol always stands for the result of a measurement or a group of

* In a late book he wrote: 'I usually call X the "external world", the "physical world" being limited to the structure of the external world' (*The Philosophy of Physical Science* (1939), p. 150).

† *The Nature of the Physical World*, p. 224.

‡ *Ibid.* p. 291.

results of measurements. Thus, the symbol l, standing for the length of a rod, represents a physical quantity, namely, the result of applying to the rod in question the standard procedure for measuring lengths. Some symbols are less directly related to the measuring procedure, but they are always ultimately expressible in terms of it. For instance, the symbol m, standing for the mass of an electron, does not represent the result of applying to an electron the standard procedure for measuring mass. Such a procedure would be intrinsically impossible. Yet we can, in fact, determine m and give it a numerical value, and we do so by making a lot of measurements of ordinary laboratory objects, similar in character to measurements of the length of a rod or the mass of a stone, and combining their results together in a certain way. Strictly speaking, then, we have no right to call m a mass; it is a shorthand symbol for a complicated combination of various measurements of pieces of apparatus in the laboratory. Every symbol we use, and therefore every physical quantity, can be reduced to measurement in this way, and the bare, unadorned meaning of every physical equation is simply and solely that various measurements which we make are found to be related to one another in the way expressed by the equation.

Why, then, do we call m the 'mass of an electron'? Simply because we find it convenient (indeed, our minds being what they are, practically indispensable) to form some imaginary picture of what is taking place behind the scenes, so to speak, of our visible experiment. Thus, we might pass a current of electricity (as we express it) through a vacuum tube and observe a patch of green light at a certain place on the tube. On bringing a magnet near, the patch moves to another place. We measure the change of position, the distance of the magnet, and various other things, and combine the measurements in a certain way so as to give a certain result. But then we superpose on all that an imaginary picture of invisible things called 'electrons' which travel along the tube and give it a green glow where they strike it. We imagine also what we call 'lines of magnetic force' streaming out from the magnet and deflecting the electrons so that they strike the tube at a different place. Having added this picture to the actual happenings, we find that the combination of measurements which we have made must correspond to the mass of one of the electrons if we are to maintain it consistently. We therefore write the symbol *m* for that combination and say that we have measured the mass of the electron.*

* The experiment has been somewhat simplified, but not distorted in principle.

When the same picture is applied to other experiments, we find that it fits, assuming this same mass for the electron, and we can go on adding detail to the picture to make it applicable to one experiment after another. We thus become in time so familiar with the picture that we think of our operations only in terms of it. The directly observable things and the particular measurements that we actually make recede to the back of our minds, and we suppose ourselves to be investigating directly a world of electrons, protons, photons, magnetic and electric fields, and so on, and regard that as *the physical world* which we are studying. We forget that we have ourselves invented that world in order to give a meaning to our measurements of quite other things, and speak as though we had been presented with it in the first place and had then measured its parts.

Now Eddington, as I said, understood all this perfectly well. He knew that the physical quantities were simply the results of measurements and were not properties of particles. He knew that an electron was a part of a conceptual physical world, something whose definition was wholly contained in the definitions of the measurements of other, observable, things that had made it possible consistently to conceive it. But he could not rid his mind of another world behind the physical one and symbolized by it—the external world as I have called it—in which the electron 'in itself' existed. It would have been better if he had kept the name 'electron' for the inhabitant of only one world—either the physical or the external one—and chosen a different name for its counterpart in the other world. However, he did not, so we must put up with a description in one place of what is said elsewhere to be indescribable. It represents no confusion in Eddington's own thought, and we shall, I think, understand him correctly if we picture the three distinct entities out of which his philosophy was built: first, physical quantities, which are simply the results of actual measurements, i.e. such things as ordinary measurements of lengths, volumes, masses, etc.; secondly, the physical world, which is an imaginary structure of which the physical quantities can be regarded as affording indirect measures and which comprises the ordinary entities of present-day physics—fundamental particles, fields of force, etc.; and finally, the external world, consisting of entities unknowable in themselves but of which the physical quantities are symbols and of the structure of which the physical world is a representation.

It needs but a brief reflexion on this state of affairs to make it clear that the external world

plays no part at all in the business, and could be left out without the loss of anything. De Sitter once remarked that certain masses of matter in Einstein's early model of the universe fulfilled no other purpose than to enable us to suppose them not to exist, but Eddington's external world denies us even that privilege. He will not let us suppose it not to exist. As physicists we must acknowledge it, although physics can tell us nothing about its nature and would be exactly what it is if it were not there at all. It is thus a useless encumbrance. But unfortunately it is far worse than that. In Eddington's philosophy it becomes a will o' the wisp, leading us astray and finally landing us in a bog of nescience from which no escape seems possible. Let us see this process at work in two directions; the first which I will take is his treatment of religion.

Now Eddington was a deeply religious man, and he was specially anxious to harmonize his religion with his scientific convictions. And this, indeed, would have been simple enough if he had adopted without complication the outlook which relativity had made possible in physics. I am far from saying that no points remain at issue between religion and science, but the particular problem that worried Eddington had, in fact, ceased to exist. It originated in the Victorian prejudices, and can be summarized in the following way. The external world, which is the real world and which we explore by physical investigation, has been examined from top to bottom, and it contains nothing that can be regarded as an object of religious experience, nothing that we can call God, nothing whose behaviour is not mechanically determinable, nothing worthy of worship by free, intelligent beings. Hence religion is an illusion, of the same nature as dreams and hallucinations that are universally admitted to be negligible when we undertake to describe the true scheme of things.

This argument depends for its validity on the assumption that the world outside is the primary reality, and our experience valid only if it can be traced to a source in that world. But, from the relativity point of view, experience is the primary thing and the world is constructed or inferred from experience; no statement about it is tenable that cannot be justified by experience. The reason why the Victorian world contained nothing corresponding to religious experience is then obviously because religious experience had not been taken into account in building it up. The religious man, however, has the same title to construct a world in which the source of his religious experience finds a place as the physicist has to construct a world in which the source of his sensory experience finds

a place. In the present state of knowledge it may be—indeed, must be—quite a different world from the physical world, but that is merely a sign of the immaturity of our studies. At one time the sources of our thermal experiences—heat, temperature, entropy—were quite distinct from the sources of mechanical experiences—mass, force, space, time—but we now picture a world, a 'thermodynamic' world, in which a single set of concepts does duty for both. We are therefore clearly not entitled to grant the world of the religious mystic any smaller degree of 'reality' or 'significance' or 'validity', or whatever word for ultimate importance you prefer, than the world of the physicist. Both may, and probably will, be modified as physics and theology advance, until they finally unite, but in the meantime they are on the same basic footing.

All this Eddington accepted. 'We have to build the spiritual world out of symbols taken from our own personality,' he wrote,* 'as we build the scientific world out of the symbols of the mathematician.' And that is really all there is to be said about it. There is scope for discussion, of course, as to what description of the 'spiritual world' most properly fits the facts, but that can be left to the theologian; it is quite independent of anything that the physicist may find or do. 'We do not

* *Science and the Unseen World* (1929), p. 50.

ask', says Eddington,* 'whether philosophy can justify such an outlook [the mystical outlook] on nature. Rather our system of philosophy is itself on trial; it must stand or fall according as it is broad enough to find room for this experience as an element of life.' But, having asserted that we do not ask such a question, he immediately devotes some twenty-five pages to the answering of it. And the reason why he does so is that the old Victorian external world, though it had clearly given up the ghost, continued to dangle its corpse before his eyes, and he could not be satisfied until he had found there the fossilized remains of a real Victorian Great First Cause. 'We want an assurance that the soul in reaching out to the unseen world is not following an illusion', he writes;† i.e. we want a philosophical justification for that which we have already realized needs none. 'Feeling that there must be more behind...', he goes on,‡ and proceeds to establish the proposition that the external world does indeed contain something 'real' which is apprehensible in spiritual experience—or at least that no one can prove that it doesn't.

This shows, I think, clearly enough the character of the bedevilment of Eddington's philosophy by

* *Science and the Unseen World* (1929), p. 29.
† *Ibid.* p. 42. ‡ *Ibid.* p. 45.

his inherent predispositions. It was not that they falsified his vision of the new revelation—that was accurate enough—but that they diverted his attention from it towards dead problems, complicating his description of what he saw and confusing the minds of his readers who could not be expected to understand a conflict of which he himself was not conscious. They forced him to look for 'more behind', when the essence of the matter was not behind but in front, and led him at last to banish the roots of religion to the world of the physically unknowable instead of recognizing them where he really knew they were—in that which is known more immediately than any external or physical or spiritual world, in experience itself:

> O world unknowable, we know thee,
> Inapprehensible, we clutch thee.

The same complication can be seen in his purely physical philosophy; for my second example I will consider his tussle with time. There are, of course, some very difficult problems connected with time, and the chief contribution that relativity has made to their solution is to show us clearly that previously we had used the same word for at least two different things: first, the time of our own experience, which appears to be inseparable from consciousness itself, and second, the time that we measure in physics, which is a definable concept just like that of space or mass. Relativity distinguished these two things, showing that the former had simply to be accepted as something to which our constructed or inferred physical world had necessarily to conform, while the latter was essentially a part of that world and could be modified and redefined *ad lib.* to meet the demands of experience in ways that would formerly have been thought absurd. Eddington again comprehended this with a completeness and a speed that are really astonishing, but what did he make of it? Instead of simply recognizing the distinction he had immediately to place some single entity called 'time' in the unknowable external world, and then to plague himself with the problem of how it made a 'dual entry into our consciousness'.* Its 'real nature', of course, was quite inapprehensible, but since, unlike space, it is represented by two types of symbol, there must be some relation between these two types arising from the fact that they symbolized the same thing. After much searching he found a relation. Entropy, which is a physical quantity, measured in terms of 'physical time' among other things, had the characteristic of the 'time of consciousness' that it always went in one direction. Here, said Eddington, is the connexion.

* *The Nature of the Physical World*, p. 91.

Entropy in some way partakes of both symbolical appearance and the real unknowable time. In physics pure and simple it is one of the ordinary quantities that represent 'conditions of the world', of the same nature as heat and temperature. But it also belongs to the non-metrical concepts, such as beauty and melody,* and so it acts as a sort of link between physics and aesthetics.

I do not think that anyone but Eddington would have had the amazing combination of courage, perverted outlook and persuasive skill necessary to advance such an utterly fantastic notion as this. There have been some remarkable theories of aesthetics, but I do not know of any that has ventured to call on entropy to help it out of its difficulties. Moreover, it was not long after this pronouncement was made that the discovery of the expansion of the universe, which he fully accepted and which his own philosophy made a necessary and not an accidental phenomenon, provided an equally good example of a physical process showing a one-way direction in time, and by the same token this also should have found a place in aesthetics. I am not aware, however, that he ventured to make this claim, and indeed even his effrontery would hardly have been equal to such an outrage. His only comment, so far as

* *Ibid.* p. 105.

I know, was that the expansion of the universe provided only a large-scale criterion of the direction of time and that 'the position of entropy as the unique *local signpost* remains unaffected'.* This, it may be noted, is not true. In the last resort, entropy provides a signpost only for a closed system, and since it is impossible to screen off gravitational action, there is no strictly 'closed system' except the whole universe. Moreover, even if the distinction were a real one it is difficult to see what the scale of the phenomenon has to do with the matter. But Eddington's prejudice was so strong that he could not shake off this weird interpretation of entropy, and he even looked forward 'in the next few years' to the discovery of some hitherto unknown relation between the expansion of the universe and the second law of thermodynamics. I am not aware that this has yet shown itself. But there is another side to the matter, and when we fully realize his problem we hardly know which feeling is the stronger, contempt for his conclusion or admiration for his achievement. We need to place ourselves in his position to appreciate the magnitude of his success. For what he had to do was to reconcile the existence of the Victorian external world with the destruction by relativity of all evidence for it, and

* *New Pathways in Science* (1935), pp. 67–8.

he did it. He could neither deny the one nor reject the other. There is an old riddle: what happens when an irresistible force meets an immovable obstacle? The answer is now available: it is Eddington's philosophy.

It would be a fascinating task to follow the development of his general ideas from their first considered expression* to their latest form, but space prevents this, and I will limit myself to two aspects: his treatment of non-metrical experiences and his conclusion that the whole of physical law is potentially deducible by reason without recourse to experience. It will be remembered that, in Eddington's view, the fundamental cleavage in the external world was not between the material and the spiritual, but between the metrical and the non-metrical aspects of it. We must first of all understand this distinction, which is not merely the giving of different names to already recognized dissimilarities, but a radically different classification. It is customary to regard such things as chemistry, cookery, sport as pertaining to the material side of things, and art, music, love, religion as wholly spiritual. Eddington rejected this contrast, and divided each of them into a metrical and a non-metrical element. He saw more affinity between the metrical aspects of, say,

* *Science, Religion and Reality*, pp. 187–218.

chemistry and music, than between the metrical and non-metrical aspects of either. The reason, I think, is clear. Before the coming of relativity his Victorian external world was something which sense observation revealed to him, and, like others, he believed that scientific discovery was making its character known. But relativity changed all that. All measures were now dependent on the motion of the observer, and the motion of the observer was not an objective thing, but something that could be assigned quite arbitrarily. Consequently, all measures became arbitrary, and the only things about them that could be called objective were certain mathematical relations. These told you only the *structure* of the external world, nothing at all about its *nature*. Consequently, all metrical investigation led only to a physical world, not to the real external world—that is, to a world which, having the same structure as the external world, revealed it only symbolically. The real nature of the external world was inaccessible by metrical investigation.

But this did not necessarily apply to non-metrical investigation. Relativity said nothing at all about the activities—or at any rate the essential activities—of the artist, the theologian, the biologist. There was therefore no compulsion to give up the belief that these inquirers were

actually getting some knowledge of the real nature of the external world. There was equally, of course, no evidence in favour of such a belief. It is, to put it mildly, not obvious that what the artist, the theologian and the biologist reveal is a part of something of which another part has the structure shown by physical theory. However, they do reveal something, and since nothing that exists can possibly be unrelated to the great reality of the external world, what else can be said about them than that in some way they give us an insight into its nature? 'The suggestion is', he wrote,* 'that when we succeed in making progress with the study of the objective† world, the result will be very different from present-day physics, and that there is no particular reason to expect that it will be called physics. We have spoken of this as a development in the future; but may it not have occurred already? It seems to me that the "enlarged" physics which is to include the objective as well as the subjective is just *science*; and the objective, which has no reason to conform to the pattern of systematization that

* *The Philosophy of Physical Science*, pp. 68–9.

† Subjective, in Eddington's sense of the word, is that which 'depends on the sensory and intellectual equipment which is our means of acquiring observational knowledge' (*Philosophy of Physical Science*, p. 17). Objective is therefore that which is independent of such equipment.

distinguishes present-day physics, is to be found in the non-physical part of science. We should look for it in the part of biology (if any) which is not covered by biophysics; in the part of psychology which is not covered by psychophysics; and perhaps in the part of theology which is not covered by theophysics. The purely objective sources of the objective element in our observational knowledge have already been named; they are *life*, *consciousness*, *spirit*. We reach then the position of idealist, as opposed to materialist, philosophy. The purely objective world is the spiritual world; and the material world is subjective in the sense of selective subjectivism.'

It is not the least of Eddington's peculiarities that he succeeded in detaching biology from physics and grouping it with theology; but again, in his unique situation, what was he to do? His fundamental cleavage between the metrical and the non-metrical was forced on him by the impact of relativity on the unshakeable conviction that behind all knowledge, and yet related to all knowledge, was the external world. All measurement, whether of dead or living, of material or spiritual things, gave but symbolic knowledge—knowledge of the *structure* of that world. What could other knowledge be but knowledge of its *nature*? He could not deny that biologists had dis-

covered something, and he was unwilling to believe that religious experience had no 'real' origin, so the biologist and the theologian had alike to be providing information about the one objective world which was hidden from the metrical physicist.

We may pause once more to see how unnecessary is this denial of the common character of all science which appears to most of us to be an obvious fact. If we accept the simple, direct statement of the scientific problem—that it is the rational correlation of experience—then physics and biology differ only in the kinds of experience with which they are concerned. The physicist correlates the artificial experiences which he produces in the laboratory, which are represented by numbers or 'pointer readings', and the biologist certain of those less artificial ones which cannot be so represented. The one creates what may be called the physical world, consisting at the present time of fundamental particles, wave functions, etc., and the other what may be called—though it less often is—the biological world, containing evolutionary development, heredity and the like. The two worlds are distinct at present, but may be expected, with the continual modification that progress always brings about in scientific conceptions, to merge ultimately into a common world, which will, however, not be a primary entity revealing or concealing its character through experience, but a rational expression of the relatedness of experience, experience alone being the primary entity.

Eddington could not bring himself to take this simple view because of his obsession with the external world. It is true that in later life he grudgingly admitted that he had done so with respect to physics. 'I accept the statement' [that science is the rational correlation of experience], he wrote in 1939,* 'provided that "science" is understood to mean "physics". It has taken me nearly twenty years to accept it; but by steady mastication during that period I have managed to swallow it all down bit by bit.' But he hadn't, and in fact he couldn't without vitiating much of the book which he was then writing. The very words he uses show the unreality of the admission. The statement is not one that can be swallowed bit by bit; you swallow it whole or not at all, because it does not consist of parts. What I think he meant was that he had been trying for twenty years to find reasons for rejecting it, and, having failed, had abandoned the effort.

Once admit, however, that the biologist, the psychologist and the theologian obtain a direct

* *The Philosophy of Physical Science*, p. 185.

insight into the nature of the external world which the physicist apprehends only symbolically, and a limitless field of uncontrolled speculation is open for you to sport in. That is the danger of words and phrases representing entities which are unknowable; they invite you to attach to them ideas difficult otherwise to fit into your scheme of things, and to believe that in so doing you have done something profound. Satan finds some mischief still for idle words to do. Something has to be said about 'life, consciousness, spirit', because they do stand, clearly or obscurely, for something in our experience that is not studied by physics. The 'nature of the external world' is a phrase waiting for a content, and these are entities waiting to be placed in the external world. What could be simpler than to bring them together and to regard the external world as having the nature of 'life, consciousness, spirit'? The temptation was irresistible, and Eddington fell.

There is an example in history that should have shown him the red light. There are certain resemblances, as Eddington himself noted, between his philosophy and that of Kant. In particular, just as Eddington placed behind the physical world the inscrutable external world, so Kant placed behind all appearances the inscrutable 'thing in itself'. He was clear-sighted enough to know that he could not scrutinize the inscrutable, but his successors were not. Fichte was the first to think he could do the impossible, and he, in effect, identified the 'thing in itself' with the ego; the unknowable something behind the things observed was that which observed. Furthermore, he foisted this monstrous notion on Kant himself. Kant, then an old man, was not long and was not uncertain in his repudiation of it, whereupon Fichte, undismayed, took on the idea for himself; if Kant would not acknowledge this philosophy, he would claim it as his own. The subsequent history of German idealism should have been an awful warning to a scientist, of all people, not to leave unknowables lying about.

Eddington became his own Fichte. The mysterious nature of the external world he identified with consciousness, which was perilously like the ego. But there was a difference, for he was not prepared to say that it was consciousness that was represented symbolically by the entities of the physical world. Instead he divided the external world into two parts, one called 'subjective' and the other 'objective'. It was the objective part only that was of the nature of 'life, consciousness, spirit', and of this we had direct knowledge through non-metrical investigation. It had 'no reason to conform to the pattern of systematization that distinguishes pre-

sent-day physics'. The nature of the subjective part remained inscrutable, for physical investigation, which was our only way of approaching it, gave us only its structure. If Eddington's philosophy were in danger of becoming as influential as Kant's, it would be safe to say that before long this distinction would be eliminated, and the physical world would be hailed as being spiritual in nature. Every physical concept would be paired with the biological or psychological concept which it symbolized. The electron would perhaps become the structure of the gene and the wave function that of the id. Fortunately, this is unlikely to happen, but the notion as it stands is sufficiently bizarre. Why one part of the external world should expose itself freely to our inspection while another modestly hides behind an impenetrable symbol is a problem even worse than that which the philosophy is intended to solve. If this is the end of our pilgrimage we might as well not have started.

I come now to that aspect of Eddington's philosophy which has probably caused more misgiving than any other and which he seems to have regarded as the culminating point of the whole thing; I mean the conclusion that the laws of physics are derivable by pure reason. This, I think, was first expressed in its completed form at the end of *The Relativity Theory of Protons and Electrons*, where he says:* 'Unless the structure of the nucleus has a surprise in store for us, the conclusion seems plain—there is nothing in the whole system of laws of physics that cannot be deduced unambiguously from epistemological considerations. An intelligence, unacquainted with our universe, but acquainted with the system of thought by which the human mind interprets to itself the content of its sensory experience, should be able to attain all the knowledge of physics that we have attained by experiment. He would not deduce the particular events and objects of our experience, but he would deduce the generalizations we have based on them. For example, he would infer the existence and properties of radium, but not the dimensions of the earth.'

Let us note at the beginning that he distinguishes sharply between the *laws* of physics and the *actual entities* among which we find ourselves and which obey those laws. This is important, because he has sometimes been unjustly charged with supposing that the whole of our experience could have been predicted by a perfect reasoner, whereas in fact he supposed that none of it

* *The Relativity Theory of Protons and Electrons* (1936), p. 327.

could.* The laws of physics characterize the behaviour of *any conceivable* physical world, and therefore tell you nothing at all about which of the conceivable ones is the actual one; for knowledge of that we must depend on experience. This he

* I think I should here add a comment on modern criticism which is particularly apposite to the present subject. While it is the duty of every writer to express his ideas as clearly as he can and to ensure that each sentence is literally as well as in probable effect accurate—even, where possible, when it is removed from its context—it is no less the duty of every reader to try to ascertain the ideas which the author is expressing and to refrain from analysing the defects of particular sentences as though that constituted a refutation of the author's thesis. The superior writer knows so well what he wants to say that he is particularly apt to overlook possible misinterpretations of his remarks by those who are dependent on those remarks for their knowledge of his meaning, and it is therefore necessary, when a reader finds an inconsistency between two separated passages, that he should make the effort to form a balanced judgement of the author's intention and criticize that rather than the faulty expression of it. This, as I say, is particularly important when reading Eddington because, as it is the main purpose of this lecture to substantiate, his unfortunate point of view made exceedingly difficult and complicated what to most of us is fairly straightforward (see *The Observatory*, **63**, pp. 20–21 (1940)), and he was therefore exceptionally liable to make misleading statements. We owe it to him, and to ourselves if we wish to benefit from his unusual insight, to take his work as a whole, in its historical development, and to arrive at the essence of his contribution to thought. I do not claim to have been myself guiltless in this respect.

maintained from his earliest* to his latest† writings on this subject, and it is certainly not his fault that it is not fully understood. But his actual claim, that the laws of physics—which he freely admitted had in fact been derived by generalization from the facts of experience—could have been foreseen and are inherent in the procedure by which we generalize, is sufficiently startling and demands the closest examination before judgement is passed on it. This it has not always received.

In the first place we must note that we are now concerned entirely with the physical world and not at all with the external world that lies behind it. (I have already alluded to Eddington's lapses from consistency in the use of terms, and there are occasional passages in his writings that seem to bring the external world into the matter. I am satisfied, however, that that was not his intention.) He is therefore not claiming that we could know anything about the external world by the unaided reason. The objection may be raised that if the physical world is (or has) the structure of the external world, then precognition of it must be

* *Science, Religion and Reality*, p. 210.

† *The Philosophy of Physical Science*, p. 217. A passage in his posthumous work, *Fundamental Theory* (1946), p. 31, may seem to contradict this, but careful reading shows, I think, that it does not do so.

at any rate partial precognition of the external world, for even structure is an essential characteristic. That is true, but here we must make a further analysis and distinguish the physical world, which is the structure of the external world, from *our idea* of the physical world at some particular time during the development of physics. What Eddington is talking about in this connexion is *our present knowledge* of the physical world, and he makes it clear that he does not assume that that knowledge is necessarily true.* It will make for clarity to call this subject of discussion the *apparent* physical world; it is our present idea of the true character of the physical world, the system of laws of nature which at present constitute the most generalized achievements of theoretical physics. It must be taken as a whole, and not in separated parts such as the law of gravitation, the laws of the electromagnetic field, etc.† Eddington claimed to have harmonized the two great divisions of present-day physics—relativity and quantum theory—sufficiently to enable us to regard physics as a unified subject, and it is the present formulation of the connected system of laws covering that subject that is the apparent physical universe which he claimed could be constructed by pure reason.

* *The Philosophy of Physical Science*, pp. 2–3.

† See *Nature, Lond.*, **148**, p. 342 (1941).

He not only claimed that it could be; he claimed that he had so constructed it. To analyse this claim would be, of course, to follow through the abstruse mathematical calculations that form the substance of his books, *The Relativity Theory of Protons and Electrons* and *Fundamental Theory*. This would be out of the question here, even if I were able to do it. What we can do, however, is to try to understand fully what it is that he believed he had done, and possibly to pass judgement on it from very general considerations. We note, then, that he regarded the laws of physics, by virtue of their rational origin, as being compulsory, universal and exact,* in contrast to the contingent, partial and approximate quality which must characterize laws having only an empirical justification. At the same time, however, he admitted that the final Court of Appeal with regard to all the conclusions of physics was observation and that 'every item of physical knowledge is of a form which might be submitted to the Court. It must be such that we can specify (although it may be impracticable to carry out) an observational procedure which would decide whether it is true or not. Clearly a statement cannot be tested by observation unless it is an assertion about the results of observation. *Every item of physical*

* *Philosophy of Physical Science*, p. 45.

knowledge must therefore be an assertion of what has been or would be the result of carrying out a specified observational procedure.'* Taken together, these claims mean that every physical observation must accord with the requirements of the rationally established laws, so that if the laws prescribe that Jupiter shall be in such and such a position at six o'clock tomorrow evening, Jupiter must be there at that time.

But now an objection immediately suggests itself. Suppose we look in that direction at six o'clock and do not see Jupiter there. Then we have submitted the case to the final Court of Appeal—observation—and it has decided against the law. How, then, can the law be compulsory? There are two answers to this. In the first place, although the law is exact, what it predicts is not certainty but *probability* of observation; it says that the probability that a specified event will happen must be exactly so and so, and if the event does not happen, the law is not thereby violated. But in such a case as this of Jupiter, the probability would be so exceedingly great that a departure from the expected place would be assigned not to this cause but to another, which we may express as follows. The laws of physics, being derived by pure reason, relate only to entities which have been postulated,

* *Ibid.* pp. 9–10. Eddington's italics.

not to those which have been observed. Consequently, our supposition, 'if the laws prescribe that Jupiter shall be in such and such a position at six o'clock tomorrow evening', is a false one. The laws cannot possibly prescribe anything about Jupiter if by Jupiter we mean the body which astronomers observe and call by that name, because they refer only to the behaviour of entities which might exist but do not necessarily do so. When we apply them to the objects we observe we must ourselves identify each such object with one of the possible entities to which the laws relate. It is only when the identification is made correctly that the observed object must behave in the prescribed way. If, then, Jupiter does not follow the prediction, we must ascribe its failure to a false identification. This need not be simply a false identification of Jupiter with a particular postulated entity. Any false identification or lack of identification between postulated and observed entities in the whole observable universe might account for the discrepancy. In this particular case, the probable explanation would be that, to use ordinary language, an undiscovered body somewhere in the Solar System would be disturbing Jupiter, or, to use Eddington's language, a postulated possible particle at some other point in space-time had been supposed to have no corre-

sponding observable object, whereas, in fact, it had one. Taking this into account, observation would be found to confirm the law.

It is clear that, startling as the claim is at first sight, it is not at all easy to show it to be false. We have, in fact, an actual example in the history of science of this kind of occurrence. The planet Uranus appeared to be violating Newton's law of gravitation, but the existence of another planet, Neptune, was assumed and later verified by observation. The law stood up to the test in exactly the way supposed by Eddington. But we have another instance of a planet—Mercury—which also departed from its expected path, and in that case it was the law that was abandoned, Newton's law of gravitation giving place to Einstein's. That was at a stage when physical law had not reached the generality now attained. Newton's law was incapable of being unified with the other laws of physics, such as those of electromagnetic theory and of optics, and Eddington would not have claimed that it was epistemological, i.e. a necessary consequence of our way of approaching our problems. What his thesis amounts to is that, in the present advanced state of knowledge, any departure from expectation that you care to imagine might take place, but the explanation of the departure will then be found to be not that the law which created the expectation was wrong but that the system of objects obeying the law was wrongly selected.

The paradoxical conclusion is therefore reached that Eddington's assertion concerning the epistemological character and inviolability of the present scheme of physical law is not that experience is controlled by reason but rather the reverse—that it is entirely independent of reason. Any imaginable event may occur without breaking the laws because the possibilities allowed by the laws are so wide that any imaginable occurrence must fall within them. An analogy might make the point clearer. Suppose you are presented with a large number of different entities of widely varying character, and you want to find the most general laws that they exhibit. After some research you may discover that they can all be grouped under five different headings, namely, solids, liquids, gases, metrical concepts such as velocities and separated durations of time, and non-metrical concepts such as ideas and jokes. This could not have been foreseen; it required observation to bring it to light. You proceed further, and find a still more general fact. The first three of these groups can be classed together as gravitating things, and the last two as non-gravitating things, so that you can say that there

are only two fundamentally distinct classes, which you may call 'material' and 'mental'. This again could not have been foreseen or discovered in any way but by examination of the entities. But now finally you realize that there is something that is true of all of them, without exception; they are enumerable and obey the laws of simple arithmetic. If you count out any number of them, and add any other arbitrarily chosen set, you find that the total number of entities you obtain will be altogether independent of the particular individuals you happen to select. At last you have reached a perfectly general law. But the penalty you pay for this success is that you sacrifice all knowledge of the entities with which you were presented. The laws of arithmetic are derivable epistemologically, and could have been arrived at before you began to study the data before you. No matter what those data may have been, they would still have obeyed the laws of arithmetic, so that your perfectly general law is quite unaffected by anything that anyone browsing among the entities might discover. The law was in fact discovered by experience, but it could have been discovered by someone ignorant of the fact that the set of entities existed.

That is the situation in physics as Eddington saw it. We must not forget his proviso that the nucleus may have a surprise in store for us, but, assuming without prejudice that it has not, he regarded the present scheme of physical law as of the same character as the final generalization in our analogy.

Two questions arise out of all this. First, supposing all Eddington's calculations to be valid, has he in fact shown that the fundamental laws of physics are logical necessities which could have been reached without any experience of the world from whose characteristics they have actually been deduced? The answer, I think, is unquestionably, no. In my example I described the laws of arithmetic as epistemological laws, meaning by that, as Eddington did, that they are derivable by pure reason from certain postulates. So long as those postulates are not logically incompatible with one another they may be freely chosen, and ordinary arithmetic is simply the set of conclusions that must follow from one particular choice. Certain things are defined and called 'numbers', and then their relations with one another must necessarily be what they are, just as, in Euclidean geometry, certain things are defined and called 'straight lines', 'angles', etc., and then the successive propositions necessarily follow. But now, what determines the choice of the original postulates or definitions? At one time it was thought that, so to

speak, they necessarily arose in our consciousness, that we could not evade them or choose any others, and that, further, anything that we found in nature—i.e. anything that we experienced—had necessarily to exemplify the conclusions drawn from them. For example, the sum of the three angles of any naturally occurring triangle had to be equal to two right angles, and the sum of 6 things and 6 things had to be equal to 12 things whatever the things might be.

We know now that that was an error. Other geometries than Euclid's, starting from different postulates and reaching different conclusions, have been constructed, and we cannot say exactly what the sum of the three angles of a material triangle will be without measuring them to see. Similarly, we have Boolean and other queer algebras in which the ordinary laws of addition and subtraction do not hold, because those algebras proceed from original postulates other than numbers, and again we cannot say without trial that any naturally occurring system of entities will obey the arithmetical laws rather than these. In the example I chose just now they happened to do so. But suppose the entities had included durations of time that were not separated. The general, universal law would then not have been found to be true. I am told, for instance, that there are realms of experience in which, as the expression goes, the sentences run concurrently. In that case, 6 months plus 6 months equals 6 months. Or again, if we had attempted to apply the law to the measures instead of the mere enumeration of velocities, we would have found it to fail. Until early in this century it was believed that, owing to the complete universality of the laws of arithmetic, we could measure speed as we liked and still apply the laws to the results. We now know, however, that if we measure it in the customary way—namely, as so many units of space covered in one unit of time—then if we add a velocity u to a body moving with velocity v, the resulting velocity is not $u+v$ but something smaller. There are numerous other examples of the same kind.

It follows, then, that our general law did, after all, tell us something about the system of entities we were presented with. We could not have predicted it, but only by actual trial could we have found that the entities obeyed it. If we had been assured that each entity could have been represented unambiguously by the number 1, then indeed we could have predicted a great deal about their mutual relations which would have been universal, compulsory and exact, but there is nothing in the nature of things or in the nature of our minds to give us that assurance. We

must discover it by experience, and by experience alone.

The effect of this on Eddington's claim is of the highest importance. Let us continue to suppose that his mathematics is impeccable and that the agreements he obtained between calculated and observed values of physical constants are valid; it still does not follow that the predictions are epistemological in the strictest sense. Before his calculations began he had to adopt certain postulates, and those postulates might have been other than they were. His justification for choosing them could only have been an empirical one. And, indeed, he was well aware of this. He cannot be reproached for not pointing it out, though I think that the extent to which, having done so, he ignored it in his more revolutionary statements has led to unnecessary misconceptions. 'To the question', he wrote,* 'whether it [epistemological knowledge] can be regarded as independent of observational experience altogether, we must, I think, answer no. A person without observational experience at all, and without that indirect knowledge of observational experience which he might gain by communication with his fellows, could not possibly attach meaning to the terms in which epistemological knowledge, like other

* *The Philosophy of Physical Science*, pp. 24–5.

physical knowledge, is expressed; and it would be impossible to put it into any other form which would have a meaning for him. We must grant then that the deduction of a law of nature from epistemological considerations implies antecedent observational experience.'

He went further, and tried to enumerate the particular elements of the epistemological scheme which were taken from experience; he called them 'forms of thought'.* For example, there is the practice of describing the physical world as a world, i.e. of expressing all our knowledge as knowledge of one connected system. Again, there is the concept of analysis, i.e. the conception of the whole as divisible into parts which are permanent and precisely like one another; in effect, this means that we describe the physical world in terms of fundamental particles. He made no attempt at an exhaustive enumeration, but even this brief statement is sufficient to show how heavily he drew on experience before he began his epistemological deductions. The decision to describe the physical world in terms of identical particles, for instance, is anything but necessary. So late as the end of the nineteenth century there was a prominent school of thought that advocated what was called *energetics*, which was an endeavour to describe the

* *The Philosophy of Physical Science*, Chapter VIII.

physical world without using the concept of atoms and in terms only of concepts of continuity. It has died out because the atomic concept has shown itself able to deal with phenomena that would otherwise appear to be intractable, but that is entirely the result of experience, and no one can say with certainty that with further experience we shall not turn again from concepts of quanta to those of continuity. Granting Eddington's achievements everything he claimed for them, therefore, it still remains true that at bottom our knowledge rests on experience, and experience alone can tell us what particular logical form describes its interrelations.

But when all that has been said, the other question must be faced: did he in fact establish his claim to have derived a comprehensive system of physical law from postulates owing nothing to experience beyond the very general 'forms of thought' which he acknowledged? This question has not yet been finally answered, yet it is of the greatest importance that it should be. It is certain that physical law as most physicists understand it has not reached the final generalization, for the great division between field and quantum conceptions has not been bridged. Eddington, however, believed that he had bridged it, and if so his contribution to physics, as distinct from the philosophy of physics, is immense. Unfortunately, the testing of his work is extremely difficult. The nature of the mathematics involved is such that very few persons are competent to criticize it, and for them the labour would be very great. I understand that there are errors in his calculations, and certainly at least one of the observationally determined quantities whose agreement with the theoretical values is essential to success has been changed since his death. The whole question is in a very unsatisfactory state, but there can be no doubt that, even when we have reduced his claims to the lowest possible content, they are so momentous that no effort should be spared to reach a definitive evaluation of them.

Returning to the less technical side of the matter, we may derive some satisfaction from the conclusion that, after all, what he is proposing is no revolution in science, but rather the relentless pursuit of the original ideal towards a culminating point. If science originates in experience and aims at constructing a logically coherent system that will express all its interrelations, it is only to be expected that the appeal to experience will become less and less prominent as the logical system grows, finally concentrating itself into a single question when the system is complete. But throughout the process the aim is the same. Galileo's view, though

we may abandon the picturesque form of its expression, is still that of Eddingtonian science: 'I incline to think that Nature first made the things themselves as she best liked, and afterwards framed the reason of man capable of conceiving (though not without great pains) some part of her secrets.'

But then our old enigma arises once more: how could Eddington make so orthodox a procedure wear so heterodox a look? We cannot directly blame the external world this time, since we are wholly on this side of that phantom, but I think it is essentially the same perversity of outlook, forcing him to describe what we do in the reverse order to that which we actually take, that is responsible for the anomaly. When we examine our procedure in science and state it in the most direct way, we realize that it is simply this. We make observations—pointer-readings, since we are now concerned with physics alone—and represent them by symbols, and we find that they are related with one another in a certain way. We then construct a logical system with postulates so chosen that their implications agree with the relations found to hold between the observations. And that is all. As an aid to progress we try to give the logical system a picturable form, calling its elements the properties of particles or waves or something else that will suggest a way of finding further relations, but that is a means of research, not a discovery, and we freely change the picture as we advance. Everything essential in physics can be described, and all its implications deduced and their significance fully evaluated, in terms of this description.

By contrast, let us now see the same process as conceived by Eddington. We begin, not with what we do but with what we imagine must be 'true'. Standing remote in the background is the awful Reality of the external world, mysterious, inaccessible. In front is the physical world which presents, but only symbolically, the structure of a part of it. Of this we can attain something called knowledge which, though its name suggests subjectivity, is in effect an objective entity that stands in front of the physical world of which it is a representation. But not a precise representation. It shows us only the probable character of the physical world, and this is what is depicted in the equations of physics. We have still to reach these equations, and before us there is a road called experience. We have for centuries been toiling painfully along this road, and at last we have reached the fundamental equations, so that now we know all that theoretical physics can tell us, namely, the probable character of the structure of part of Reality. But on looking behind we can see that there is another road called reason which also

comes out at the same equations. We follow it back, and at the far end we find ourselves again in the land of pure ignorance from which we began our journey. We could therefore have reached the same goal if we had proceeded that way instead of by experience. But we see also that from this point an indefinitely large number of other roads go out. They are all marked reason, and there is nothing in the roads themselves to tell us which one leads to the same destination as the road of experience. There is, however, one way by which we can discover this. If we compare them with the road of experience we see that one, and only one, is parallel to it. If, then, we follow that, we shall get to the equations of physics and so learn the probable state of the symbolical structure of the external world without calling on experience at all. That is the final conclusion that Eddington reached.

When this amazing conception is laid bare, we can only pause before it in mute wonder. How is it possible, we eventually ask, that what is in essence so simple can be twisted into a form so intricate? I do not think an answer can be given on any supposition other than that which I have indicated, that the description had to grant full recognition to both the Victorian external world, from which all life had gone, and the necessary implications of the relativity theory. The practical difficulties of thinking in terms of this labyrinth are obvious enough, but what is of far greater moment is the essentially wrong representation which it gives of the place of experience in science. Instead of showing experience as the origin and centre of interest of the whole effort, it leads us to regard it as merely the lesser of two alternative means towards a greater end. Intent on preserving what it misconceives as the 'Truth', it has lost the 'Way' and the 'Life'. Relativity was not so much a revolution in science as a purification; it recalled physics from its traffic with metaphysical notions to its true concern with what we actually observe. By its acknowledgement of the final authority and inviolability of experience it opened the possibility, for the first time in modern history, of granting full licence to science to pursue the rational correlation of experience without danger of conflict with art, religion and other forms of philosophy so long as they also assert nothing that is not grounded in experience. In Eddington's philosophy of science that inestimable clarification is obscured. The essence of the matter is there, but instead of being illuminated it is shrouded in mist.

That is one aspect of the matter, but there is another on which it is more pleasant to dwell.

It is easy enough to recognize the enormous burden that Eddington's philosophy must have imposed on its victim, but the incredible fact remains that he not only bore it but used it to reach heights which his contemporaries, for all their advantages of equipment, could not attain. It is not only that he escaped the throes of instinct at strife with reason, of which the Victorian age exhibits so many spectacles, described in Tennyson's *In Memoriam*, Huxley's Romanes Lecture, and countless other records. That struggle he evaded so easily that it is only with an effort that we become aware that it should have involved him in its toils. But the chief marvel is that he could use the dread machinery in which most of us can only become hopelessly entangled to produce a theory which, whatever the ultimate verdict on it may be, is beyond all question a work of the highest genius. It is notoriously dangerous to prophesy unless you know, and in a matter of such difficulty I am very far indeed from knowing, yet I do not hesitate to express the belief that when Eddington's fundamental theory is translated from the terms of his unspeakable philosophy into a language that ordinary mortals can understand, it will be found not only to be a work of outstanding technical skill, but also to contain scientific truths which he alone in his generation had the depth of vision to perceive. It seems a tragedy that a man with such incomparable sight should have been placed at such a point of disadvantage, but let us not fail to recognize that his description of what he saw, though abnormal and in our eyes distorted, was in all probability true. I said that he did not know what he was doing; but I believe that what he did was supremely great.