DISCUSSIONS

I

SIR ARTHUR EDDINGTON'S

THE PHILOSOPHY OF PHYSICAL SCIENCE[1]

THIS book contains the Tarner Lectures on the philosophy of science delivered by Sir Arthur Eddington in Trinity College, Cambridge, last year. It is a work which should be of great interest to philosophers, and the Editor of *Philosophy* has asked me to give a fairly full account of it, which I shall now proceed to do.

According to Eddington there is something that may properly be called "the philosophy of science," as distinct from the philosophies of various scientists. It is the philosophical position which is implicit in the procedure of contemporary physicists, and it can be elicited by reflecting on that procedure. This philosophy may be called "Subjective Selectivism" or "Structuralism," according to which of its two interconnected aspects one happens to be stressing.

We may start with some definitions. "Physical Knowledge" may be defined as cognition acquired by the methods of physical science up to date, and generally accepted as valid by experts. It is to include much that is not absolutely certain, but nothing which has not a very considerable degree of probability. Now every item of physical knowledge is an assertion of what has been or would be the result of carrying out a specified observational procedure. A large part of it consists of conditional propositions about what *would* be observed if certain things were done which in fact never have been and never will be done because of insuperable practical difficulties. Thus the statement that the moon is 240,000 miles from the earth *means* (roughly speaking) that, if a yard-stick were repeatedly laid down on a line from the earth to the moon, it would have to be laid down 240,000 × 1,760 times on end in order to reach the latter. But this experimental procedure cannot be carried out, and the evidence for the statement is a combination of the results of a quite different experimental procedure together with generalizations made from other experimental results.

The set of propositions which form the content of physical knowledge are taken as constituting the description of a world, or universe, or system; just as the propositions which form the content of *The Pickwick Papers* constitute the description of an institution called "the Pickwick Club." In neither case need we raise questions about whether, or in what sense, the object which these propositions are taken to describe "exists." Eddington asserts that it is "in accordance with a supposed necessity of thought" that physical knowledge is formulated as the description of a universe. He defines "the Physical Universe" as that of which the contents of physical knowledge constitute a description.

Now it is an essential part of Eddington's doctrine that many important physical propositions, which have been thought to record purely objective

[1] *The Philosophy of Physical Science* (Tarner Lectures, 1938). By Sir Arthur Eddington. Cambridge, at the University Press, 1939. Pp. ix + 230. Price 8s. 6d.)

facts independent of any observer, really correspond to certain features in the sensory or intellectual equipment of human beings. It would follow that the Physical Universe, as defined by him, is in part subjective. Eddington does not consider that this is any serious objection to his use of terms; but, if anyone takes complete objectivity to be part of the meaning of the phrase "Physical Universe," he can substitute the phrase "the World of Physics" for what Eddington calls "the Physical Universe." Eddington himself uses the two as synonymous.

Laws of Nature are at once generalizations and systematizations of what has actually been observed. They are generalizations because they state what *would be* observed under assignable conditions, which may never be fulfilled, as well as what *has* been observed under conditions that were in fact fulfilled. It is only because some laws are generalizations that any laws can be systematizations of actually observed facts. Physical knowledge includes knowledge of particular facts, though the physicist (as distinct, e.g., from the astronomer) is interested in them only as evidence for or illustrations of general laws.

We can now pass to the notion of Subjective Selectivism. Eddington holds that the fact that all physical propositions state what would be observed if certain assignable experimental procedures were carried out necessarily introduces a subjective element into physical knowledge. For it involves an essential reference to the sensory and intellectual equipment of human observers. Many people would be inclined to admit this in the abstract, but Eddington goes much further. From a detailed consideration of this equipment he claims to be able to deduce certain physical laws and to evaluate certain physical constants. He admits, of course, that most of these laws were in fact discovered, and most of these constants were in fact evaluated, from the results of special experiments of a highly complicated kind. He illustrates this situation by the following analogy. Suppose that a person always fished with nets of a certain minimum mesh. If he examined his catches, he would find that none of the fish that he had caught were smaller than a certain size. He might proceed to generalize this into a law about the dimensions of fish. But, if he had noticed the fact about the mesh of his fishing-nets, he could have deduced the result independently, and he could have seen that the generalization ought to take the form "No fish *that I can catch* will ever be smaller than such and such a length."

Eddington expresses this doctrine by saying that some of the laws of nature are "of epistemological origin." A law, governing the results of experiments of a given kind, is of epistemological origin if it can be inferred from the mere fact that the procedure to be followed in making such experiments is of a certain specified kind. Laws of this sort have an altogether different certainty from those which are reached by inductive generalization of experimental results. There can be no exceptions to them. The worst that can happen is that there may be situations in which the specified experimental conditions cannot be fulfilled, and so the law which would follow from the supposition that they have been is inapplicable to the observations. In the case of epistemologically derivable laws Eddington allows only a negative use to experimental tests. It is worth while to do experiments to check the results which you have deduced from your epistemological premisses, because, if the experimental result conflicts with your inference, it will show either that you have made a mistake in your reasoning or that you have overlooked or misunderstood something in the specified experimental procedure from which you argued. It is quite easy to commit one or other of these mistakes.

We can now pass from these generalities to what Eddington regards as concrete instances. He begins with certain examples which, he admits, do not seem *prima facie* to fit in very well with the analogy of the fish and the net. These examples all consist of certain pseudo-concepts of the following kind. In each case a phrase, e.g. "simultaneity of two physical events in remote places," was current, which *seemed* intelligible because it was grammatical and was similar in form to certain other phrases, e.g. "simultaneity of a flash and a bang in my experience," which really *were* intelligible. Further reflection, however, showed that this phrase was in fact meaningless; for it was found impossible to conceive any consistent experimental procedure which should be a criterion for deciding where it did and where it did not apply. Now, Eddington says, there are two ways of dealing with such pseudo-concepts. One would be to reformulate physical propositions in such a way that no pseudo-concepts or symbols for them were involved. Another is to allow such symbols to remain, but to arrange that the truth or falsity of every proposition which contains such a symbol shall be completely independent of the numerical value which may be assigned to it. The latter is the method generally adopted in mathematical physics. Now this condition of "invariance" with respect to these pseudo-concepts imposes certain general restrictions on the form of all expressions in which they occur. These restrictions look like physical laws capable of experimental test. But in fact they are imposed by the following epistemological condition: If a physical proposition contains a symbol for something whose numerical value could not be determined by any conceivable experimental procedure, then its truth or falsity must be completely independent of any value which we may choose to assign to that symbol.

The examples of such pseudo-concepts which Eddington discusses are "the velocity of the ether relative to moving bodies," "the combination of exact velocity with exact position in the case of an ultra-atomic particle," "the directed distance between two qualitatively indistinguishable particles," and "the simultaneity of two remote events." According to him, the application of the epistemological condition just mentioned to the first and last of these pseudo-concepts gives rise to the equations of the special theory of relativity. The application of it to the third of them gives rise to the law of electrostatic attraction between electrons and protons. Plainly this is a highly technical assertion which can be appraised only by experts who are able and willing to grapple with the detailed deduction in Eddington's mathematical works.

The question now arises: What is the range of the epistemological method in modern physics? Eddington summarizes the difference between the classical and the contemporary microscopic physics as follows. The former sought for equations connecting the positions, motions, etc., of particles at one moment with their positions, motions, etc., at a later moment. The latter seeks for equations connecting an *observer's best possible estimates of* these magnitudes at one moment with *his best possible estimates* of them at a later moment. These estimates are always more or less inexact, but the range of inexactitude under given conditions can be exactly stated. It is in this way that the notion of probability enters into quantum physics. Probability is a property of beliefs, estimates, and so on; not of perfectly objective things and events. Its entry is therefore a sign that epistemological conceptions have become an essential part of the fundamental equations of sub-atomic physics. Many people have been shocked by talk of "waves of probability." Such talk ceases to upset us when we are told that the equations state how the accuracy of an observer's best possible estimates of certain magnitudes varies from moment to moment and from point to point.

Eddington thinks that the fact that some of the laws of physics are of epistemological origin is commonly admitted by physicists; but it is admitted grudgingly, and no attempt is made to follow it up and see whether other important laws cannot be inferred in the same way *in advance of* experiment. For his own part he states his belief that " 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.*"

This may strike the reader as "a large order," but Eddington goes further. The laws of nature contain certain numerical constants. There are four such independent constants, viz. the mass-ratio of proton and electron, the fine-structure constant, the ratio of the electrical to the gravitational force between a proton and an electron, and the ratio of the natural radius of curvature of space-time to the wave-length of a mean Schrödinger wave. These are all pure dimensionless numbers, and they have all been experimentally determined. (The first is about 1840, the second about 137; the other two are enormously great numbers, viz. $2{\cdot}3 \times 10^{39}$ and $1{\cdot}2 \times 10^{39}$ respectively.) Now Eddington claims to be able to infer these numbers from purely epistemological considerations; i.e. he claims that, not only the mathematical *form*, but also the *numerical constants*, of the fundamental laws of nature can be inferred from the mere fact that our senses and our intellects work in certain specifiable ways.

Do we know of any laws which are not of epistemological origin? Eddington's answer to this question is as follows. Since all the fundamental laws of physics are of epistemological origin, we can safely assume that, if there are any purely objective regularities in nature, they will stand in sharp contrast to the laws of physics. Now physics is by no means the whole of science. The suggestion is that the purely objective laws of nature are most likely to be found in those branches of scientific knowledge which are most remote from mathematical physics, viz. in those parts (if there be any) of biology which are not covered by bio-physics, and in those parts of psychology which are not covered by psycho-physics.

In Chapters V and VI Eddington considers in more detail the relation of epistemology to relativity theory and to quantum theory respectively. The fundamental innovation in relativity theory was to define distance and time-lapse in terms of the operations and calculations which have to be performed in order to measure them. This is specially important because these two magnitudes are involved in all other physical quantities.

In Chapter V Eddington devotes himself mainly to a discussion of length. What is needed is to specify a standard of length which shall be available for comparison at any time and place. If a vicious circle is to be avoided, the specification must not itself involve the measurement of length. In consequence of this, Eddington says, the standard must be some material structure consisting of a certain number of nuclei and electrons whose arrangement can be completely specified in terms of quantum numbers. What he has in mind is the ultra-microscopic lattice structure of some crystal of definite chemical composition.

In this connection Eddington makes the following remark. The theory of relativity is primarily a theory of *macroscopic* phenomena. But it is not self-contained, since it has to borrow its standard of length (and of duration) from ultra-microscopic physics. On the other hand, this latter theory is also not self-contained. For the physical magnitudes connected with ultra-microscopic particles must in turn be defined in terms of operations which we macroscopic beings can carry out with our macroscopic instruments. Eddington alleges that this circle is not logically vicious.

There are two further points which Eddington makes about length. (1) Ultra-microscopic structures, such as we considered in defining a standard of length, are not reproducible in strong electric or magnetic fields. The quantum specification of such a structure presupposes the absence of such fields. Yet a person may want to do experiments, which involve the measurement of length, on the effects of strong fields; e.g. to find out the curvature produced in the path of an electron when it passes through them. He will, of course, use some highly indirect method, such as taking photographs and measuring the curvature of certain lines which appear on the photographic plate. Now he can quite properly apply the standard definition of length to *these lines* and to his measurements of *them*; for they are not in a strong field. But suppose he proceeds to infer from them propositions about the paths of the *electrons* themselves. In doing so he will be applying to objects which were in a strong field a standard of length which explicitly involves the condition that the standard shall not be in such a field. It is plain that no unambiguous results can be reached in this way.

(2) The definition of distance applies directly only to very small distances. It can be applied to long distances only indirectly through summing or integrating a very large number of successive adjoined short distances. Now it is not axiomatic that such summation will lead to consistent results no matter where or when it is carried out. It turns out that the postulate that it will do so is equivalent to assuming complete absence of gravitational forces. Any departure from this condition will appear as a gravitational field, and the nature of the field will be determined by the kind and degree of departure from this condition. This, Eddington says, is the essential point of Einstein's theory of gravitation.

Chapter V concludes with an important distinction between "personal" and "generic" subjectivity. The former consists in the fact that what any individual observes is in part determined by his position and velocity and acceleration. The latter consists in the fact that the scientific knowledge which the human race acquires by sense-perception and subsequent reasoning is in part determined by the sensory and intellectual equipment common to the species. Now the first achievement of the theory of relativity was to show that *personal* subjectivity had certain subtle effects which had not hitherto been allowed for. And, by the tensor method, it does in a sense enable us to transcend this personal subjectivity by a symbolism which presents the physical world from the standpoint of every possible observer. But this leaves the *generic* subjectivity, with which Eddington is concerned in this book, untouched. It is to some extent illustrated, as we have seen, by relativity theory; it is still more clearly illustrated, in Eddington's opinion, by the fundamental part which the notion of probability plays in quantum theory.

This brings us to Chapter VI, which is concerned with epistemology and the quantum theory. I must confess that I do not find this chapter very easy to summarize. I think I can understand most of the several items in it, but I am far from clear about their precise interrelations.

We may begin with the following statements, which seem to be fundamental. The laws of contemporary physics connect "probabilities in the future" with "probabilities in the present"; those of classical physics claimed to connect "ordinary physical quantities in the future" with "ordinary physical quantities in the present." As a means of calculating future *probabilities* the laws of contemporary physics form a completely deterministic system; but, as a means of calculating future *observational knowledge* the system of law leaves a range of indeterminism open. I think that these statements are quite clear.

Next we are told that there is no possibility of reducing laws of the contemporary kind to laws of the classical kind. The ground for this assertion is that probability is not "an ordinary physical quantity." This latter assertion is supported in two ways, viz. (i) by a positive account of what "probability" means in physics, and (ii) by an attempt to show that there is a characteristically different kind of relation between (*a*) an observation and the knowledge of an ordinary physical quantity which it gives us, and (*b*) an observation and the knowledge of a probability which it gives us. These two points are treated quite separately, and I have not discovered any attempt to connect them; so I will now take them in turn.

(i) In physics the probability of an event of a given kind occurring under given conditions simply *means* the frequency with which such events are found to happen under such conditions. For physical magnitudes must be defined in terms of the procedures by which they are to be measured, and no other procedure is available for measuring probability. No further use seems to be made of this positive account of probability in the present argument.

(ii) The relation of probability to observation is said to be characterized by a peculiar irreversibility, which is not present in the relation of an ordinary physical quantity to observation. This cryptic remark is supposed to be elucidated by an example on pp. 92 to 93 about drawing balls from bags. I think that this is one of the most confused and confusing "elucidations" that I have ever met with. It is not worth while to go into detail. It will suffice to say that Eddington's statement on p. 92, "It can be deduced that the chances are 2 to 1 that the bag is A," requires the premiss (which he omits to mention) that the drawing which has been made is *equally* likely to have been from bag A or bag B. Now at the next stage of the argument on the same page he supposes that "we are handed one or other of the two bags with the information that the chances are *2 to 1*" (my italics), "that it is the bag B." So the hypothesis on which the later stage of the argument is conducted is inconsistent with the suppressed premiss from which the conclusion of the first stage was derived. It is therefore not surprising that Eddington can produce a paradox at the end of the argument. He takes this to illustrate or demonstrate the peculiar irreversibility of the relation of probability to observation; but it is surely obvious that no paradox derived by using inconsistent premisses at different stages of an argument can do anything of the kind.

I should be inclined to suppose that the fact behind all this very confusing talk is simply the following. Probability is essentially a relational term, and it is essentially relative to data. There is no more sense in talking of "the probability of p" (except as an ellipsis) than in talking of "the distance of London." The minimal intelligible statement is of the form "the probability of p relative to the datum q." Now, if the numerical value of this be given, there is no way of inferring from it the value of the probability of q relative to p as datum. Does Eddington mean anything more or anything different from this by the peculiar irreversible relation of probability to observation?

The question still remains: Why has it become necessary to formulate the laws of physics as interconnections of probabilities? Eddington's answer appears to be as follows. The conditions required for measuring any one physical magnitude with complete accuracy require the elimination of other physical magnitudes from the region under investigation at the time. But in physics we are concerned with the interrelations of various physical quantities in the same time and place. Therefore, if any empirical meaning is to be given to the laws and concepts of physics, we must consent, even in theory, to put up with something less than complete accuracy. It is in this way that the notion of probability is introduced into the fundamental definitions.

In Chapter VIII Eddington discusses the notion of Analysis, which he considers to be a fundamental form of thought common to pre-scientific and scientific cognition. In its most general form it is the notion of a whole composed of a set of interrelated parts in accordance with some scheme of interrelation. He is careful to point out that what counts as one part of a given whole is always relative to a particular scheme of interconnection. In reference to the anatomical mode of analysis a thigh-bone is one part of a human body and a single cell is not. In reference to the physiological mode of analysis a cell is one part and a thigh-bone is not.

This general notion of analysis takes various special forms. Cf., e.g., the analysis of a body into a set of organs and the analysis of a complex wave-motion into a set of superimposed simple-harmonic components. Modern physics does not confine itself to the first and more familiar form, which allows only of *positive* parts or elements and is, Eddington thinks, bound up with the notion of substance.

Eddington holds that another form of thought, which has great influence in physics, is the persistent tendency to reduce all variety to differences of relation among intrinsically homogeneous elements. (He seems not to be acquainted with the works of M. Meyerson, or he could not have failed to mention them at this point.) He suggests that this ideal has actually been reached in the case of electrons and protons, in spite of the *prima facie* appearance to the contrary, because the difference in the mass and in the nature of the electric charge can be ascribed to a difference in the relations of intrinsically similar particles to external matter.

Another important demand of thought is that the individual elements in any scheme of analysis shall have a considerable degree of permanence. Here we have to treat microscopic and macroscopic physics separately. Eddington says that the natural time-unit for microscopic phenomena is so short in comparison with a human being's specious present that any such phenomenon must last for an immense period, as measured by that unit, if it is to be capable of entering into the field of human observation. So he has no difficulty in attributing the persistence which we seem to find in the elements of microscopic physics to subjective conditions. But we also find a great deal of persistence, which forces itself on our attention, on the macroscopic scale. We are surrounded with visibly persistent solid objects; and the law of the conservation of mass is illustrated on a large scale, both spatially and temporally, under our very noses. Eddington finds this tendency of the macroscopic world to "play up to" certain of the demands of our intellects somewhat embarrassing. He tries to account for it by arguing that we could not live if the macroscopic world, with which we have to deal in practice, did not more or less answer to our intellectual demands. This rough agreement is, he thinks, secured by the existence of our very specialized brains and nervous systems, which select and concentrate stimuli in such a way as to present us with an environment of perceptibly steady and persistent large-scale objects. (The similarity of this view to certain doctrines in M. Bergson's *Matière et Mémoire* will be obvious.)

Eddington holds that one feature in the conceptual scheme of analysis is the demand that the ultimate elements shall be existentially independent of each other. Now he holds that this demand, if pressed to the limit, would make the physical universe intrinsically unobservable and thus lead to a contradiction. He takes the concept of *interaction* to be the means by which such a contradiction is avoided; and he congratulates the quantum theory on being able to show that "*all* interaction-forces in physics arise from the indistinguishability of the ultimate particles," so that "interaction has . . . a subjective origin." It seems to me that these statements are too condensed to be at all intelligible to non-experts. Also I think that there are several confusions in the previous argument. So far as I can see, the only kind of independence which is required in the ultimate elements of any scheme of analysis is that it should be *logically* possible for any one of them to have *existed* without the rest. There is surely no conflict between this and the supposition that the *variations in the states and the relations* of any one of them are *causally dependent* on variations in the states and relations of the rest.

Chapter IX contains an important, but difficult, account of the notion of *Structure*. It starts by explaining the mathematical notion of a "Group of Operations." A set of operations constitutes a "group," in this technical sense, if the following conditions are fulfilled. Let P and Q be any two members of the set. Suppose that the operation Q is performed on any entity x, and that then the operation P is performed on the result which has been obtained by performing Q on x. Then there is always another member R of the set, such that the result of performing R on x is the same as the result of the two successive operations mentioned in the last sentence. Thus the members of any group fall into sets of three, such as P, Q, and R. Any particular group will be specified by specifying the interrelations of such triads. This constitutes the "structure" of any set of entities to which the operations of the group could be applied. It is quite unnecessary for us to know anything about the intrinsic nature of the individual operations in a group thus specified or about the intrinsic nature of the entities to which they are applied. If you try to fill out a purely structural concept of this kind by some concrete picture of the individual entities and operations, you have what Eddington calls (surely very oddly) a "*general*" concept. I should prefer to call it a "schematized" concept. E.g., the notion of Euclidean space is a schematized concept in which the entities are supposed to be points and the operations are supposed to be certain kinds of movement by which one point can be made to coincide with another. This group of operations can be specified by its purely formal group-properties, and we can then cease to consider whether the operations are movements and the entities are points. We thus extract from the schematized concept the corresponding purely structural group-concept. Now, as mathematical physics has developed, it has ceased to be concerned with schematized concepts and has ended by dealing with nothing but pure group-structure.

Eddington uses these contentions to get rid of a dualism between events in a person's brain and the correlated sensations in his mind. So far as I can understand his doctrine, it is as follows. (1) A sensation and the brain-event which is its immediate physiological correlate are not two events standing in the relation of effect to cause. They are one and the same entity. This counts as a sensation, e.g. of sound, in respect of the peculiar sensible quality which it has for the experient; and it counts as a physical event in respect of its relations to other things and events in the physical world. (2) The logical (though not the historical) starting-point of physics is knowledge of the interrelations of an individual's contemporary sensations. This is filled out by his memories and by the reports of others about their sensations. It is further filled out by inferences based on regularities which have been discovered, under the guidance of certain intellectual habits, already described, in the directly experienced portions. (3) Physical knowledge is knowledge of the group-structures of this whole mass of interrelated actual and conditional human sensations. (4) What is called the "physical world" is just the world described in purely physical terms. Since physical knowledge turns out to be knowledge of pure group-structure, the physical world is just the world considered as having that pure group-structure which physics ascribes to it. (5) Certain parts of the world are events in the brains of living organisms; most parts of it, so far as we know, are not. Both these parts can be described in purely physical terms. But something further can be said of the former; since we know by direct experience that they are also sensations of various kinds, interrelated in various ways of which we can be directly aware. Of the nature and interrelations of the other parts of the world we can speak with certainty *only* in physical terms, i.e. only in terms of pure group-structure. But we know that this is not *incompatible* with their intrinsic nature being sensational; and, if we insist on ascribing an intrinsic nature to them, the qualities and relations which are directly manifested to us in our own sensations are the only materials at our disposal for filling out the pure group-concept into a schematized concept.

(In the above account I have departed in certain ways from Eddington's actual use of terms. He talks of the "*external* world," where I have talked of "the world." And he speaks of the "physical world" as "the structure of the external world." I prefer not to use the phrase "external world" in this connection, because it seems to me odd to call one's own brain part of the external world. And I think it is less confusing to say that the physical world is just the world considered as having that structure which physics assigns to it than to say that the physical world is the structure of the external world. I do not think that these verbal changes in any way distort Eddington's meaning.)

Chapter X is concerned with the concept of existence. The first two sections of it are intelligible, but not, I think, of much importance. The third and fourth sections, about "idem-potent symbols" and double symbols for relations, probably refer to matters which are highly important. But they are so sketchy that they will be utterly unintelligible to almost all readers. I content myself with noting that the idem-potent symbol J has the same formal properties as what is called "truth-value" in the two-valued algebra of the propositional calculus in logic.

The earlier parts of Chapter XI are concerned with that constant of nature which is called the "Cosmical Constant" and is commonly described as the number of electrons in the universe. Eddington claims to be able to deduce this number from epistemological considerations, and says that the result of his deductions agrees pretty well with the value which has been inferred from certain experimental results. Since the number of electrons in the universe seems *prima facie* to be something typically contingent, Eddington feels that he must do something to obviate the paradox of his claim to determine it *a priori*. He does this by pointing out that the nature of an electron, on the quantum theory, is such that the notion of electrons being countable involves a contradiction. Therefore the phrase "number of electrons in the universe" cannot be interpreted in the way in which we should interpret the phrase "number of inhabitants of England in 1940." It has actually to be regarded as the maximum possible value which a certain function in quantum-theory, which can take only integral values, can have. When seen in this light the claim to deduce this number from purely epistemological considerations appears less preposterous. The extremely sketchy outline which Eddington gives of the process by which the number is deduced will, I think, be unintelligible to nearly all his readers. It is certainly so to me.

Section III of Chapter XI is concerned with the nature of teleological behaviour and its relation to the laws of physics. It is highly condensed, and

I am not at all sure that I understand it. The gist of it appears to be as follows. All the laws of physics are *a priori* and therefore apply to all matter without exception. But they do not suffice to determine completely the behaviour of any system at a later moment in terms of data available at an earlier moment. We can make the hypothesis that there is no correlation between the behaviours of the various particles of a system within the range that is left undetermined by the laws of physics. This hypothesis is fully verified by *inorganic* systems; any departure from it would lead to results which are in conflict with observation. But there is no necessity about this hypothesis of non-correlation. There is nothing to forbid us supposing that in certain systems there is a high degree of correlation between the behaviours of the various particles within the range which is left undetermined by the laws of physics. Such an hypothesis seems necessary in order to account for the characteristic behaviour of those systems which are living and intelligent. The laws of this correlation would be non-physical and not epistemologically derivable.

The last two chapters of the book, entitled *The Beginnings of Knowledge* and *The Synthesis of Knowledge*, deal directly with psychological and epistemological problems familiar to philosophers. The main points in the first three sections of Chapter XII are as follows.

(1) The primary data from which physical knowledge is derived are the sensations of which a person is directly aware at any moment of his life. Of the special sensations only those of sight are of fundamental importance to physics. But we must also include under the head of sensation the direct awareness which a person has of the passage of time. This sensation is connected with changes of entropy in some part of the brain; a state of greater entropy being felt as later than one of lesser entropy. (2) To the sensations of which a person is directly aware at any moment must be added those which he remembers having had. He is directly aware of these present memory, experiences, and he takes them as knowledge of the fact that he has had such and such sensations in the past; but he is not now directly aware of those past sensations, as he is of his present sensations. (3) Lastly, we must add further the sensations which other men tell us that they have had. Each of us postulates that his direct awareness of certain of his own present sensations (viz. those associated with listening and reading) is an indirect awareness of sensations occurring outside his own consciousness. (4) Eddington describes this last-mentioned form of cognition as "sympathetic understanding." He rejects the logical positivist view that the *meaning* of statements about other men's sensations consists in the bodily changes by observing which we should test such statements. He recognizes that no other test is available, but he holds, nevertheless, that sympathetic understanding gives us knowledge (more or less certain) of the existence and experiences of other persons. He compares the basing of knowledge of *other* persons and their experiences on *one's own* sensations to the basing of knowledge of one's own *past* experiences on one's *present* memory-experiences. (5) The minimum datum for physical knowledge is, not the occurrence of any one sensation, but the awareness that a sensation which one is now having is or is not like a certain sensation which one has had before.

The point made by Eddington in the last section of this chapter is directly linked with the topics of Chapter XII, so I will take them together.

I think that the main point which Eddington wishes to make here is that the linguistic expressions, by which a person indicates the fact that he is having an experience and tries to describe it to others, are liable to suggest by their grammatical structure an analysis which is doubtful and probably mistaken. Take, e.g., the sentence "I am now hearing a squeaky noise." The form of the sentence suggests that a particular of one kind—an Ego—is standing in a certain relation—a species of sensing—to a particular of another kind—an auditory sensum. Take again the sentence "I know that I am hearing a squeaky noise." The form of this suggests a still more complex state of affairs. We may be led by the form of the first sentence to ask whether this very noise might not have existed unheard by me; and we may be led by the form of the second to ask whether I might not be hearing a squeaky noise without knowing that I was doing so.

I understand Eddington to hold that both these questions are nonsensical. It would generally be admitted that "to feel tired" just means to feel *tiredly*; and his suggestion appears to be that "to hear a squeaky noise" just means to feel "squeaky-noisily." Our language is rich in nouns and poor in adverbs, and that is why the latter mode of expression, which accords better in structure with the facts than the usual one, is not available. Again, it is meaningless to suggest that a person could be hearing a squeaky noise without knowing that he was doing so. Eddington thinks that the expression in which the word "I" occurs twice arises in the following way. Each of us believes that there are other persons beside himself. *You* may be hearing a squeaky noise without *my* knowing that you are doing so; and *I* may believe that *you* are hearing a squeaky noise without your hearing one. Hence the phrase "*I* know that *you* are hearing a squeaky noise" does state a different fact from the sentence "*You* are hearing a squeaky noise," if it states a fact at all. This makes it appear that the sentence "I know that I am hearing a squeaky noise" states a different fact from "I am hearing a squeaky noise." A solipsist would be under no temptation to use the more complex mode of expression.

But, although a solipsist would have no occasion to use such expressions or to talk of "my" experiences, since he would have no occasion to contrast them with any other experiences, he would have occasion to use such reflexive expressions as "I am aware of myself." By using this expression he would not, in Eddington's opinion, be meaning to contrast *his* self with any other self. He would be recognizing that he is not a mere aggregate of his various experiences. These experiences are united in a characteristic form of unity; each of us is directly aware of this form of unity as well as the several experiences; and the expression "I am aware of myself" indicates this awareness.

I have now given what I hope may be a fair and adequate summary of the main contentions in Eddington's book. I will end with a few brief comments.

(1) It is, from the nature of the case, quite impossible for anyone to form a rational opinion about the truth of Eddington's main thesis from the materials provided in this book. No one would wish to deny the possibility that some of the laws of nature, which appear to be merely inductive generalizations, are really consequences of certain facts about the sensory and intellectual equipment of human observers and the nature of experimental research and verification. But the question whether this possibility is realized, and, if so, to what extent, can be decided only by having the actual argument presented to one in each case in which it is alleged that a law can be epistemologically derived. The proofs of all such puddings are in the eating. Now the "eating" can be done only be those who are able to chew and digest the extremely tough meat of Eddington's technical mathematical writings. A peptonized form of this is presented in his previous semi-popular book *New Pathways in Science*; but, although the rather more detailed account of Group Theory given in that does help one to *understand* much that

is obscure from sheer sketchiness in the present work, it does not and could not put one in a position to estimate the validity of the arguments.

Now in many cases this would not much matter. As philosophers we might reasonably be expected to accept as valid the technical deductions of so eminent an authority as Eddington, even though we could not follow the detailed reasoning ourselves. But, unfortunately, the situation is not so comfortable here. When I ask my expert colleagues whether I can safely accept Eddington's conclusions in these matters, they always answer in the negative. But this does not satisfy me. For I am quite convinced that their unfavourable answer is not based on a first-hand study of the arguments. It is quite plain that their attitude may be summed up in the sentence: "This kind of thing *must* be wrong somewhere; but I can't be expected to waste my valuable time in finding out precisely where the mistake lies." This is exactly the same attitude as philosophers took up towards McTaggart's *Nature of Existence*. In that case the detailed examination which I undertook showed conclusively that their worst suspicions had been fully justified. It is greatly to be wished that some competent mathematical physicist, with a critical rather than a creative intellect, should undertake an "Examination of Eddington's Mathematics" comparable to my *Examination of McTaggart's Philosophy*. It is possible that, although McTaggart was ploughed, Eddington might pass with honours. But, until something of this kind has been done, philosophers will do well to be extremely cautious in either accepting or rejecting Eddington's detailed contentions.

(2) There is one elementary point to be raised about the allegation that the numerical values of the constants of nature, as distinct from the general laws of nature, can be deduced from purely epistemological considerations. No valid argument can derive a *singular* conclusion from premisses which are all *universal*. If you are to reach a particular number in your conclusion, you must have at least one premiss in which a particular number appears as a term. What is the purely epistemological premiss which contains a particular number as a term? Is it, perhaps, the fact that human spatial perception is three-dimensional, and that to locate an event completely one further bit of information is needed, viz., a date? This does introduce a premiss, which might fairly be said to be epistemological, containing the number 4 as a term in it.

(3) I do not think that there is much connection between the "selective subjectivism" and the "structuralism" of Eddington's theory. Of course both of them may be true. But the structuralism might be true and important, so far as I can see, even if the selective subjectivism were false or greatly exaggerated.

(4) Eddington mentions the affinity of his views in certain respects to those of Kant. In the course of this review I have pointed out resemblances to characteristic doctrines of M. Bergson and the late M. Meyerson. It remains for me to remark that Eddington's account of the function of experiment in connection with laws which are really of epistemological origin reminded me of Descartes's views on a similar topic. For Descartes the laws of motion were deducible from the perfection of God, whilst for Eddington they are deducible from the peculiarities of the human mind. In each case the real function of the experiments by which they were ostensibly suggested and verified must be very different from what it appears to be. For both philosophers the experiments are rather a concession to our muddle-headedness and lack of insight.

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