EDDINGTON, PHYSICS AND PHILOSOPHY

SIR ARTHUR EDDINGTON in his recent book[1] has presented a relatively non-technical account of the theory of the fundamental laws and constants of physics which he developed in his *Relativity Theory of Protons and Electrons.*[2] But he has also embedded his contributions to science, which are recognised to be of the greatest importance, in a philosophical setting which carries by no means the same authority. It is unfortunate that physical advances, the brilliance of which it would be impertinent to commend, should be obscured, by reason of this embellishment, as seems to have happened in recent controversy.[3] It seems useful, therefore, to discuss what is the real status of Eddington's results, what points of interest arise from his reflections on the method of physics, and what is true in those parts of the book which deal with genuinely philosophical questions. We shall be mainly concerned with the philosophical setting, and scientific technicalities will be reduced to a minimum.[4]

I

Without pre-judging the methods by which they are reached, Eddington's results are briefly as follows. He claims that it is possible, solely from a consideration of the

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[1] *The Philosophy of Physical Science.* (Cambridge, 1939; 8/6).

[2] Cambridge, 1936.

[3] *Cf.* Eve, in *Nature,* Nov. 12, 1938, p. 857, and references there given.

[4] The scientific background can be studied in the scientific parts of Eddington's other popular works. In what follows I have inserted short statements of the two or three new ideas which are at the bottom of the twentieth-century advances in physics.

ways in which physical observations are made, to deduce both the mathematical forms of the fundamental laws of modern physics and the numerical values of the constants which occur in them. These fundamentals differ from those of nineteenth-century physics because of the introduction of relativity theory and of quantum theory. The fundamental laws include Einstein's law of gravitation and the relativistic wave-equation for an electron. The fundamental constants are the mass of an electron, the mass of a proton, the charge of an electron, Planck's constant, the velocity of light, the gravitational constant, and the cosmical constant; and by eliminating from these the arbitrary units of length, mass and time, we are left with four fundamental numerical ratios, namely the ratio of the masses of the proton and electron, the 'fine-structure constant,' the gravitational constant, and the 'cosmical constant.' The values obtained by Eddington are in accordance with experiment.

Clearly such calculations are of the greatest interest. But in deciding their status much depends upon exactly what propositions form the basis of the deductions. In particular, as will appear later, these propositions include the fundamental principles of relativity and of quantum mechanics, whose basis is *empirical*, and which in fact are inductively established, depending on a vast amount of experimental work. The experimental basis of relativity is that numerous experiments have shown that the velocity of light is finite (so that it is not possible, even in principle, to observe an event at exactly the time it happens); and that experiments such as those of Michelson and Morley lead to the conclusion that the velocity of light is the same for all observers irrespective of their motion. The experimental basis of quantum mechanics is that results on radiation from hot bodies, on spectra, etc., lead to the conclusion that energy can only be transferred in discrete quantities; or more accurately that only such discrete transfers can be observed (so that to make any observation causes a finite disturbance of the system observed, and we cannot in principle make exact predictions of the state of the system). The recognition that Eddington's conclusions rest upon propositions whose status is that of inductive generalisations (however brilliant), depending on experimental data (however extensive), leads to a view of their significance markedly different from that of Eddington himself. As we shall see, he calls his approach an " epistemological method,' and seems to claim a more than inductive certainty for the results. This claim might be justified if the results were deduced solely from propositions whose truth or falsehood is independent of experimental work—for instance, that material objects are extended and that therefore we can measure distances; that is, if the results were deduced solely from a consideration of the method which characterises physics, namely, the restriction of observation to inorganic matter and to its measurable aspect.[5] But it will appear that Eddington's results are not deduced from this basis alone, but require also certain propositions which are dependent upon the results of particular observations. (The validity of these observations, incidentally, is not affected by the limitations on observation in general which they reveal.) Taking this view, the significance of Eddington's results (assuming the actual processes of deduction to be correct) is that the particular forms of the fundamental laws of physics, and the particular values of the constants which occur in them, can be deduced, using symbolic logic, from a consideration of the general metrical method of physics, *plus* certain methods which by reason of their success are always used in interpreting experimental results, *plus* the inductively-based propositions of relativity and quantum theory. That this is a very remarkable contribution to science is obvious. But the point here is that it seems incorrect to claim for these results a certainty greater than inductive. Edding-

[5] *Cf. Blackfriars*, Nov., 1939, p. 779.

ton's work, on the present view, has the status of a unifying theory, whose 'probability' is increased by every deduction from it which accords with experiment.

Besides the theories of relativity and of the quantisation of energy already referred to, and the proposition that all physical observations are measurements, there is a third group of propositions which Eddington uses in his deduction of the fundamentals of modern physics.[6] Their status is peculiar at first sight and Eddington's formulation of them seems particularly valuable. They may be summarised by saying that it is considered legitimate and useful in modern physics to interpret observations in terms of a physical model such that the whole is no more than the sum of its parts, which parts have a certain degree of permanence, and are precisely alike except in respect of certain relations to other entities. In physical interpretation an analysis is *de facto* regarded as incomplete until this stage is reached. These methods are familiar enough in certain application; all protons, for example, are regarded as identical in nature, though occupying different states; and the mathematical description of, say, a hydrogen atom by a wave-equation is such that the corresponding description of the hydrogen molecule is derivable from that of the constituent atoms without introducing any new principle of unity. The way in which protons and electrons are reduced to units identical except for being differently related to the general distribution of matter in the universe[7] is less familiar, but it is a good illustration of the same methods.

These methods of physical interpretation are always applied in modern physics, and fundamental theory is explicitly based on them. But it is a mistake to jump to the conclusion that they have therefore a philosophical status,

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[6] *Op. cit.*, Chap. viii..

[7] *Op. cit.*, p. 124.

let alone that they are known *a priori*, as Eddington does when he speaks of them as engrained forms of thought imposed by the intellectual equipment of physicists. Several points need elucidation here. First, Eddington seems to confuse various senses of the term '*a priori*,' one of which senses is peculiar to himself; of this more anon. Secondly, these methods of interpretation derive their validity from the fact that they have been found successful in formulating theories whose logical consequences are in agreement with experiment. Therefore they are probabilified inductively,[8] though less directly than the various theories which exemplify them (which in turn are probabilified inductively, though less directly than the empirical generalisations which they interpret, such as the gas laws). This seems a far more convincing account than the unsupported statement that they are forms of thought imposed *a priori*. The formulation of them is a part of the general evolution of science, in which empirical discovery and theoretical interpretation are closely connected. Thirdly, these methods of interpretation are not philosophical principles, as is obvious from what has been said; yet Eddington seems to believe that they are. This is, perhaps, an example of a not uncommon failing among physicists,[9] namely, a failure to realise that philosophy is not restricted like physics to the consideration of the metrical aspect of the dead world, and that its problems are entirely different from those of physics (some of them indeed being concerned with the *presuppositions* of physics).

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[8] On the probabilification of scientific theories through their agreement with experiment and deductions from them, see Eaton, *General Logic*, Part IV.

[9] Another example is to be found in Einstein and Infeld's *Evolution of Physics* (Cambridge, 1938), where the change-over from the mechanical models of nineteenth-century physics to more modern views is regarded as a change of philosophical outlook.

The problem which physics presents to philosophy is not to decide which physical principles are true, but to decide what is the validity of empirical generalisations based on a relatively small number of measurements none of which is exact, and what is the validity of mathematical theories developed so that by deduction from them one obtains equations agreeing with the empirical generalisations. This is the philosophical problem of induction, but its existence is hardly ever suspected by scientists who believe themselves to be writing about the philosophical basis of science. In passing it may be noted that the methods of physical interpretation outlined by Eddington themselves emphasize the sharp distinction of physics, working within its self-imposed restrictions, and philosophy, with every aspect of every experience to draw upon. For they show that it is impossible in physics to speak of a substance; or rather, it is impossible to decide whether a given physical system is a substance, or even to decide on physical grounds whether there are as many material substances as ultimate particles or whether there is only one; for the way in which the physical interpretation is formulated ensures that when, say, two hydrogen atoms approach so close as to form a molecule, no new principle of unity is required by physics.

The last element in Eddington's work is the use of mathematical logic. As is well known, mathematical or symbolic logic is concerned with the forms of valid inference, irrespective of the truth of premisses, and it has *a priori* validity within these limits. Eddington introduces the 'mathematical theory of structure' by means of which he is able to carry out in a precise manner the general methods of interpretation outlined above. He introduces what he calls 'a structural concept of existence' and a 'structural concept of relation.' These really amount to algebraic symbols which can only possess certain definite values, which can be so interpreted as to correspond with certain of the characteristics of existent and related objects

—much as in Boole's two-valve algebra the two possible values of the variables can be interpreted as corresponding to 'true' and 'false' and the symbols themselves as corresponding to propositions. He calls them 'structural' presumably because they are analogous to the symbols which occur in the mathematical theory of groups, which deals symbolically with structure. The usefulness of these symbols is that of symbolic logic generally; by their aid Eddington is able to handle problems which otherwise would be too complex.

Eddington himelf does not mention this reason for the introduction of the mathematical theory of structure, but stresses rather the fact that it is common to many minds, whereas sense-data are private to the individual. He emphasizes that fundamental physics is now formulated explicitly in terms of structure theory in order that it may be common property. This leads to a most interesting situation in connection with Whitehead's views on the independence of philosophy and natural science.[10] The reason why Eddington's emphasis is laid where it is, seems to be that he regards sense-data not, as a realist philosopher does, as signs of something other than the cognising mind, but merely as elements whose origin need not be discussed but which have to be integrated with an interpretatory scheme of laws so that the resulting synthesis of experience may be as coherent as possible. This treatment of sense-data, which in a philosopher might lead to the Cartesian error of trying to come to know all things by considering only the subjective aspect of cognition, seems to be harmless in a scientist considered as such—that is, so long as he does not venture out as a philosopher.[11] If I have understood his doctrine correctly Whitehead has shown that scientists can, if they will, proceed without paying atten-

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[10] A. N. Whitehead, *The Concept of Nature* (Cambridge).

[11] Which, ironically enough, is exactly what Eddington does.

tion to philosophy,[12] provided that they limit their outlook, regard science as the rational systematisation of certain sensory experiences, and do not attempt to 'bifurcate' their experience into a cognising self and a cognised world. Now the use of group-structure, in terms of which all the fundamentals of modern physical theory are formulated,[13] enables the physicist to avoid this bifurcation, while still keeping the objects of physical science common to different physicists in a way that sense-data are not. Eddington's language is rather cloudy, but I may quote the following passages to exemplify this point.[14] 'The recognition that physical knowledge is structural has abolished all dualism of consciousness and matter.' 'The externality of the physical world results from the fact that it is made up of structures found in different consciousnesses.' And much else might be quoted. If this interpretation is correct, it means that modern physics explicitly adopts a method in virtue of which it can go ahead, as Whitehead showed, without considering the relation of the cognising self to the objects of cognition.[15]

Presumably we have here the explanation of Eddington's apparently Cartesian insistence on the subjective aspect

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[12] So also students of symbolic logic can proceed without asking the philosopher to decide what they mean by propositions, the self, etc., in virtue of the device of logical constructions.

[13] *Op. cit.*, p. 142-143.

[14] *Op. cit.*, p. 150, p. 198. Explicit statements which accord with the view that modern physics adopts implicitly the Whiteheadian view will be found on pp. 49, 50, 148, 150, 185, 186, 198.

[15] It is curious that Eddington does not seem to be aware of Whitehead's work, although he writes much about 'epistemology'; he is astonished to find that the view that science is concerned with the 'rational correlation of experience, rather than the discovery of fragments of absolute truth about an external world,' is commonly accepted.

of cognition as the source of our physical beliefs.[16] If this is so, Eddington's views here are not to be treated as philosophical, but rather as applications of Whitehead's view of the way a scientist may work if he wishes to evade philosophising. In that case there is no real quarrel between Eddington and the realist philosophers, except where Eddington misinterprets his method and draws philosophical conclusions from it.[17] On their own ground, each is correct, and Eddington's criticisms of the realists are beside the point.

We may now summarise the data of which Eddington makes use in the theory under consideration. They are: (i) The propositions of symbolic logic: which are all hypothetical, concerned only with the valid forms of inference, and *a priori* valid. (ii) The proposition that physical observations are measurements on inorganic objects; this defines the scope of physics. (iii) The propositions referred to as the modern physical 'method of interpretation'; these depend ultimately upon inductive probabilification. (iv) The propositions which summarise relativity and quantum theory; these also depend upon inductive probabilification.

The way in which these data are used in the calculation of the fundamental constants is described by Eddington for the case of the cosmical constant or 'number of particles in the universe.'[18] He begins by defining symbols corresponding to 'existence' and 'relation,' by means of which the operations of the mathematical theory of groups can be brought to bear on certain characteristics of existent entities and related entities. He then introduces the definition of a physical observation, namely that it is a measurement; and notes that, since a measurement consists in com-

[16] *Cf. Op. cit.*, pp. 67, 143, 190, 195, 203, 204.

[17] *Cf.* S. Stebbing, *Philosophy and the Physicists, passim.*

[18] *Op. cit.*, Chap. xi,

paring a length with a standard length, and each length depends upon a spatial relation between two physical entities, any measurement is associated with four physical entities, and consequently with a 'quadruple existence symbol.' No empirical data have yet been used and no numerical results can be deduced so far. By introducing now the fundamental results on relativity and quantisation, one can deduce the forms of the fundamental laws of physics and the values of the constants in them. For the case of the cosmical constant, which is the maximum number of ultimate particles in the universe, one finds the upper limit to the number of 'quadruple wave-functions,' which turns out to be finite. Any relativistic wave function embodies both the fundamentals of relativity and quantum theory and the methods of physical interpreta tion'; the *quadruple* wave function also takes account of the association of measurement with the number 4. Thus all the four types of data summarised above are required for the calculation, which will serve as an example of Eddington's calculations of the fundamental constants.

An example of the calculation of the form of a fundamental law of physics is provided by Eddington's derivation of Dirac's equation—the relativistic wave-equation for an electron; and Podolsky has shown[19] that in the derivation he makes use of the usual physical assumptions, though in a somewhat disguised form which is easily overlooked.

Such a condensed account cannot do justice to the brilliance of Eddington's mathematical methods, but it has sought to bring out the physical significance of a very remarkable physical theory, by placing it in a suitable philosophical setting. For this purpose it has been necessary to isolate the physical theory from a large number of philosophical statements which Eddington apparently believes to be interdependent with it; and incidentally it has appeared that the theory is specially well adapted to White-

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[19] Podolsky. *Physical Review* (1938), Vol. 53, p. 591.

head's views on how scientists can evade philosophy when they wish to do so.

II

It is worth considering in more detail the philosophical views which Eddington appears to regard as integral to his theory. If the foregoing interpretation is correct, they are not essential to it; and if the following comments are correct, they are largely false. We will first state them briefly, then discuss them point by point.

(i) Eddington begins by claiming that his results are based solely upon 'scientific epistemology,' by which he means a consideration of the knowledge (using the word in a wide sense) obtained by the methods of physical science. (ii) He states that these results are, therefore, known to us *a priori*. (iii) He adopts an epistemological position which is perhaps best described as pseudo-Kantian, in that whereas Kant held that a man imposes the categories of substance and causality in virtue of the nature of his mind (considered in isolation from its objects), Eddington appears to hold that a physicist likewise imposes the relativity and quantum restrictions on observation because of the limitations of his 'sensory equipment.' (iv) He concludes that the fundamentals of modern physics are 'wholly subjective.' Each of these four points calls for examination.

(i) The phrase 'scientific epistemology' suggests a body of philosophical beliefs, independent of the results of any particular observations. But such a body of beliefs would seem to consist simply of two propositions: that physical science ignores all the objects of experience except inorganic matter, and that it ignores every aspect of the latter except the measurable. But Eddington's deductions depend also upon data empirically obtained.

Eddington does not use the term 'scientifc epistemology' very clearly. In several passages he states that scientific epistemology is subject to observational test and that his conclusions have a purely scientific basis.[20] But in other passages he states that laws thus established are 'compulsory, universal and exact,' that they 'are of the nature of truisms,' and are 'not empirical regularities.'[21] It does not seem possible to reconcile these two points of view. The various kinds of evidence which Eddington uses have been discussed above and it is clear that his conclusions are not deducible without the use of the results of particular observations. That the results lead to very comprehensive theories does not alter the fact that those theories are probabilified by induction and have no more exalted status than is implied by this.

(ii) Eddington's conclusions, then, depend upon propositions which are believed *a posteriori*, and are not based solely on propositions known *a priori*—that is, propositions known independent of all experience except such as is necessary to render the terms intelligible and the propositions capable of being entertained.[22]

Eddington's use of the term '*a priori*' is confusing. When he first introduces it, he says: 'I think I am using the term "*a priori* knowledge" with the recognised meaning—knowledge which we have of the physical universe prior to actual observation of it.'[23] This is ambiguous. Sometimes, as when he claims that laws established epistemologically 'are compulsory and will be obeyed universally and invariably,' he seems to make '*a priori*' mean 'independent of any particular observation.' Elsewhere he abandons ordinary philosophical usage and writes: 'Epistemological or *a priori* knowledge is prior to the carrying out of the observations but not prior to the develop-

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[20] *Op. cit.*, pp. 24, 103, 104, 105.

[21] *Op. cit.*, pp. 5, 57, 187.

[22] Neglecting, for the moment, Kant's special use of the term.

[23] *Op. cit.*, p. 24.

ment of a plan of observation.' But this plan of observation rests upon previous experience, namely (in current physics) the experiments which lead to the relativity and quantum theories. It is formulated *a posteriori*. In consequence, Eddington's usage here of the term *a priori* is a very odd one; the propositions to which he refers are not *a priori* in any sense relevant to philosophy.

Later on in the book, Eddington seems to alter the meaning of *a priori* and make it characterise propositions about physical method which he regards as known to the mind in virtue of its own nature and activity, and not in virtue of any characteristic of its objects. (Apart from the limitation to physics, this is just the usage which Kant seems to adopt in the later part of the *Analytic.*) Thus, Eddington states that in physics uniformities are imposed on the results of observation by the procedure of observation; and that we impose the usual methods of physical interpretation willy-nilly on the observations; that, in fact, the fundamental laws and constants of physics represent 'the mark of the observer's sensory and intellectual equipment,' and that they can be discovered *a priori* by scrutinising certain 'engrained frames of thought.'[24]

(iii) Thus we have three senses of the term *a priori* in use in the same book. One, which is barely mentioned but which alone is relevant to the scientific work described in the book, is confused with a second (the usual philosophical sense) and a third (the special sense used by Kant in some passages). Eddington nowhere justifies his transitions from one usage to another, although they are very important for much of his thought. The confusion of the first usage with the second seems to account for his claiming a better than inductive certainty for his results. The confusion of the first and second usages with the third leads him to suppose that the mind imposes upon its objects certain characteristics which depend on the nature of the

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[24] *Op. cit.*, pp. 116, 134, etc.

mind and not at all upon that of its objects—whereas in fact these characteristics are formulated in view of the results of numerous experiments and have the same kind of status as a theory which predicts results in agreement with experiment. Incidentally, Eddington is not dealing with the same problem as Kant, and he rightly rejects the Kantian label; Kant, like Eddington, believed in the imposition of characteristics by the mind on the manifold of sense, but he was considering the categories, and not the much less fundamental characteristics dealt with by Eddington.

(iv) It is because he drifts into using '*a priori*' in this pseudo-Kantian sense that Eddington comes to regard the fundamental laws and constants of physics as 'purely subjective.' This appears clearly from the following passage: 'The fundamental laws and constants of physics are wholly subjective . . . for we could not have this kind of *a priori* knowledge of laws governing an objective universe. The subjective laws are a consequence of the conceptual frame of thought into which our observational knowledge is forced by our method of formulating it.'[25] But we have rejected the pseudo-Kantian view of the fundamentals of physics, as being unsupported and due to a confusion; we may therefore deny also that they are wholly subjective. It is evidently true that in investigating the laws of material nature we are limited both as to our sensory data and as to our mathematical technique. But these limitations do not introduce characteristics due solely to the nature of the mind. The 'frames of thought' are developed with constant reference to the empirical data, and there are no grounds for the belief that they are formally dependent on the nature of the mind alone and independent of its objects.

It seems impossible, then, to accept Eddington's own interpretation of his work on the fundamental laws and con-

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[25] *Op. cit.*, p. 105, *cf.* p. 134.

stants of physics. It is impossible also to accept many points of view that we have not mentioned; for instance, the beliefs that a philosophy can be 'scientifically grounded,' that serious contributions to philosophy can be made as a result of advances in natural science, that the indeterminacy principle has a bearing upon human action, and that realism is subject to scientific test.

But the scientific importance of the work is immense; moreover, in the course of it there are indications of great interest of the way in which modern physics is being developed with explicit attention to its limitations. While one regrets that such a contribution to physics should be presented as if allied with so inadequate a philosophy, the proper comment doubtless is that which St. Jerome made about Origen: 'Let us not imitate his defects, whose virtues we cannot follow.'

E. F. CALDIN.