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THE NATURE
OF THE
PHYSICAL WORLD

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PREFACE

This book is substantially the course of Gifford Lectures which I delivered in the University of Edinburgh in January to March 1927. It treats of the philosophical outcome of the great changes of scientific thought which have recently come about. The theory of relativity and the quantum theory have led to strange new conceptions of the physical world; the progress of the principles of thermodynamics has wrought more gradual but no less profound change. The first eleven chapters are for the most part occupied with the new physical theories, with the reasons which have led to their adoption, and especially with the conceptions which seem to underlie them. The aim is to make clear the scientific view of the world as it stands at the present day, and, where it is incomplete, to judge the direction in which modern ideas appear to be tending. In the last four chapters I consider the position which this scientific view should occupy in relation to the wider aspects of human experience, including religion. The general spirit of the inquiry followed in the lectures is stated in the concluding paragraph of the Introduction (p. xviii).

I hope that the scientific chapters may be read with interest apart from the later applications in the book; but they are not written quite on the lines that would have been adopted had they been wholly independent. It would not serve my purpose to give an easy introduction to the rudiments of the relativity and quantum theories; it was essential to reach the later and more recondite developments in which the conceptions of greatest philosophical significance are to be found. Whilst much of the book should prove fairly easy reading, arguments of considerable difficulty have to be taken in their turn.

My principal aim has been to show that these scientific developments provide new material for the philosopher. I have, however, gone beyond this and indicated how I myself think the material might be used. I realise that the philosophical views here put forward can only claim attention in so far as they are the direct outcome of a study and apprehension of modern scientific work. General ideas of the nature of things which I may have formed apart from this particular stimulus from science are of little moment to anyone but myself. But although the two sources of ideas were fairly distinct in my mind when I began to prepare these lectures they have become inextricably combined in the effort to reach a coherent outlook and to defend it from probable criticism. For that reason I would like to recall that the idealistic tinge in my conception of the physical world arose out of mathematical researches on the relativity theory. In so far as I had any earlier philosophical views, they were of an entirely different complexion.

From the beginning I have been doubtful whether it was desirable for a scientist to venture so far into extra-scientific territory. The primary justification for such an expedition is that it may afford a better view of his own scientific domain. In the oral lectures it did not seem a grave indiscretion to speak freely of the various suggestions I had to offer. But whether they should be recorded permanently and given a more finished appearance has been difficult to decide. I have much to fear from the expert philosophical critic, but I am filled with even more apprehension at the thought of readers who may look to see whether the book is "on the side of the angels" and judge its trustworthiness accordingly.

During the year which has elapsed since the delivery of the lectures I have made many efforts to shape this and other parts of the book into something with which I might feel better content. I release it now with more diffidence than I have felt with regard to former books.

The conversational style of the lecture-room is generally considered rather unsuitable for a long book, but I decided not to modify it. A scientific writer, in forgoing the mathematical formulae which are his natural and clearest medium of expression, may perhaps claim some concession from the reader in return. Many parts of the subject are intrinsically so difficult that my only hope of being understood is to explain the points as I would were I face to face with an inquirer.

It may be necessary to remind the American reader that our nomenclature for large numbers differs from his, so that a billion here means a million million.

A. S. E.

August, 1928

INTRODUCTION

I have settled down to the task of writing these lectures and have drawn up my chairs to my two tables. Two tables! Yes; there are duplicates of every object about me—two tables, two chairs, two pens.

This is not a very profound beginning to a course which ought to reach transcendent levels of scientific philosophy. But we cannot touch bedrock immediately; we must scratch a bit at the surface of things first. And whenever I begin to scratch the first thing I strike is—my two tables.

One of them has been familiar to me from earliest years. It is a commonplace object of that environment which I call the world. How shall I describe it? It has extension; it is comparatively permanent; it is coloured; above all it is *substantial*. By substantial I do not merely mean that it does not collapse when I lean upon it; I mean that it is constituted of "substance" and by that word I am trying to convey to you some conception of its intrinsic nature. It is a *thing*; not like space, which is a mere negation; nor like time, which is—Heaven knows what! But that will not help you to my meaning because it is the distinctive characteristic of a "thing" to have this substantiality, and I do not think substantiality can be described better than by saying that it is the kind of nature exemplified by an ordinary table. And so we go round in circles. After all if you are a plain commonsense man, not too much worried with scientific scruples, you will be confident that you understand the nature of an ordinary table. I have even heard of plain men who had the idea that they could better understand the mystery of their own nature if scientists would discover a way of explaining it in terms of the easily comprehensible nature of a table.

Table No. 2 is my scientific table. It is a more recent acquaintance and I do not feel so familiar with it. It does not belong to the world previously mentioned—that world which spontaneously appears around me when I open my eyes, though how much of it is objective and how much subjective I do not here consider. It is part of a world which in more devious ways has forced itself on my attention. My scientific table is mostly emptiness. Sparsely scattered in that emptiness are numerous electric charges rushing about with great speed; but their combined bulk amounts to less than a billionth of the bulk of the table itself. Notwithstanding its strange construction it turns out to be an entirely efficient table. It supports my writing paper as satisfactorily as table No. 1; for when I lay the paper on it the little electric particles with their headlong speed keep on hitting the underside, so that the paper is maintained in shuttlecock fashion at a nearly steady level. If I lean upon this table I shall not go through; or, to be strictly accurate, the chance of my scientific elbow going through my scientific table is so excessively small that it can be neglected in practical life. Reviewing their properties one by one, there seems to be nothing to choose between the two tables for ordinary purposes; but when abnormal circumstances befall, then my scientific table shows to advantage. If the house catches fire my scientific table will dissolve quite naturally into scientific smoke, whereas my familiar table undergoes a metamorphosis of its substantial nature which I can only regard as miraculous.

There is nothing *substantial* about my second table. It is nearly all empty space—space pervaded, it is true, by fields of force, but these are assigned to the category of "influences", not of "things". Even in the minute part which is not empty we must not transfer the old notion of substance. In dissecting matter into electric charges we have travelled far from that picture of it which first gave rise to the conception of substance, and the meaning of that conception—if it ever had any—has been lost by the way. The whole trend of modern scientific views is to break down the separate categories of "things", "influences", "forms", etc., and to substitute a common background of all experience. Whether we are studying a material object, a magnetic field, a geometrical figure, or a duration of time, our scientific information is summed up in measures; neither the apparatus of measurement nor the mode of using it suggests that there is anything essentially different in these problems. The measures themselves afford no ground for a classification by categories. We feel it necessary to concede some background to the measures—an external world; but the attributes of this world, except in so far as they are reflected in the measures, are outside scientific scrutiny. Science has at last revolted against attaching the exact knowledge contained in these measurements to a traditional picture-gallery of conceptions which convey no authentic information of the background and obtrude irrelevancies into the scheme of knowledge.

I will not here stress further the non-substantiality of electrons, since it is scarcely necessary to the present line of thought. Conceive them as substantially as you will, there is a vast difference between my scientific table with its substance (if any) thinly scattered in specks in a region mostly empty and the table of everyday conception which we regard as the type of solid reality

—an incarnate protest against Berkeleian subjectivism. It makes all the difference in the world whether the paper before me is poised as it were on a swarm of flies and sustained in shuttlecock fashion by a series of tiny blows from the swarm underneath, or whether it is supported because there is substance below it, it being the intrinsic nature of substance to occupy space to the exclusion of other substance; all the difference in conception at least, but no difference to my practical task of writing on the paper.

I need not tell you that modern physics has by delicate test and remorseless logic assured me that my second scientific table is the only one which is really there—wherever "there" may be. On the other hand I need not tell you that modern physics will never succeed in exorcising that first table—strange compound of external nature, mental imagery and inherited prejudice—which lies visible to my eyes and tangible to my grasp. We must bid good-bye to it for the present for we are about to turn from the familiar world to the scientific world revealed by physics. This is, or is intended to be, a wholly external world.

"You speak paradoxically of two worlds. Are they not really two aspects or two interpretations of one and the same world?"

Yes, no doubt they are ultimately to be identified after some fashion. But the process by which the external world of physics is transformed into a world of familiar acquaintance in human consciousness is outside the scope of physics. And so the world studied according to the methods of physics remains detached from the world familiar to consciousness, until after the physicist has finished his labours upon it. Provisionally, therefore, we regard the table which is the subject of physical research as altogether separate from the familiar table, without prejudging the question of their ultimate identification. It is true that the whole scientific inquiry starts from the familiar world and in the end it must return to the familiar world; but the part of the journey over which the physicist has charge is in foreign territory.

Until recently there was a much closer linkage; the physicist used to borrow the raw material of his world from the familiar world, but he does so no longer. His raw materials are aether, electrons, quanta, potentials, Hamiltonian functions, etc., and he is nowadays scrupulously careful to guard these from contamination by conceptions borrowed from the other world. There is a familiar table parallel to the scientific table, but there is no familiar electron, quantum or potential parallel to the scientific electron, quantum or potential. We do not even desire to manufacture a familiar counterpart to these things or, as we should commonly say, to "explain" the electron. After the physicist has quite finished his world-building a linkage or identification is allowed; but premature attempts at linkage have been found to be entirely mischievous.

Science aims at constructing a world which shall be symbolic of the world of commonplace experience. It is not at all necessary that every individual symbol that is used should represent something in common experience or even something explicable in terms of common experience. The man in the street is always making this demand for concrete explanation of the things referred to in science; but of necessity he must be disappointed. It is like our experience in learning to read. That which is written in a book is symbolic of a story in real life. The whole intention of the book is that ultimately a reader will identify some symbol, say BREAD, with one of the conceptions of familiar life. But it is mischievous to attempt such identifications prematurely, before the letters are strung into words and the words into sentences. The symbol *A* is not the counterpart of anything in familiar life. To the child the letter *A* would seem horribly abstract; so we give him a familiar conception along with it. "*A* was an Archer who shot at a frog." This tides over his immediate difficulty; but he cannot make serious progress with word-building so long as Archers, Butchers, Captains, dance round the letters. The letters are abstract, and sooner or later he has to realise it. In physics we have outgrown archer and apple-pie definitions of the fundamental symbols. To a request to explain what an electron really is supposed to be we can only answer, "It is part of the A B C of physics".

The external world of physics has thus become a world of shadows. In removing our illusions we have removed the substance, for indeed we have seen that substance is one of the greatest of our illusions. Later perhaps we may inquire whether in our zeal to cut out all that is unreal we may not have used the knife too ruthlessly. Perhaps, indeed, reality is a child which cannot survive without its nurse illusion. But if so, that is of little concern to the scientist, who has good and sufficient reasons for pursuing his investigations in the world of shadows and is content to leave to the philosopher the determination of its exact status in regard to reality. In the world of physics we watch a shadowgraph performance of the drama of familiar life. The shadow of my elbow rests on the shadow table as the shadow ink flows over the shadow paper. It is all symbolic, and as a symbol the physicist leaves it. Then comes the alchemist Mind who transmutes the symbols. The sparsely spread nuclei of electric force become a tangible solid; their restless agitation becomes the warmth of summer; the octave of aethereal vibrations becomes a gorgeous rainbow. Nor does the alchemy stop here. In the transmuted world new significances arise which are scarcely to be traced in the world of symbols; so that it becomes a world of beauty and purpose—and, alas, suffering and evil.

The frank realisation that physical science is concerned with a world of shadows is one of the most significant of recent advances. I do not mean that physicists are to any extent preoccupied with the philosophical implications of this. From their point of view it is not so much a withdrawal of untenable claims as an assertion of freedom for autonomous development. At the moment I am not insisting on the shadowy and symbolic character of the world of physics because of its bearing on philosophy, but because the aloofness from familiar conceptions will be apparent in the scientific theories I have to describe. If you are not prepared for this aloofness you are likely to be out of sympathy with modern scientific theories, and may even think them ridiculous—as, I daresay, many people do.

It is difficult to school ourselves to treat the physical world as purely symbolic. We are always relapsing and mixing with the symbols incongruous conceptions taken from the world of consciousness. Untaught by long experience we stretch a hand to grasp the shadow, instead of accepting its shadowy nature. Indeed, unless we confine ourselves altogether to mathematical symbolism it is hard to avoid dressing our symbols in deceitful clothing. When I think of an electron there rises to my mind a hard, red, tiny ball; the proton similarly is neutral grey. Of course the colour is absurd—perhaps not more absurd than the rest of the conception—but I am incorrigible. I can well understand that the younger minds are finding these pictures too concrete and are striving to construct the world out of Hamiltonian functions and symbols so far removed from human preconception that they do not even obey the laws of orthodox arithmetic. For myself I find some difficulty in rising to that plane of thought; but I am convinced that it has got to come.

In these lectures I propose to discuss some of the results of modern study of the physical world which give most food for philosophic thought. This will include new conceptions in science and also new knowledge. In both respects we are led to think of the material universe in a way very different from that prevailing at the end of the last century. I shall not leave out of sight the ulterior object which must be in the mind of a Gifford Lecturer, the problem of relating these purely physical discoveries to the wider aspects and interests of our human nature. These relations cannot but have undergone change, since our whole conception of the physical world has radically changed. I am convinced that a just appreciation of the physical world as it is understood to-day carries with it a feeling of open-mindedness towards a wider significance transcending scientific measurement, which might have seemed illogical a generation ago; and in the later lectures I shall try to focus that feeling and make inexpert efforts to find where it leads. But I should be untrue to science if I did not insist that its study is an end in itself. The path of science must be pursued for its own sake, irrespective of the views it may afford of a wider landscape; in this spirit we must follow the path whether it leads to the hill of vision or the tunnel of obscurity. Therefore till the last stage of the course is reached you must be content to follow with me the beaten track of science, nor scold me too severely for loitering among its wayside flowers. That is to be the understanding between us. Shall we set forth?

CONTENTS

Chapter I

THE DOWNFALL OF CLASSICAL PHYSICS

The Structure of the Atom. Between 1905 and 1908 Einstein and Minkowski introduced fundamental changes in our ideas of time and space. In 1911 Rutherford introduced the greatest change in our idea of matter since the time of Democritus. The reception of these two changes was curiously different. The new ideas of space and time were regarded on all sides as revolutionary; they were received with the greatest enthusiasm by some and the keenest opposition by others. The new idea of matter underwent the ordinary experience of scientific discovery; it gradually proved its worth, and when the evidence became overwhelmingly convincing it quietly supplanted previous theories. No great shock was felt. And yet when I hear to-day protests against the Bolshevism of modern science and regrets for the old-established order, I am inclined to think that Rutherford, not Einstein, is the real villain of the piece. When we compare the universe as it is now supposed to be with the universe as we had ordinarily preconceived it, the most arresting change is not the rearrangement of space and time by Einstein but the dissolution of all that we regard as most solid into tiny specks floating in void. That gives an abrupt jar to those who think that things are more or less what they seem. The revelation by modern physics of the void within the atom is more disturbing than the revelation by astronomy of the immense void of interstellar space.

The atom is as porous as the solar system. If we eliminated all the unfilled space in a man's body and collected his protons and electrons into one mass, the man would be reduced to a speck just visible with a magnifying glass.

This porosity of matter was not foreshadowed in the atomic theory. Certainly it was known that in a gas like air the atoms are far separated, leaving a great deal of empty space; but it was only to be expected that material with the characteristics of air should have relatively little substance in it, and "airy nothing" is a common phrase for the insubstantial. In solids the atoms are packed tightly in contact, so that the old atomic theory agreed with our preconceptions in regarding solid bodies as mainly substantial without much interstice.

The electrical theory of matter which arose towards the end of the nineteenth century did not at first alter this view. It was known that the negative electricity was concentrated into unit charges of very small bulk; but the other constituent of matter, the positive electricity, was pictured as a sphere of jelly of the same dimensions as the atom and having the tiny negative charges embedded in it. Thus the space inside a solid was still for the most part well filled.

But in 1911 Rutherford showed that the positive electricity was also concentrated into tiny specks. His scattering experiments proved that the atom was able to exert large electrical forces which would be impossible unless the positive charge acted as a highly concentrated source of attraction; it must be contained in a nucleus minute in comparison with the dimensions of the atom. Thus for the first time the main volume of the atom was entirely evacuated, and a "solar system" type of atom was substituted for a substantial "billiard-ball". Two years later Niels Bohr developed his famous theory on the basis of the Rutherford atom, and since then rapid progress has been made. Whatever further changes of view are in prospect, a reversion to the old substantial atoms is unthinkable.

The accepted conclusion at the present day is that all varieties of matter are ultimately composed of two elementary constituents—protons and electrons. Electrically these are the exact opposites of one another, the proton being a charge of positive electricity and the electron a charge of negative electricity. But in other respects their properties are very different. The proton has 1840 times the mass of the electron, so that nearly all the mass of matter is due to its constituent protons. The proton is not found unadulterated except in hydrogen, which seems to be the most primitive form of matter, its atom consisting of one proton and one electron. In other atoms a number of protons and a lesser number of electrons are cemented together to form a nucleus; the electrons required to make up the balance are scattered like remote satellites of the nucleus, and can even escape from the atom and wander freely through the material. The diameter of an electron is about 1/50,000 of the diameter of an atom; that of the nucleus is not very much larger; an isolated proton is supposed to be much smaller still.

Thirty years ago there was much debate over the question of aether-drag—whether the earth moving round the sun drags the aether with it. At that time the solidity of the atom was unquestioned, and it was difficult to believe that matter could push its way through the aether without disturbing it. It was surprising and perplexing to find as the result of experiments that no convection of the aether occurred. But we now realise that the aether can slip through the atoms as easily as