J. S. Haldane

THE PHILOSOPHICAL BASIS OF BIOLOGY

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DONNELLAN LECTURES, UNIVERSITY OF DUBLIN, 1930

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PREFACE

This volume represents the lectures which I gave under the Donnellan Foundation at Trinity College, Dublin, in the spring of 1930. They are carefully revised and considerably extended, but for various reasons I have retained the lecture form, and particularly because, through their connection with the philosophical ideas of George Berkeley, they are specially associated with the place where they were delivered. A Supplement is, however, added, dealing with three books which have appeared since the original lectures were written. The references to these books will, I think, render more clear the argument of the lectures.

It is difficult to realise the great development which is at present occurring in the scientific interpretation of our experience. Since the time of Galileo and the Renaissance, European thought had become more and more accustomed to the idea that, leaving aside the consideration of invisible spiritual reality, the visible and tangible universe of our experience corresponds with what Galileo and his great successors in physical science represented to themselves as the physical world. This idea had come to be accepted as only "common sense"; but we are now witnessing its gradual passing.

Galileo and his successors did not realise that in taking whatever is visible and tangible as corresponding to their picture of physical reality they had, in fact, made an assumption which was inconsistent with common observation of life and of conscious behaviour, and which finally was to prove inconsistent with physical observation itself, even when life and conscious behaviour are left out of account. This assumption has led to very great confusion in biology and psychology, and has greatly hampered the development of these branches of knowledge.

The main object of the present lectures was to present as clearly and simply as possible the theoretical picture which biological observation seems to force upon us. In the last lecture I have also discussed the relation of this picture to that which we reach through observation of conscious behaviour; and final conclusions are arrived at as to the relations between scientific interpretation of any kind and the reality which lies behind it.

I trust that the lectures may contribute towards a realisation and understanding of the intellectual development which has just been referred to.

OXFORD, J. S. HALDANE.
April 1931.

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THE AXIOM OF BIOLOGY

Perhaps no one could appreciate more than I do the honour of being asked to give the Donnellan Lectures at this old and celebrated seat of learning. Trinity College is associated with contributions to knowledge in every direction. There was, however, one Trinity College man of over two centuries ago to whose writings my thoughts often came back while I was preparing these lectures. This was George Berkeley, better known as Bishop Berkeley. It was Berkeley who, in modern times, first questioned the independent reality of what we interpret as a physical world, and maintained that *esse est percipi*. Although there are now no philosophers who could call themselves Berkeleians, yet his reasoning has been carried forward by his philosophical successors, and I think that if you listen to my lectures you will hear it coming to life again, though in a different form from that which he gave it.

My subject is "The Philosophical Basis of Biology"; and biology is the science which deals with the phenomena of life. I think the wording of this definition is of great importance. We might, for instance, call biology the science which deals with living matter, or with living organisms. In either case we should convey in our definition a presupposition which seems to me fatal to any satisfactory scientific treatment. We should be presupposing that living organisms can be satisfactorily treated scientifically, either as consisting of matter existing outside other matter, or as peculiar entities existing apart from a foreign environment. It is often regarded as self-evident that it is justifiable, or even necessary, to approach biology from the standpoint of one of these presuppositions; but, as we shall see, there is a previous question as to whether any scientific meaning can be attached to the conception of living matter, or to that of an organism apart from its environment. This previous question is analogous to that which Berkeley raised when he questioned whether there is any meaning in a physical universe apart from its being perceived.

Let us consider what we mean by the scientific study of any subject. Are we attempting to define the reality which lies behind our more or less confused experience? To a certain extent we certainly are; but when we consider the matter further we can see that our attempt is a limited one, since in every science we start with certain axioms which we do not discuss or question. If we begin to question them, and consider how far they are consistent with the whole of our experience, we have passed from science into philosophy. When, for instance, we question, as Berkeley did, whether the axioms of Newtonian physics are consistent with the fact that our world is only revealed to us in perception, we have left physical science. In spite of Berkeley, Hume, and Kant, the physicists were quite content with their axioms, and could point to their enormous practical uses, beyond which they were not looking. As applied to that part or aspect of our experience which was under consideration, these axioms were extremely useful and apparently satisfactory.

The scientific treatment of any part of our experience makes prediction of a certain kind possible, or enables us to see back into the past. But the manner in which our own activity enters into the prediction does not come into the scientific treatment.

From the scientific study of mathematics we are enabled to predict from given data such matters as the extent of an area, the capacity of a space, the time at which, what we call a certain event will, under certain assumptions, happen, or the past time at which an event has happened. We do not discuss whether, or in what sense, the space and time which we assume are real.

From the scientific study of physics and chemistry, which presuppose sufficient mathematics, we can deduce far more about what will happen, or what has happened. We can predict, for instance, how much of what we call power must be applied, or deduce what power has been, for the production of what we call a certain change; or how to go about designing a telescope or microscope, or the transmission of power or information from place to place. We can see also how to make all sorts of useful substances, or separate them when they are in a crude or impure state. There is no end to the usefulness of physics and chemistry in enabling us to predict what will happen under certain conditions, and so enabling us to act advantageously. In our ordinary physical science, however, we do not attempt to give any account of the sense in which what we treat as physical data are real or come to appear to us as a perceived world, and to take part in the realisation of values. Nor do we question the justification for making use of the conceptions of matter and energy. We assume provisionally that we are in presence of a world of self-existing bodies and self-existing energy within what we call space and time.

Laplace swept the heavens with his telescope, and by doing so could find no trace of God, or of a spiritual world. Had he looked at both ends of his telescope, taking into account the activity of the observer as well as his physically interpreted observations, the result would have been different; but physical science deals with an aspect of experience in which no account is taken of anything to which physical axioms are not applicable; and this excludes consideration of perception or of how what we perceive is of value, or is spiritually significant.

From mathematical, physical, and chemical treatises we learn the general principles and axioms on which the corresponding sciences are based; and we can also learn the history of the manner in which these principles were gradually discovered and built up by successive investigators. When, however, we come to the phenomena of life, the principles and axioms appear by no means so clear. The relations between a living organism and its environment, and between the parts of a living organism seem to be, at least on the surface, different from what we call physical and chemical relations. A living organism seems to be continuously adapting itself to its environment, or its environment to itself, and its parts to one another, in such a way that during its life its structure and activities are maintained in a manner which is characteristic of it, and are transmitted from generation to generation. We are unable to see how this maintenance can be described in terms of physical and chemical principles. In the biological sciences we are constantly also making use of expressions which are either peculiar to biology, or used in a sense which is peculiar. Such words as "life," "function," "organ," "species," "heredity," are of this sort.

When we ask how the conceptions and expressions used in biology are related to those used in the physical sciences, we meet with different answers. The answer which was most usual among scientific men till about the middle of last century was that living organisms are different from anything that is not living, owing to the fact that each of them is the seat of action of a specific influence—that of the vital principle or vital force—the peculiarity of which determines in each case the peculiarities of the behaviour of an organism. This conception represents what is generally known as vitalism. Vitalism came, however, during the latter half of last century, to be almost universally rejected by biologists, and for a very good reason. We can show from both common observation and experiment that whatever happens within the body of a living organism is ultimately dependent on conditions outside it, in its environment. This is becoming constantly more evident. I need hardly mention, for instance, that the life of a higher organism is dependent from moment to moment on a continuous supply of oxygen from the environment, and that there is a similar dependence, though not so immediate, on various materials in food and drink, and on the energy which is constantly passing into or out of the organism.

It seemed, therefore, that despite superficial appearances, there can be no ultimate difference between the modes of interpretation which we employ in the physical sciences and in biology. The ultimate identity between the two sets of interpretations came thus to be treated as an axiom by the majority of biologists. It followed, of course, that in the investigation of biological phenomena we must aim at nothing less than the physical and chemical interpretation of all the phenomena of life.

This became the actual ideal of nearly all the leading biologists in the latter part of last century; and to most existing biologists it remains at least the nominal ideal. In accordance with it, biology, and particularly physiology, came to be taught as a body of knowledge describing, as far as possible, the physical structure of organisms, the action of physical and chemical factors in the activities of life, and the physical and chemical origin of organic structure. Matter had, however, to be distinguished as "living" or "non-living." This was necessary, since repeated attempts to interpret various physiological activities as definite physico-chemical processes had hitherto broken down, leaving a great and extremely important residuum of what was usually called "vital activity," though this activity was theoretically assumed to be only very complex physico-chemical action.

Into the residuum went reproduction and all the central facts relating to heredity and the specificity of a species. Along with reproduction went the activities of assimilation and secretion, together with all the integrative processes which follow or accompany every kind of physiological activity. This meant that almost the whole of what might properly be called elementary physiology or biology went into the residuum. But any conception of how the phenomena of this residuum could be interpreted physico-chemically was absent.

I think that the general public, misled by the parrot-like assertions of various popular writers, have only a very small knowledge of the obscurity hidden behind such expressions as "living matter." Physiologists themselves, moreover, have acquired the habit, almost unconscious, of referring to the "mechanisms" of various physiological activities, though they have not the remotest conception of what sort of mechanisms these activities represent. Hence the use of the word "mechanism" is a mere empty formality, though it is calculated to mislead an unsuspecting outside public.

As it seems to me, the result of the attempt to place biology on a physico-chemical basis has been far from encouraging. It has been necessary to pass by, without theoretical recognition, the persistent and specific co-ordination of structure, activity, and environment which shows itself in the lives of organisms, whether plants or animals, and which is transmitted from parent to offspring in the course of inheritance. The more we discover as to physiological activity and inheritance, the more difficult does it become to imagine any physical or chemical description or explanation which could in any way cover the facts as to the persistent co-ordination. From the standpoint of the physical sciences the maintenance and reproduction of a living organism is nothing less than a standing miracle, and for the reason that co-ordinated maintenance of structure and activity is inconsistent with the physical conception of self-existent matter and energy.

Though the physico-chemical, or mechanistic, conception of life is still very much alive in the minds of popular writers, I think it is now far from being so among serious students of biology. Such support as it still receives is, at least, nearly always very half-hearted, and depends mainly on the absence of any clear conception of what can take the place of physico-chemical interpretation.

ORGANISM AND ENVIRONMENT

It is my object in this course of lectures to discuss what can be substituted, and in doing so to define and defend, if possible more clearly than hitherto, the scientific principle or axiom which seems to me to emerge in the study of biology, and to be essential in the scientific study of the phenomena of life.

Let us consider the relation between a living organism and its environment. The environment may be said to be constantly acting on the organism, and the organism on its environment. The environment is conveying to it food materials, oxygen, and all sorts of stimuli, while the organism is reacting in various ways. We might say the same of any machine or other system working at the expense of material and energy supplied to it by its environment; and we might attribute the peculiarities in the response to peculiarities in the structure of the machine, system, or organism.

We find, however, that the apparent action and reaction between organism and environment has a distinguishing character which prevents us from regarding it as simply action and reaction. The apparent actions and reactions are, when regarded as a whole, seen to be normally so co-ordinated that what appears as structure in the organism is actively maintained. Thus structure and activity cannot be separated. The actions cannot be separated from what seem to be innumerable other simultaneous actions and reactions, so co-ordinated as to express the maintenance of the structure. Hence in interpreting the phenomena we cannot apply the physical conceptions of action and corresponding reaction, or reciprocal action, between self-existing units of matter and energy. We must regard the phenomena as being, in so far as we understand them at all, the active manifestation of a persistent whole; and the whole is what we call the life of the organism, or of the stock to which it belongs. Apart from the conception of life we are lost in endless details—indefinite because they cannot be separately defined. General Smuts has coined the word "holism" for the general principle involved in the conception of life.

When we consider the structure of an organism and of its environment in so far as the environment is concerned in its life, we find that the structural elements in organism and environment are co-ordinated with one another in a specific manner. The organism is adapted to its environment, or the environment, including the internal environment, to the organism, in such a manner that life is maintained. The environment is thus expressed in the structure of each part of the organism, and conversely. When, moreover, we examine what appears to us as organic structure and the structure of organic environment closely, we find that it is the expression of continuous activity, so co-ordinated that the structure is maintained. Thus we cannot separate organic from environmental structure, any more than we can separate the action of the environment from the reaction of the organism.

Moreover, the spatial relations of the parts do not imply their separate existence from one another, since we cannot define them as existing separately when their very existence expresses co-ordination with one another. The co-ordination extends over surrounding environment, and the spatial relations of parts and environment express unity, not separation. They also cannot be described as existing within space; for the co-ordination embodied in them is not limited to a certain position in space, but extends indefinitely beyond any spatial position which we might attempt to assign to it.

We are also unable to apply mathematical reasoning to life, since mathematical treatment assumes a separability of events in space which does not exist for life as such. We are dealing with an indivisible whole when we are dealing with a life. The sciences to which mathematical reasoning can be applied are sometimes distinguished as exact sciences; but biology is just as much an exact science as any other science. In so far as we discover co-ordinated maintenance we reach exactitude in biology. If, however, biology is treated as a science which seeks for physico-chemical explanation, it is neither an exact science nor a real science at all, but only a blind groping after something which can never be found.

Physiologists are constantly discovering what, following the present custom, they denominate as physical or chemical mechanisms within the living body. But these so-called mechanisms are at the same time actively maintained at the right places and in the right functional states. Their discovery is thus no more a step towards a physico-chemical conception of life than a step away from it, but simply a step in the direction of knowledge as to how life as such manifests itself.

It has for long been a familiar idea that within an organism the mutual influences of the parts on one another can be regarded as manifestations of the maintenance of the life of the organism regarded as a whole. The different organs were regarded as each performing a function or functions necessary to the maintenance of the whole organism. But alongside this idea there remained the idea that the environment of an organism can be regarded as simply a physical and chemical environment outside this whole, and capable of description in terms of physical and chemical principles; also that even within the organism the same physical and chemical conceptions are applicable, except in so far as there is interference by a peculiar influence within the organism, which influence accounts for the maintenance of the organism as a specific whole.

Thus the idea in question was inseparable from vitalism, and consequently fell into the background in recent times, and came to be generally treated as being, at the best, only a heuristic idea, to be discarded as knowledge accumulated with regard to the physical and chemical processes which actually determine all the phenomena in living organisms.

When we see that not only are physico-chemical conceptions incapable of representing the phenomena of life, but that the conception of life embraces the environment of an organism, as well as what is within its body, the objections to using it as the basis of biology disappear. The conception of life corresponds simply to what we perceive when we observe the phenomena of life as such. We perceive the relations of the parts and environment of an organism as being of such a nature that a normal and specific structure and environment is actively maintained. This active maintenance is what we call life, and the perception of it is the perception of life. The existence of life as such is thus the axiom on which scientific biology depends.

I must now turn more specifically to morphology or anatomy, which is still commonly regarded as a fundamentally different side of biology from physiology. Morphology deals with the relationships which are found to exist within the structure of organisms, and with the relations of structure to environment.

In investigating the structure of any species of organism morphology, or scientific anatomy, assumes, and demonstrates with ever-increasing completeness, the persistent and specific character of the relationship between the parts. In comparing the structure of different species it also takes as a working hypothesis that specific identities in relationships of parts are fundamentally the same in many different species of organisms, so that the latter form naturally related genera or families; and in the light of the theory of organic evolution and the facts revealed by palæontology it has become possible to attribute the fundamental identities in structural relationships to community in descent.

It is often supposed, or assumed off-hand, that the Darwinian theory of differentiation of species by natural selection amounts to a physico-chemical theory of the differentiation of structure in living organisms, and a step towards a mechanistic conception of life. It seems to me that this is by no means the case. The theory assumes in the first place the natural occurrence of variation, and in the second place the fact of hereditary transmission.

Now any variation which was not heritable would count for nothing in the theory; and the fact of hereditary transmission implies the distinctively biological conception that the life of an organism is a unity which is constantly maintaining and reproducing itself. Quite evidently this conception does not exclude variation, provided that in the variation the unity of life is maintained. In the adaptation of an organism to new circumstances, such as life at a high altitude or in a warmer or colder climate, there is not only adaptation of activities, but also of structure, to the new circumstances. There is therefore variation of structure, whether or not the structural variation is actually inherited. It is the same with variation which is constantly originating in what appears to us as the element of chance existing in the transmission from parents to offspring of different structural characters concerned in hereditary transmission. Life is adapted to the new circumstances which arise in this way, particularly in sexual reproduction; and in the adaptation the unity of life is maintained. The variations thus arising may be regarded as experiments which are essential to securing successful adaptation to new conditions. Variation is therefore consistent with the maintenance of life; and heritable variation must be regarded as a fresh striking out of life, not as an effect under which the organism is passive, as when, in the physically interpreted world, one object is acted on by another. We cannot possibly interpret organic variation as a mere physico-chemical action of environment on organism.

The part played by heredity in the theory of natural selection implies the distinctive conception of life as fundamental in biology. So does the occurrence of heritable variation, which is also an essential feature in the natural selection theory. Both the ordinary structure in any species of organism, and what we regard as variation in it, are active manifestations of life as a unity. They are actively there, and we cannot distinguish between the structure and the activity of which it is the manifestation. Thus the theory of natural selection does not constitute the smallest step in the direction of a mechanistic conception of life.

When, moreover, we examine carefully into what we might superficially interpret as the mere physical and chemical structures of the different individuals in a species—for instance man—we find distinct differences which are actively maintained in the individual, and are presumably heritable. To take one instance, the constitution of proteins, including hæmoglobin, which can be separated from the bodies of different individual men, varies appreciably between different individuals; and this is no mere accidental circumstance, but is as characteristic for the individual as the shape or size of his hands or face, or the colour of his hair. Life is constantly striking out in new directions, as well as propagating itself. The normal of biology is an individual normal and not a statistical normal. Accurate investigation in human physiology has forced this fact upon me again and again. In different individuals of the same species the normal activities of life are appreciably different, and what is normal to one individual may not be so to another.

It is only if we make an impossible separation between living organisms and a physico-chemical environment surrounding them that it appears to us as if living organisms or their germs, with fixed hereditary tendencies, were in contact with a physical environment. As soon as we realise that the unity of life extends over the environment the appearance of a mechanical action of environment on life ceases. Structure and functional relation to environment cannot be separated in the serious scientific study of life, since structure expresses the maintenance of function, and function expresses the maintenance of structure.

Biology deals, not with the dead bodies of organisms, but with their living bodies in constant active relationship with their environment. It has sometimes been attempted to divide biology sharply into anatomy or morphology, a branch dealing with the structure, including chemical structure, of organisms, and physiology, a branch dealing with the manner in which each element in this structure reacts with its physical and chemical environment. At once, however, if we are studying the subject seriously, we are faced with the problem as to how the structure is produced, and is constantly being maintained or reproduced from moment to moment: also as to how this constant reproduction is related, as it evidently is, to the reactions we had set out to study in physiology. We can only go a very short way without encountering these questions, in both morphology and physiology. Hence the division breaks down. The break-down is just as evident if we assume, with the vitalists, that the maintenance and reproduction are due to the influence of a vital principle or "entelechy." It is of course possible to study anatomy as a department of knowledge dealing with the structure which can be distinguished in dead organisms; and such study is of much practical use. But anatomy in this restricted sense can hardly be called biology or dignified with the name of science. We can also study physiology as if it concerned only the reactions of structures discovered in dead organisms; and this also is of some practical use, but not science.

As, moreover, no physico-chemical explanation of the maintenance and reproduction of structure is even remotely conceivable, we tend, if we separate morphology from physiology, to relapse into vitalism, even if it is veiled, in order to fill the gaps in both morphology and physiology. If we will not have anything savouring of vitalism, but still endeavour to retain the distinction between morphology and physiology, we can only acknowledge that we are not in sight of any scientific explanation—in other words any scientific principle capable of throwing light on the phenomena in question. This is not science, but nescience.

The biological interpretation avoids these difficulties, since structure and activity are, from the scientific standpoint of biology, regarded, not as physical structure and action but as an indivisible manifestation of the unity which is called the life of an organism. This unity extends over its relations to environment as well as over the mutual relations of its parts. There is thus no real separation between morphology and physiology. The distinction between them is only an expression of the fact that morphologists and physiologists commonly use different experimental methods of investigation, just as do physiologists who are mainly working with chemical methods, as compared with those who are working at, say, the physiology of the nervous system. To a physiologist, the fact is always immediately present, or should be, that each part of an organism is in constant active relation, not only with other parts of the organism, but also with the environment; and to the physiologist who approaches his subject from the biological standpoint his aim is to exhibit the phenomena as manifestations of the unity of the life of the organism. The question he is always putting before himself is what the function is, in the maintenance of life, of the activity he is investigating; and the same question is in reality constantly before the morphologist as regards the maintenance of structure.

This means the place of every detail of activity and structure in the maintenance of life. Biological explanation is just the finding of this place. The phenomena to be explained biologically appear first as unrelated or very vaguely related —hardly more than mere isolated and therefore imperfectly defined physical and chemical phenomena, unrelated to other phenomena of any sort. The problem before the biologist is to discover how these apparently isolated or unrelated phenomena express aspects of inherent co-ordinated unity. This can only be discovered by observation and experiment, guided, of course, by the idea of what is being sought after and by existing knowledge as to how far this idea has already been verified. A physiologist assumes that such discovery is possible; and in so far as he can contribute towards the discovery he is adding to physiological knowledge.

The tendency to interpret structure as the final outcome of heredity, and to neglect function in this connection, is now passing away. Both morphologists and physiologists are coming to realise that in every detail of living structure the influence of its environment is implied, so that we cannot separate the investigation of structure from that of its physiological environment. Each part of a living organism depends from moment to moment on its active relations with neighbouring parts and with the surrounding environment. We cannot interpret this relationship as a physico-chemical one, since it is so co-ordinated that the specific unity and continuity of a life is maintained. The structure of any one part is determined by various stimuli and inhibitions which can be localised in surrounding parts and the external environment; but the manner in which the stimuli and inhibitions are co-ordinated shows that they can only be described as an expression of life.

Morphology is thus becoming more and more an experimental science, like physiology. The physiological relations implied in the existence of various structural elements in living organisms are coming to be worked out by experimental methods indistinguishable from those of physiology. Weismann's conception of the overwhelming influence of heredity in the determination of structure marked a culminating point in the development of the old idea that structure can be regarded as existing apart from function.

Attracted by his vigour and genial personality, I went to work under Weismann when I was a young man; but I soon realised that, since it is actively maintained structure that we are dealing with, we cannot hope to interpret living structure, whether in the embryonic or adult stage, apart from its environment, although, since we are also dealing with actively maintained life, neither can we disregard heredity.

Like most other biologists of his time, Weismann was endeavouring to work out a mechanistic conception of life. As a morphologist, he was thus faced by the problem of how to regard heredity as a physico-chemical process. It seemed to him that this problem was simplified if there was no transmission of variations acquired after the early embryonic state. Actually, however, the problem remained just as impossible of solution, and he could make nothing of it. It is insoluble because it involves a presupposition inconsistent with biological observation, just as we are putting an insoluble problem if we ask what the difference is between living and non-living matter. The presupposition is that we can regard the parts of an organism, and the environment influencing it, as consisting of self-existing bodies, whether molar or molecular.

Many scientific men have thought that in making this presupposition they are on known and sure ground. But presuppositions must bow before the facts of observation. The supposed self-existing bodies are found by observation to be inseparable from wholes which determine their nature, so that in biological interpretation we are compelled to interpret the apparent self-existing bodies as an expression of the whole which we call the life of the organism. What part is to part, or environment to organism, can only be expressed in terms of the organism's life as a whole. This gives definition to the parts and environment alike, along with their activities, and so makes it possible to treat them scientifically.

I have up till now considered biology as if it dealt only with separate individual lives. In many cases, however, it is evident at once that individual lives cannot be separated from one another. Thus if we attempt to regard as mere individual lives the lives of the cells which make up the bodies of any higher animal or plant, we find that we cannot do so. The behaviour of an individual cell is unintelligible apart from its being also an expression of the life of the higher organism as a whole. The individual cells as such express in their genesis, behaviour, and deaths, the life of the whole organism. Both the origin and the fate of these cells express the maintenance of this wider life. Their lives are thus no mere individual lives. We may say the same of the apparent units of life which are distinguishable in the nuclear body of a dividing cell, and of which each plays a specific part in heredity.

In the lives of the individuals which form a species or stock we see what is similar. The individual life appears, and at death disappears, but the disappearance, as well as appearance, make for the maintenance, since the individuals of the stock must constantly be varying their mode of life in accordance with changing relations to other individuals of both their own and other stocks. New stocks or species may themselves appear and disappear and in their disappearance make for the appearance of new stocks or leave descendants so changed as to constitute new species.

When, moreover, we consider the various species of living organisms we find that they are dependent on one another. Plants are dependent on lower organisms and animals, while animals are dependent on plants or on other animals. Hence, just as the life of any individual organism exists only as including within itself what are often called its physical environment, so does its life, when more widely interpreted, include within itself the lives of other organisms, so that these lives are not outside its own life, though for practical purposes we usually regard separately what we can most readily treat as individual lives.

I wish now to stress as strongly as I can that the existence of life is the fundamental axiom of biology. It is life that we are studying in biology, and not phenomena which can be represented by the causal conceptions of physics and chemistry. Nor can life be represented by the conception of a "vital principle," or by the veiled vitalistic conception of "vital activity," acting and reacting with a physically interpreted basis or environment. I am not, and never have been, a vitalist, although simply because I am unable to accept the traditional mechanistic biology of the last few decades, I am often regarded as a vitalist. Vitalism in any form has the same fundamental defect as the mechanistic theory of life. It assumes that a living organism and its environment can be separated in observation and thought, when they cannot be separated. Let us consider what this implies. If, in biological interpretation, the parts and actions with which we are concerned cannot be separated from one another in perception, it is impossible to combine physical with biological interpretation. Thus when we interpret biologically any observation which we had previously tried to interpret in physical or chemical terms, we have radically transformed our mode of perception. We are no longer perceiving in terms of how matter and energy are influenced, but in terms of life and its maintenance. Nothing but confusion can result if we do not realise this. We cannot, for instance, combine the conception of self-existent molecules with that of life; and from the standpoint of biology, physically interpreted phenomena become mere imperfectly perceived phenomena, awaiting further interpretation or perception. Physical realism is thus adherence to what is only imperfect perception of our experience.

It may still be asked, can we not look backwards to a period in the earth's history when there could be no life? If so, life must have arisen in some way out of physical and chemical conditions. This presents us with what twenty or thirty years ago seemed a much more obscure problem than it does now. In the Presidential Address which I gave to the Physiological Section of the British Association in this college in 1908 I spoke as follows on the subject:

"Let me endeavour to state shortly the main conclusion which I have endeavoured to place before you. It is that in physiology, and biology generally, we are dealing with phenomena which, so far as our present knowledge goes, not only differ in complexity, but differ in kind, from physical and chemical phenomena; and that the fundamental working hypothesis of physiology must differ correspondingly from those of physics and chemistry.

"That a meeting-point between biology and physical science may at some time be found, there is no reason for doubting. But we may confidently predict that when that meeting-point is found, and one of the two sciences is swallowed up, that one will not be biology."[1]

This was how the matter appeared to me twenty-three years ago. I think, however, that it would be generally admitted that the gap between physico-chemical knowledge and biology seems far less great now than it did at that time; and this apart altogether from the introduction into physics of the principle of relativity, which seems to me to bring physics more into direct touch with psychology than with biology.

[1] This address is reprinted in *The New Physiology*, 1919.

Roughly speaking, we are now confronted at various points in physical investigation with facts which indicate the existence of inherent co-ordination at the base of what was formerly believed to be capable of being interpreted mechanically in agreement with the Newtonian or Galilean interpretation of visible and tangible reality. This is illustrated specially by the further study of electrical phenomena, the discovery and interpretation of radio-activity, and the study of radiation and the nature of atoms. The facts elicited have shown that mass, form, and internal activities of atoms are co-ordinated in a manner which is not only specific, but is maintained. An atom tends to maintain intense co-ordinated internal specific activity, which does not become dissipated in its environment, and on which both its mass and its other properties depend. Of all this we can give no account in terms of Newtonian conceptions. Thus the assumed basic conceptions of the Newtonian physics have been shown not to be in reality basic; and we are presented instead with what seem to resemble in essential respects the facts which biological study forces on us.

In the specifically determined emission and absorption by atoms of what appear to us from the Newtonian standpoint to be electro-magnetic waves, we seem to have something analogous, as regards the relation of an atom to its environment, with the unintelligible reaction between a living organism and its environment, when the latter is regarded as a physical environment.

On the specifically determined maintenance of activity in atoms depends, so far as we can see, their chemical behaviour, and that of their compounds. We see a vista beyond what we could see from the Newtonian standpoint, which seemed to reveal to us a world in which mass, energy, and their distribution and properties were in no way co-ordinated with one another as manifestations of wholes.

More exact study of the specific heats of solid substances at very low temperatures has, moreover, shown us that, apparently, we cannot regard the external activities of atoms as not co-ordinated with their existence as atoms. From the Newtonian standpoint in its modern development the temperature of a substance is a measure of the amount of the chaotic kinetic energy of its molecules or atoms. But when we lower sufficiently the temperature of a solid substance we find that it becomes impossible to deprive any sort of solid substance of more than a certain proportion of this assumed chaotic energy. Just as an atom resists loss of its internal activity, so, apparently, do all substances resist loss of what we previously interpreted as their chaotically distributed atomic or molecular energy.

All this limits the applicability to physical phenomena of the so-called second law of thermodynamics, which depends upon the assumption that the activity of the elementary parts of matter is chaotic, so that energy passes from one elementary part to others quite freely, and, on an average, simply in accordance with abstract probability, or chaotically. In any case, the existence of life as inherently co-ordinated structure and activity is quite inconsistent with the assumption on which the second law is based, since the phenomena of life cannot be described or interpreted in terms of the physical conception of a relationship between self-existent units.

In one connection there is at present no definitely known analogy between physical and biological phenomena; for atoms are not known to reproduce themselves as living organisms do. Yet it seems to me that some of the known facts relating to the distribution of elements in the earth's crust suggest that atoms reproduce themselves at the expense of their environment, and thus become irregularly distributed like plants or animals. Such a theory would apparently account for the extraordinarily patchy distribution of the rarer elements such as platinum or tin. This distribution seems to bear no reference to strata formed during what may be called geological time. Platinum, for instance, crops up, if it crops up at all, through all sorts of geological strata, just as if it had been, or was still being, generated in deeper layers of the earth's crust over certain restricted districts only.

We can thus see that although we continue, for practical purposes, to make use of ordinary Newtonian physical and chemical conceptions, it is only for practical purposes that we are justified in doing so. Behind the Newtonian conception of physical reality there has loomed up at every point a deeper conception which is not alien to the biological conception. Hence there is now no difficulty in assuming that life is not a mere product of physical and chemical conditions as represented on Newtonian principles, but corresponds to what is more primary than these conditions, and has always been there. It is only an assumption of what we might call Newtonian metaphysics that there must have been a time when there was no life. However low down we may go in the scale of life, and however far back we may trace the development of life, it is still life that we find. I can see no limit to further progress in this direction, though the limits of what is visible with a microscope present apparent difficulties.

In so tracing back life it is, however, individual life that we are tracing, and not mere statistics of life. Assuming that life has always been present, it is only from a statistical standpoint that ordinary physical and chemical investigation deals with it. Into individual life such investigation can hardly penetrate; and there seems to be nothing to prevent us from assuming that behind the appearance of a physcial world there exists a world in the interpretation of which biological principles must be applied. This accords with Professor Whitehead's general conclusions, although it seems to me that he is somewhat confused through attempting to conceive an organism apart from its environment.

It has been suggested by certain philosophical writers, including Professors Lloyd Morgan and Alexander, that when a certain stage of physical and chemical complexity has been reached, living organisms "emerge" as something new. I confess that, as a physiologist, I can attach no meaning to this suggestion. Not complexity, but persistent co-ordination, is what distinguishes biological from physical interpretation. An "emergence" of life out of a Newtonian world would be a quite unintelligible miracle. It is only the present popular acceptance, even among philosophical writers, of the idea that our experience as interpreted in terms of Newtonian physics represents reality, that gives rise to the apparent need for the emergence theory. If, moreover, a living organism emerged as a consequence of the physico-chemical complexity of its structure, it would only be such an organism as the vitalists imagined.

I have so far referred only to the relations between living organisms and their external environments. But within the bodies of organisms we are able to distinguish what appear to be internal physico-chemical environments, related to living substance. The case of the blood, and those of other liquid, gaseous, or solid accumulations within the body, or within individual cells, are instances; and what has been said of the external environment applies to them also. Their existence and their activities are co-ordinated with the other phenomena of life, though when we regard them in abstraction from their actively maintained presence and influence in the living body they appear to us as if we could interpret them on Newtonian principles. I shall refer further to them in the next lecture.

It results from this discussion that the application of biological principles does not stop at what have been imagined to be the boundaries of what is living, but extends over its whole environment. Life does not merely include relations within living organisms, but also relations to their environment. By this extension of the conception of life we get rid of the fatal difficulties associated with vitalism, while preserving what was of value in vitalism, which at any rate gave theoretical recognition to the persistent co-ordination which is characteristic of life. We can at the same time claim that biology is a science different from the physical sciences, because it makes use of a working conception which is different from theirs, and in which neither the causal descriptions of ordinary physics are valid, nor any description which, as a merely mathematical description does, assumes the existence of separable events or units. A purely mathematical, as distinguished from a mechanical, conception of physical reality is no help in enabling us to interpret or describe the phenomena of life.

The world of biology is the same world as that of physics and chemistry; but this does not prevent its being differently interpreted or perceived, provided we have realised that in no science are we seeking for ultimate reality. We are only seeking for a practically useful way of interpreting or perceiving our experiences when they are regarded apart from the rest of our experience, as they constantly must be in the absence of deeper reflection or investigation. There is, however, no doubt about the practical usefulness of physical and chemical interpretation as developed on Newtonian lines. Its position, like that of the old mathematics, is quite secure from the practical standpoint; and the same is true of biological interpretation, which, however, has a wider basis.

These considerations bring us back to the fundamental importance of the fact that what our experience reveals to us depends on how we are interpreting it in perception. It is useful to us to interpret certain aspects of our experience in certain ways—the ways of the sciences; but we must not forget that they are ways of interpretation or perception, which are only useful up to a certain point, like maxims of common sense.

Meanwhile let us endeavour to realise how far this discussion has separated us from the philosophical physico-chemical realism which so strongly permeates popular thought in our times, and apparently to a still greater extent than at any time since the Renaissance. When we have considered biological phenomena it has appeared that in perceiving them as manifestations of life we are no longer interpreting our experience physically, but biologically in the light of the conception of life as an inherent unity which extends over this experience. Such interpretation is inconsistent with physical realism; and the world of physical realism has become no more than an appearance which is constantly fading away in the light of wider experience, since the biologically interpreted world extends over the whole of whatever we might otherwise interpret physically. When we pass from physical to biological interpretation we are re-interpreting the whole of what was previously physical interpretation; and since the re-interpretation embodies wider knowledge, it brings us nearer to reality than physical interpretation can bring us. For this reason it is on a higher plane than physical interpretation. Those who have aimed at reducing biological to physical interpretation have been unconsciously aiming at degrading scientific biology from its rightful position; and this degrading influence was inherent in the philosophical ideas which originated with the Renaissance and have been further developed since that time.

Science is at present quite commonly identified with physical science, since physical science is assumed to represent fundamental or objective reality. But physical science cannot express or describe biological phenomena, so that its claim to represent objective reality cannot be admitted; and this apart from the difficulties, already referred to, which physical interpretation ultimately encounters without taking account at all of the phenomena which we ordinarily recognise as those of life. If physical science seriously made any such claim to objectivity it would have to take life into account. Those who claim that physical interpretation corresponds with objective reality have thus no justification for their claim.

If we seek to be realists we cannot be physical realists.

It remains to illustrate the practical applications and usefulness of specifically biological interpretation, and the following lecture will be devoted to this object.

LECTURE II

BIOLOGICAL METHOD ILLUSTRATED

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As I am myself a physiologist, I shall try to illustrate in physiology the case for studying it in the light of distinctively biological conceptions, in place of merely trying to study it in the light of physical and chemical conceptions; and I shall take as the example progress in our knowledge of the physiology of breathing—a subject to which a great part of my experimental work as a physiologist has been devoted.

The movements of breathing are perhaps the most constant and easily visible signs of life in all except the very lowest classes of animals; but it is surprising how comparatively recent is most of our knowledge as to how breathing is co-ordinated with other activities and with structures and environment in the maintenance of life. That breathing is in some way a necessity for life has, of course, been known from primitive times; but it was only in the seventeenth century that Boyle showed that the presence of air is needed to prevent death from asphyxiation, and Mayow demonstrated the connection of breathing with the consumption of what afterwards came to be known as oxygen, and also pointed out the connection of this absorption with muscular exertion. Their work at Oxford was soon, however, forgotten; and it was a century later before, mainly through the work of Black, Priestley, and Lavoisier, the fact was finally established that oxygen is absorbed and carbon dioxide given off in breathing, and that this exchange is an essential aspect of the life of any higher organism, equally essential being the peculiarities of structure in the lungs and other parts concerned.

Lavoisier also established the relation of this exchange to heat-production and the maintenance of body-temperature; but it was not till 1845 that the relation of oxygen consumption to muscular activity was pointed out convincingly by Mayer, almost two centuries after Mayow's forgotten work on this subject. It is now a familiar fact, however, that the essential feature in the act of breathing is the absorption of oxygen and giving off of carbon dioxide, and that the maintenance of this and of the structures involved in it is not only essential for heat-production and the doing of muscular work, but also for the maintenance of nervous activity, consciousness, assimilation, secretion, and all other bodily activities. It is equally familiar that the actively maintained structure of the lungs, in conjunction with the abundant flow of blood through them, is admirably fitted for the exchange of gas.

There is also now clear evidence that not only is function dependent on a suitable supply of oxygen, but also bodily structure. If the oxygen supply to the brain or various other parts is shut off completely for a short time, or considerably diminished for a longer time, various structural changes are produced, and recovery may not occur at all. Similar changes appear to be produced by excess or deficiency of carbon dioxide.

Thus the activity expressed in breathing, the structure involved in it, and the relation of this activity and structure to environment, form one aspect of the maintenance of activity and structure in which the life of an organism is expressed. In the perception of this maintenance we cannot separate organism from environment, part from part, or action from action. If we attempt to do so we lose sight of life as a whole, and almost inevitably fall back into overt or veiled vitalism, since we have to give some sort of account of the development and maintenance of the structure and activity. It is a life that we perceive, and no mere sum of physical, chemical, and "vital" reactions.

Our knowledge of the co-ordination of breathing with other physiological activities and structures has now become far more detailed and exact through continued physiological investigation. We not only know, as was discovered last century, that through the agency of oxyhæmoglobin oxygen is carried from the lungs to the tissues, and through the agency of bicarbonate and hæmoglobin carbon dioxide is carried from the tissues to the lungs; but we also know now that oxyhæmoglobin is so constituted that in the presence of the inorganic salts of the red corpuscles and of carbon dioxide, it discharges its load of oxygen with a readiness which is strikingly peculiar, and greatly increases its efficiency as a carrier, while at the same time, in the act of discharging its oxygen, it greatly facilitates the uptake of carbon dioxide as bicarbonate. These actions are reversed in the lungs, so that re-formation of oxyhæmoglobin there is facilitated by loss of carbon dioxide, and facilitates the discharge of carbon dioxide. We can thus see how not only the hæmoglobin, but also salts which are maintained in the blood as part of its normal composition play a part in maintaining a condition of normal activity within the body. We have to this extent discovered their function, so that their presence as structural elements is biologically intelligible as a manifestation of life.

In the blood and tissues the reaction or hydrogen-ion pressure has for long been known to be extremely steady, and always slightly on the alkaline side, whether or not the food and drink taken in is acid or alkaline. If what is taken in is acid, or forms acid when it is oxidised in the body, the urine excreted becomes to a far greater extent more acid. More ammonia, which is an alkaline substance, is also formed in the body. The net result is that the reaction within the body tends to be kept practically constant. Similarly the urine becomes much more alkaline, and the formation of ammonia much less, if what is taken in is more alkaline than the body, so that in this case also the reaction within the body is kept sensibly steady. Any considerable disturbance in the reaction within the body implies extreme physiological disturbance or death.

Temporary derangement of reaction might, however, occur owing to rapidly produced excess or deficiency of carbon dioxide, which, when in solution, acts as an acid, though a weak one. The production of carbon dioxide in the body varies very rapidly, and may, for instance, be suddenly increased ten times or more by muscular exertion, so that the kidneys, which act only slowly, do not cope with the disturbance of reaction. If, now, the lung-ventilation was not so regulated as to carry off the excess of carbon dioxide brought to them by the venous blood, the reaction of the blood would fall considerably below the normal alkalinity. If, on the other hand, the breathing was more than sufficient, the alkalinity would rise considerably above normal.

It has been shown comparatively recently that the blood and other liquids in the body are so constituted that, when a given quantity of either acid or alkali is added to them, only a much smaller change in their reaction occurs than if they consisted merely of water or a solution of neutral salts. This is expressed by saying that they are highly "buffered" by the substances dissolved in them. On the other hand, however, experiment shows that an extremely minute deviation in reaction from excess or deficiency of carbon dioxide implies great physiological disturbance and subjective distress. The buffering of the blood and other tissues thus plays a very important part in facilitating the control of reaction, although it does not in any way account for the control. The control is just an expression of the fact that the body maintains its normal reaction, just as it maintains what else is normal to it; and the manner in which it is constantly doing this has already been pointed out.

Now experiment has shown that the breathing is so regulated through the nervous system that the mean partial pressure of carbon dioxide in the air present at any moment within the lungs remains very nearly constant in spite of great increase or diminution in the amount of carbon dioxide being given off, and in spite also of very considerable variation of the partial pressure of carbon dioxide in the air inspired. The breathing is simply increased or diminished so as to compensate almost exactly for the increase in question. On the other hand the breathing never increases naturally beyond the point which is just sufficient to keep the pressure of carbon dioxide normal. Thus a practically steady pressure of carbon dioxide is normally maintained in the air in diffusion equilibrium with the arterial blood.

By voluntary effort we can hold the breath for a short time, thus raising the pressure of carbon dioxide in the air of the lungs, and consequently in the blood. But within less than a minute the effort becomes insupportable, though this time is somewhat increased if plenty of oxygen is present in the lungs. Similarly, we can voluntarily force our breathing, so as to keep, for a short time, the pressure of carbon dioxide in the lungs much below normal. But this is followed by a period of either complete cessation of breathing, or great diminution in the amount of carbon dioxide given off. The effort, also, becomes insupportable and results in impairment of consciousness and other abnormal symptoms; and it has been shown on animals that death results from the direct effects and after-effects of continued excessive artificial ventilation of the lungs. Carbon dioxide is thus no mere waste product, to be got rid of as quickly and completely as possible, but a normal constituent of the body, as essential to life as oxygen.

We can thus see that the breathing is regulated, and with extraordinary delicacy. We can continue to breathe for an indefinite time with either much greater or much less frequency than usual.

But if so we unconsciously adapt the depth so as to keep the pressure of carbon dioxide in the lungs steady. We can also breathe very irregularly, as during speaking or singing; but all the time the regulation is being maintained; and owing to the buffering of the blood and tissues transient variations in the pressure of carbon dioxide in the lungs are of no account. What is being regulated so exactly is the reaction or hydrogen-ion pressure of the arterial blood; and this control of the disturbances which, but for the regulation, would be produced by carbon dioxide, is so delicate that none of our existing methods of following changes of reaction outside the body is capable of following it more than very roughly. If, from any cause, non-volatile acid in the blood is temporarily increased or diminished, the breathing is likewise increased or diminished, so that the arterial blood carries less or more carbon dioxide.

It is evident, however, that what is important is not the pressure of carbon dioxide in the arterial blood, but in the tissues of the body; and since the rate of production of carbon dioxide is constantly varying in different organs or tissues, it will only be when the local rate of circulation varies correspondingly that the pressure of carbon dioxide can remain constant. There is, however, evidence that not only does the local circulation vary to a very great extent with varying local physiological activity, but that, other things being equal, increased circulation depends upon rise in pressure of carbon dioxide or in hydrogen-ion pressure in the blood circulating locally. Hence the pressure of carbon dioxide tends to be kept normal, not only in the arterial blood, but also in each organ or tissue. The discovery by Krogh that vast numbers of capillaries which are closed during rest open out during activity renders far more intelligible the great variation which occurs in local circulation.

Nothing has so far been said about the regulation of oxygen pressure in the blood. But considering how delicate, and how necessary, is the regulation of pressure of carbon dioxide, we might expect similar delicacy in the regulation of oxygen pressure. If, however, the pressure of carbon dioxide is kept constant, as is actually the case normally, at about 5.6 per cent. of an atmosphere (without allowance for moisture in the air) the oxygen pressure will be nearly constant at about 14 per cent., and the hæmoglobin of the blood leaving the lungs will, with this pressure, be nearly saturated with oxygen. Its saturation will also be very little influenced by an increase, or a moderate diminution, in the oxygen pressure of the air within the lungs. Since, however, the tissues are everywhere taking up oxygen from the passing blood, and even a very moderate fall in saturation of the hæmoglobin with oxygen implies a large fall in the oxygen pressure, it is evident that the pressure of oxygen in the tissues will not only be considerably lower than in the arterial blood, but will depend to a very marked extent on the rate at which blood passes through them, as compared with the rate at which they are consuming oxygen. These considerations do not apply nearly so much to the pressure of carbon dioxide in the tissues, since it is far more soluble than oxygen, and both blood and tissues are heavily buffered towards it. A given increase in the volume of carbon dioxide formed per minute in the tissues will therefore have a much smaller relative effect on its pressure in the passing blood than a corresponding increase in the consumption of oxygen. Moreover, a comparatively slight increase or diminution in lung-ventilation can easily prevent any small increase or diminution in local pressure of carbon dioxide.

It follows at once that in the maintenance of oxygen pressure in the tissues the regulation of circulation will be far more important than regulation of the oxygen pressure in the air within the lungs, provided that the lung ventilation is sufficient to bring about a high saturation of the hæmoglobin with oxygen in the arterial blood. On the other hand the lung ventilation will be relatively more important in regulating the pressure of carbon dioxide in the tissues, since an increase in the lung ventilation will easily compensate for a considerable increase in the rate of formation of carbon dioxide in the tissues, or even a considerable decrease in the rate of blood circulation.

We can now return to the influence of oxygen in the regulation of breathing. If we diminish rapidly and very considerably the pressure of oxygen in the inspired air the breathing is at once increased greatly. But the increase in breathing soon becomes much less, though it does not disappear. We can see at once what is happening. The diminished oxygen pressure in the blood, through its influence on the central nervous system, stimulates the breathing. But this produces a diminished pressure of carbon dioxide in the air of the lungs, and by degrees a correspondingly lower pressure of carbon dioxide acting on the central nervous system. This tends to diminish the breathing. The final result is a compromise, in which the breathing is only slightly increased.

At very high altitudes or correspondingly reduced atmospheric pressures, before acclimatisation takes place, the increase in breathing is not very marked, even when consciousness is beginning to fail owing to fall in the oxygen pressure; but if carbon dioxide is added to the inspired air the breathing is at once much increased, and the symptoms of loss of consciousness disappear. This led Mosso to the wrong conclusion that the symptoms produced by a very low barometric pressure are primarily due to what he called "acapnia," or deficiency of carbon dioxide.

When pure oxygen is breathed there is no diminution in the breathing, in spite of the great increase of oxygen pressure in the lungs and in the arterial blood leaving them, together with the presence in the arterial blood of much more oxygen in free solution. At first sight this fact, along with the small effect produced by even very considerable diminution in the oxygen pressure in the lungs, appeared to indicate that the oxygen pressure in the body is not regulated with anything like the delicacy with which the pressure of carbon dioxide is regulated, and that provided the oxygen pressure does not fall very low it is not regulated at all. The regulation of carbon dioxide pressure was, in fact, supposed to suffice also for regulation of oxygen pressure.

Clearly, however, the oxygen pressure in the tissues can be regulated easily by regulating the circulation; and further investigation has indicated that this is the means of regulation normally employed, and that regulation of oxygen pressure is in reality extremely delicate. When pure oxygen is breathed, particularly at a pressure above atmospheric pressure, careful observation has shown that the lung ventilation is actually increased above normal. This increase is attributable to the fact that the circulation in the brain, and apparently also in other parts, is slowed down so as to prevent local increase of oxygen pressure there. A very slight slowing down suffices if the oxygen is only breathed at one or two atmospheric pressures. The slowing down would, if its effects were not compensated, produce at the same time an increase in pressure of carbon dioxide. The compensation is, however, found to be brought about by increase in the lung ventilation, and consequent fall in the pressure of carbon dioxide in the arterial blood. Calculation showed that the observed increase in lung ventilation would suffice for this purpose.

When pure oxygen is breathed at a pressure of more than three or four atmospheric pressure in a steel chamber, it produces a rapid poisonous effect on the central nervous system, discovered by Paul Bert about fifty years ago. Experiments published quite recently have shown that when this effect is produced the pressure of carbon dioxide in the tissues becomes also extremely high. This seems to me to indicate very clearly that the circulation has been slowed down to such an extent as to produce this effect; and it is apparently when the blood-flow can be slowed down no further without producing poisonous effects from carbon dioxide, and when the breathing is enfeebled by the high pressure of oxygen or carbon dioxide, that the poisonous effects discovered by Paul Bert are produced.

In the lungs, on the other hand, where there is no escape from the high oxygen pressure, symptoms of inflammation, discovered by Lorrain

Smith, are produced after a time by a quite moderate increase in oxygen pressure, causing no abnormal symptoms whatever in the central nervous system, though the latter is presumably far more sensitive than the lungs. Apart from regulation of oxygen pressure by the circulation, this fact would be quite unintelligible. It also seems probable that one cause of œdema or inflammation of the lungs is excessive alkalinity in them during long-continued excessive breathing caused by want of oxygen or defective circulation in the brain.

There is, as already mentioned, abundant evidence that local circulation is regulated, not only with reference to oxygen pressure, but also with reference to pressure of carbon dioxide or hydrogen-ion pressure. The effect of increased hydrogen-ion pressure in increasing the rate of blood-flow through an artificially perfused fresh part of an animal has been known for long, although, owing apparently to the very defective method which is all that has hitherto been employed, the corresponding result for want of oxygen has not yet been obtained.

Some of the most striking evidence as to the influence of pressure of carbon dioxide on the circulation is afforded by adding carbon dioxide to the air breathed by an animal when this air contains sufficient carbon monoxide to render the animal comatose. As is well known, carbon monoxide acts as a poison by combining with hæmoglobin and thus paralysing it as an oxygen carrier. The whole of the symptoms produced by carbon monoxide are simply those of want of oxygen; and the increased breathing due to want of oxygen lowers the pressure of carbon dioxide in the blood and tissues. This not only diminishes the increased breathing, but also the increased circulation through the brain which would otherwise result. When, therefore, we add carbon dioxide to the poisonous air which the animal is breathing, the immediate result is not merely an increase in the breathing, which can be shown to do the animal no good, but an increased circulation through the brain, and consequent increased oxygen pressure, the effect of which is that the animal immediately becomes much more lively. Carbon dioxide is now employed with striking success for various purposes in medicine and surgery.

Increased pressure of carbon dioxide and diminished pressure of oxygen act normally on the local circulation in the same direction, thus apparently accounting for the enormous local increase which is required, for instance, during muscular exertion. When, however, as often happens in disease or in some forms of poisoning, diminished oxygen pressure is accompanied by diminished pressure of carbon dioxide, the results may be disastrous. The grey lips seen in a dangerous case of pneumonia, or during the war in cases of phosgene poisoning, and indicative of diminished circulation added to defective oxygenation of the arterial blood, are examples of this. A full blue colour of the lips, indicating a good circulation, maintained by both excess of carbon dioxide and deficiency of oxygen, is a much less dangerous symptom, since the pressure of oxygen in the brain and other tissues is not so low, in spite of equally defective saturation of the arterial blood with oxygen.

A very interesting form of breathing was first described early last century by two Dublin physicians, Drs. Cheyne and Stokes, and is generally known as Cheyne-Stokes breathing. The breathing is periodic. It gradually dies away and stops completely. It then begins again very gently and increases till it is very vigorous, only to die away again. This form of breathing is apt to be produced whenever want of oxygen is taking part along with carbon dioxide in regulating the breathing. We found that we could produce it experimentally by various methods. When the breathing is responding only to the normal stimulus of pressure of carbon dioxide the variations of breathing occur gradually and steadily, owing to the buffering of the blood and tissues towards carbon dioxide. But in so far as the breathing is also responding to want of oxygen there is hardly any buffering. Thus since there is a delay during the period which the blood requires to get from the lungs to the brain, particularly if the circulation is defective owing to disease, the regulation overshoots its mark, and periodic breathing results.

Cheyne-Stokes breathing is exactly the same sort of phenomenon as the "hunting" of the governor of an engine when the governor is not sufficiently damped. When, as is normally the case, carbon dioxide is the only stimulus which affects the nervous governor, Cheyne-Stokes breathing is, owing to the buffering or damping of the stimulus, never met with; but it is common at high altitudes before acclimatisation has occurred, or wherever, owing to imperfect oxygenation of the blood in the lungs, imperfect circulation, or other causes, want of oxygen is beginning to stimulate the breathing apart from the normal stimulus of carbon dioxide.

Perhaps nothing connected with breathing has been more instructive than the study of acclimatisation to high altitudes. At a high altitude the pressure of oxygen in the lung air is greatly diminished owing to the diminution of atmosphere pressure; and, as was first shown by Paul Bert, the whole of the characteristic symptoms observed at high altitudes are due primarily to consequent defective saturation of the arterial blood with oxygen. On going rapidly from about sea level to a height of over 10,000 feet, and staying there for a few hours, these symptoms are usually very severe, and are known as mountain sickness. They pass off in the course of at most a few days however, during residence at the high altitude; and they do not occur at all, even at altitudes of over 20,000 feet, if the ascent is in gradual stages from day to day, as occurs almost of necessity in the Himalayas.

Quite evidently, therefore, there is acclimatisation to the low oxygen pressure; and investigation has shown that it is brought about in several different ways, all contributing towards the result.

For one thing, as has been known for long, the blood becomes richer in hæmoglobin. This does not, by itself, raise the oxygen pressure in the arterial blood; but with the same rate of circulation it lessens the fall in oxygen pressure as the blood passes through the tissues, and thus tends to raise the oxygen pressure in them, which is the essential matter. The percentage of hæmoglobin in the blood has recently been shown to vary inversely, not only with the oxygen pressure when this is below normal, as at high altitudes, but also when it is above normal, as when an animal is kept at a high atmospheric pressure, or in air enriched with oxygen. This illustrates very clearly the connection between function and structure. The bone-marrow, where the red corpuscles of the blood are produced, becomes altered in structure at a high altitude, just as the blood itself is altered in structure.

The second factor, and a much more important one, in acclimatisation is a marked increase in the breathing, without this being due directly to want of oxygen as a stimulus. In the Mount Everest Expedition the climbers, when at their greatest heights, were gasping for breath during the exertion of climbing, and had to take about five breaths or more for each step upwards. This condition was scarcely relieved at all when oxygen was added to the inspired air, so it was not due immediately to want of oxygen, but to the acclimatisation. What happens during the acclimatisation is this. At first the breathing is directly stimulated to an appreciable extent by want of oxygen. But the resulting excessive removal of carbon dioxide makes the blood and tissues abnormally alkaline. To this condition the kidneys respond by removing gradually what is now the excess of alkali from the body, with the result that a lower pressure of carbon dioxide in the lung air, and correspondingly increased lung ventilation, is made possible without the blood being too alkaline and the circulation being correspondingly diminished; and the consequent increased pressure of oxygen in the lungs helps to counteract the diminished saturation of the hæmoglobin with oxygen.

The third factor is that, as a result of a stimulus originating in the lowered oxygen pressure in the tissues, the living walls of the lung capillaries begin to secrete oxygen into the blood actively, and gradually become more efficient in doing so, just as other activities become more efficient with practice. They help in this way to increase the saturation of the arterial blood. Without this help acclimatisation such as was observed in the Mount Everest Expedition, or even during our residence on the summit of Pike's Peak in the Rocky Mountains at a much lower altitude, where we investigated the acclimatisation, would, so far as I can calculate, be impossible. The evidence that this active secretion occurs is direct and quantitative. Some physiologists have attempted to upset this evidence, and the corresponding evidence with regard to active absorption of oxygen during carbon monoxide poisoning and muscular exertion; but I think with no success at all.

Active secretion of oxygen is analogous to the active secretion which occurs in various glands. It is called " active " because it occurs in the opposite direction to that which would be taken if the secreting layer played only a passive part, like what we interpret as a passive physical structure. Thus when the kidneys are separating almost pure water from the blood, which contains a considerable proportion of dissolved salts, or when the sweat-glands are separating sweat containing much less salt than the blood, we call the secretion " active," because with a non-living layer under otherwise similar conditions any transference of the liquid would be backwards into the blood. Secretion of oxygen occurs in a particularly striking manner into the swim-bladders of deep sea fishes, against an adverse pressure of oxygen which may amount to 100 atmospheres. In an actively secreting lung the adverse pressure is only a fraction of an atmosphere, and the secreting membrane has only a fraction of the thickness of that in the swim-bladder; but the secretion is just as definite. Neither in the case of the kidney nor in that of the lung does the active secretion occur normally except under conditions where it is required for the maintenance of normal life.

In the living body of the common fresh-water unicellular organism, *Arcella vulgaris,* we can actually watch under the microscope the liberation of bubbles of oxygen when a suitable stimulus is applied. Curiously enough, the most certain stimulus is a reduction of the oxygen pressure in the water which surrounds the *Arcella.*

During rest at normal atmospheric pressure there is no active secretion of oxygen by the lungs and no active secretion is required in the maintenance of life during rest. But the structure of the lung is actively maintained in such a manner that oxygen passes into the blood freely and in the large amount required.

Still another factor in acclimatisation appears to come into play after long exposure to low atmospheric pressure. It appears that the tissues of the brain and other parts become in some way tolerant towards the unusually low pressure of oxygen in the arterial blood. Hence natives or long residents at a high altitude show marked blueness of the skin, and a correspondingly low arterial oxygen pressure, though they remain in good health. The tolerance seems to make oxygen secretion unnecessary in their case, and on going to a lower altitude there is marked reddening of the skin. It appears also that in many cases of chronic heart affection of emphysema a similar tolerance to low arterial oxygen pressure becomes established, so that normal health is maintained in the absence of much exertion. By administering oxygen to certain of these patients the skin may be turned pink again, but with no appreciable benefit; whereas with a person who is blue from a rapid reduction in atmospheric pressure, oxygen at once causes the symptoms to disappear, as well as the blueness.

The phenomena of acclimatisation, and of acquired immunity generally, illustrate well what, in old-fashioned language, was called the "consensus" of activity and structural maintenance in a living organism. Struck by facts which he had discovered as to the manner in which the normal composition of blood in the living body is maintained during different phases of nutrition in face of influences which might naturally be expected to alter it, Claude Bernard drew the general conclusion that "all the vital mechanisms, varied as they are, have only one object, that of preserving constant the conditions of life in the internal environment." Bernard was ignorant of the facts described above as to the manner in which, by the co-ordinated action of the lungs, kidneys, heart, blood-vessels, nervous system, the pressures of oxygen and carbon dioxide are maintained nearly constant, not merely in the arterial blood, but in each separate organ. It is evident, however, that the facts relating to the physiology of breathing accord extremely well with his general conception, and that this conception can be said to sum up the phenomena and so enable us to predict them.

Let us, however, follow the matter further. From all kinds of evidence we know that unless the blood is normal in composition the various organs will not fulfil normally the functions which Bernard assigns to them, nor maintain their normal structure; and quite evidently the maintenance of normality in the blood is not an end by itself, but can be regarded as a means towards ensuring normal functioning and structure in the various parts of the body. We are only reasoning in a circle, however, if we regard the concerted action of the various organs of the body as the cause of the blood's normality, and at the same time regard the blood's normality as the cause of the concerted action and normal structure of the organs. The normality of blood composition is only one aspect of a specific normality which expresses itself generally in the life of an organism, and which hangs together and maintains itself as a whole.

Bernard regarded the blood as an internal environment bathing all the living cells in the body. In reality, however, the environment of each cell depends on the influence of other cells, so that properly speaking there is no common internal environment, but only a common element in environment. Thus the blood bears to actual cell-environment a similar relation to what the external environment does, but of a much closer and more defined sort.

The life of an organism is ultimately just as much bound up with its external as with its internal environment. Without, for instance, a continuous supply of oxygen and food-material life could not continue. But, just as with the internal environment, we can no more regard the activity of the organism as a determining cause of the external environment than the external environment as a determining cause of the organism's activity. Organism and external environment hang together in the specific manner which is a normal expression of the life of the organism. Life is Nature expressing herself as a characteristic whole which has no spatial bounds. There is no spatial limit to the life of an organism just as there is no spatial limit to what can be perceived. If, however, like the vitalists and many philosophical writers, we start from the conception of a living organism apart from its environment, or, like the mechanists, from the conception of living matter as part of a physically interpreted universe of self-existent units and events, we are unable to frame any coherent conception of life, or of biology as a science.

In the physiology of breathing, as just described, we have a clear example of the manner in which environment, maintenance of bodily structure, and mutual influence of bodily activities are so co-ordinated that life is maintained. We cannot study breathing successfully apart from other physiological activities, from the maintenance of bodily structure, and the nature of bodily environment, and when we do study it, bearing in mind what the study involves, the conception of co-ordinated maintenance, or life, becomes the axiom which guides us in the work of observation and experiment. In all my own experimental work on the physiology of breathing this axiom has been the guiding influence; and it seems to me to have been so, either consciously or unconsciously, with all important work in physiology.

Some physiologists have maintained that however strange the facts of physiology may be, it is only by their "objective" study as physico-chemical events that we make progress in physiology. If this merely signified that we cannot make progress by studying living organisms or living parts apart from their environments, I should entirely agree. But it means a great deal more, which, as a physiologist, I emphatically dissent from. It means that we must study physiological phenomena as essentially separable events and not as manifestations of the maintenance of life regarded as a whole. When we endeavour to treat physiological phenomena as separable events we only reach unintelligible chaos to which there is no end. When we seek to understand them as manifestations of life regarded as a whole we find that we can make them intelligible and predictable, and it is as manifestations of life that I have endeavoured to treat the phenomena of breathing, and have myself investigated them in the laboratory. We cannot make real and useful progress in the study of breathing without studying at the same time life as a whole. If we systematise physiology by describing or studying only one thing at a time, we are just missing what we set out to study, which is essentially a whole.

It is clear, however, that in adding to knowledge of physiology we are constantly, in the course of investigation and interpretation, transforming into biological knowledge what had at first appeared to us as imperfectly defined physicochemical knowledge. The latter knowledge forms the raw material for biological interpretation. A knowledge, for instance, of the composition of expired air and its volume per minute at one particular time does not by itself tell us even how far breathing is essential to life, and nothing as to its relations to other physiological activities and bodily structures. It is only by experimental investigation that we reach further physiological knowledge of the subject, and in so far as we reach it we understand breathing as an essential manifestation of the many-sided but indivisible activity which we call the maintenance of life. In this activity the details of environment are just as much concerned as the details of the living organism: we cannot separate organism from environment.

If we attempt to define separately each event or unit in life apart from other events, we lose ourselves in unintelligible, indefinite, and unpredictable detail. Physiology, on the other hand, is the attempt to render the phenomena intelligible and predictable by showing them to be manifestations of maintained life as a whole. We cannot study with any success the physiology of breathing without at the same time studying the lives of organisms as wholes; and the distinctive language which a physiologist uses, such as "breathing" or "respiration," is a testimony to this. The whole which is studied is, moreover, no mere aggregate of separable units and events, but is constantly showing its indivisible nature by adaptation from moment to moment to varying circumstances. In this adaptation, which we can test and verify experimentally, the objective reality of the wholeness is demonstrated.

Those who do not realise the metaphysical character of the popular assumption, prevalent at the present time, that physically interpreted reality is in a special sense "objective" reality, may well be puzzled as to the relation of biology to the physical sciences; but when it is realised that physical interpretation has no special claim to objectivity the source of confusion disappears. It is simply metaphysics, and bad metaphysics, long out of date, to assume that physical interpretation is perfect objective interpretation.

It is only when we seriously attempt to frame a physico-chemical conception of the co-ordination expressed in the maintenance of life that we realise how hopeless the problem is from the physico-chemical standpoint. The more we discover as to the relations expressed in a life, the clearer does this become. When we discover, for instance, the existence of an intraprotoplasmic enzyme or other substance on which life depends, we are at the same time faced by the question how this particular substance is present at the right time and place, and reacts to the right amount to fulfil its normal functions. It is always, therefore, to the conception of life as a whole that we are driven forwards.

In the case of respiration we can see at once that everything depends, not merely on the regulation of breathing, circulation, kidney excretion, and nervous activity, but also on the maintenance in a sufficiently normal state of all the various structures concerned in respiratory activity, and of a sufficiently normal external environment. The structure of the lungs, for instance, must be sufficiently normal. If they failed to keep the fluid of the blood from leaking, œdema of the lungs and death would result. The structure of the central nervous system must be normal, or the nervous regulation would break down. The blood must be normal in composition. In fact, every part of the body must be sufficiently normal if respiratory activity is to function normally.

If we ask what keeps any particular part of the body normal, the only answer is that it is normal because its multifarious relations to other parts and the rest of its environment remain normal. The fact that they are constantly keeping normal is just the fact of life, and if we attempt to analyse life into separable elements we are only going round and round in a circle. Nature just mocks our efforts. For biological interpretation the fact of life is elementary.

From a physical and chemical standpoint the development and maintenance of the exquisitely delicate structures and activities which biological investigation reveals to us is totally unintelligible. We just have to admit that from the physico-chemical standpoint we are in presence of something which we do not understand—the "mystery" of life. In reality this mystery is of our own making. We are approaching the subject under the presupposition that our visible and tangible world must be a mechanical world in the Newtonian sense, or at least a world of separable events and entities. If we approach it as being the world of life, which it evidently is when regarded from a biological standpoint, the mystery disappears, and so far as mere life is concerned, we have only problems before us that we can hope to solve by further investigation. We can also look back at the history of physiology as a record of continuous progress in the knowledge of how life expresses itself.

The physical and chemical description of respiratory and other activity, so far as we are able to carry it, is only preliminary work. Physiology is always searching for and finding a deeper and more thorough description, into which the preliminary description is taken up and thereby transformed in our perception of it; and the more complete the preliminary description, the better will be the physiological interpretation. In the history of physiology we find numerous instances of the manner in which erroneous physical or chemical description has led to impossible mechanistic or vitalistic interpretations of phenomena which neither physico-chemical nor vitalistic theories are capable of interpreting.

I was taught physiology at a time when attempts at a mechanistic interpretation of life were general. To regard either physiological activity or organic structure from a functional standpoint as the manifestation of a whole was not considered scientific. It seems to me that the result of all this was to impede the progress of physiology, and to make it appear to students of medicine a subject with comparatively little bearing on their future work.

Without, for instance, a knowledge of the functional significance of changes in breathing, they could put such information as they received to very little practical use in interpreting respiratory symptoms or devising treatment. To take another example, without instruction as to how the kidneys are, under normal conditions, regulating the composition of the blood with the utmost delicacy, they were left helpless in the understanding of derangement in kidney function. A certain amount of rough knowledge was, it is true, available in the literature; but this knowledge was not taught; and what was taught was an inconclusive and unedifying discussion of the possible mechanism of renal secretion: whereas the conception of mechanism cannot possibly fit the facts.

Still another example is more fundamental. The very basis of the practice of both medicine and surgery is the fact that, as taught by Hippocrates, injury of any kind tends to be recovered from whenever the conditions are made such that recovery is possible. But the mechanistic physiology had, of necessity, nothing to say on the processes of healing and recovery. The subject was simply left a blank: and this in a science which used to be called Institutes of Medicine!

It has for long seemed evident to me that the sooner physiologists realise that biology is an independent science, since the axiom on which it is based is different from those of the physical sciences, the more useful, as well as the more intelligible, will physiology become, and the clearer will become the physiological problems to which fruitful investigation can be applied. The attempted mechanistic physiology, just like the attempted vitalistic physiology, has been a failure. Neither of these interpretations of physiology has actually represented what this subject-matter is.

It is only by observation and experiment that physiology has advanced and can advance; but it is nevertheless true that we can make our observations, and devise our experiments, far more effectively if we are guided by adequate general theory, and not just drifting along with only obsolete general ideas to guide us and no real trust in even these ideas. We need better and more detailed crude physically and chemically interpreted data for advance in physiology, but these data are of no direct use till they are transformed through the experimental demonstration of their co-ordination with the other phenomena which express the maintenance of life. Thus crude physical and chemical data relating to breathing or circulation can only become physiologically significant through proof of the part which they take in the co-ordinated maintenance of life; and the idea of this maintenance guides us in performing the right experiments, and not wasting time in making experiments which cannot have anything but an indefinite result, because they are not based on a coherent scientific conception of what life is.

The account I have given of the phenomena of breathing is based on the conception that breathing is a manifestation of the co-ordinated maintenance which is denoted by the life of an organism. Apart from this conception it does not seem to me to be possible to give any useful scientific account of breathing.

LECTURE III

BIOLOGY AND WIDER KNOWLEDGE

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Before proceeding to the main subject of this lecture I wish to refer to the physiology of nervous activity. There is a very general impression that apart from consciousness and the associated peculiarities of voluntary action the physiology of nervous activity may be treated from a purely mechanistic standpoint. It certainly can be so treated if we pay no attention to essential facts, just as other sides of physiology can be so treated when essential facts are left out of account. But in the case of nervous activity the missing out is perhaps not so evident, and nervous activity, apart from that of the higher centres, is commonly regarded as a process whereby the action of or on a physical environment is transmitted physically to or from nerve centres, the muscles, etc., being regarded as participating in the process.

Now, I wish to point out that the physiologically or biologically interpreted environment is something different from the physically interpreted environment. The mere raising of such a point carries us back in scientific history to the time of

Galileo and the manner of interpreting our experience which he and others introduced. The world which we perceive around us is not the mere world of physics, but a world of things possessing all sorts of what Locke called secondary qualities—of things cold or hot, coloured in various ways, bright or dark, with various odours or tastes, emitting various sounds, offering various resistances to effort, and with various concrete qualities. In physical interpretation we do not take secondary qualities into consideration, but treat them as "subjective"—not belonging to the "objective" world of physics as conceived by Galileo, Descartes, or Newton. But when, as in physiology, we are considering the relation of an organism to its environment, the so-called secondary qualities become all-important, since they determine afferent nervous activity. A physical world without secondary qualities would mean nothing to us; and yet in interpreting our experience as that of a physical world we leave secondary qualities out of consideration. Physiologists have for the most part been willing to accept at its own metaphysical valuation the physical world as it is, or rather was, interpreted by physicists; but it is evident from the considerations discussed in the two previous lectures that this submissive attitude must be revised.

When we examine physiologically the conditions under which afferent impulses are liberated in contact with environment outside the living body, several facts, both positive and negative, emerge. In the first place, excitation is not, or need not be, proportional to what we interpret as the physical strength of the stimulus. This fact is embodied in what is known as Weber's law, since the physiologist Max Weber first drew attention to it. The phenomena of vision may be used most easily to illustrate Weber's law.

Roughly speaking, the visibility of what we see depends, not on the physical strength of the light-stimulus coming to us from the illuminated object, but on the contrast between its strength and the strength of the light-stimulus in surrounding parts of the visual field. A shadow thrown by an object lighted by a single candle in a dark room is, for instance, very prominent. But when the room is brightly illuminated from some other source the shadow thrown by the light of a candle becomes almost or wholly invisible. We can easily, however, evade Weber's law over a limited part of the field of vision. Thus if the general illumination is made such that at some distance from a candle a shadow thrown by it is just visible on brightly illuminated objects, it is no more visible on objects which, if not too large, are in shadow as regards the general illumination. With the help of light projected on a white screen by a lantern this fact may be made very evident. A physicist might therefore say that our response to the light has then become objective, because it corresponds to "objective" differences in light-stimulus. But a physiologist could then reply that within enormously wide limits of the physicist's objective illumination the visibility of things is about the same. It is only when we get down to very low general illuminations that their visibility begins to diminish. In this case, moreover, a definite threshold of "objective" illumination is reached, below which there is no physiological response at all.

As regards vision of "coloured" objects the difference between the physicist's and the physiologist's standpoint becomes even more marked. If we look at what, for the physicist, is a white object with light-rays of all sorts of wave-lengths emanating from it, and not with selected wave-lengths, it appears white whatever the quality of the light from the source of illumination. But if we compare the shadow cast by candlelight with that cast simultaneously by daylight or a modern electric or incandescent-gas light, the shadow thrown by the candle is blue, and that thrown by the other light yellow. We have the phenomenon of coloured shadows, which led to Goethe's opposition to the Newtonian conception of light. The appearance of difference in colour depends, not merely on difference in prevailing wave length of light, but also on contrast and other conditions; and of these conditions the physical interpretation of light takes no account.

When we diminish sufficiently the intensity of illumination, discrimination of colour disappears. "All cows look black" if their relatively shaded side is turned to us. With still greater diminution of illumination we can see nothing "objective." But in the absence of all appreciable "objective" light our field of vision is by no means empty. With no light entering a room at night the field of vision still appears illuminated. We usually pay no attention to this illumination unless, as happens with some people, it takes the form of striking colours and shape. But this "subjective" illumination, taken in conjunction with the fact that brightness or visibility does not vary with "objective" brightness of illumination, is of great physiological significance. What it means is that as regards visual activity our whole field of vision is not only determined physiologically, but is determined in such a way that it remains constantly present in spite of variation as regards its details. Its brightness or colour may vary in different parts, but the general balance of physiological brightness or colour tends to remain the same whatever the degree of intensity or quality of illumination in the physically interpreted sense may be, and whether illumination in the physical sense is present or not.

The physiological field of vision is thus something which tends to persist as a whole just as life in general does, and which has no spatial limits any more than life has. In each detail of it, moreover, the whole is expressed. Brightness and colour have no meaning in it apart from their relation to the whole field, just as the details of other physiological activities have no physiological meaning apart from their relations to one another. This is true of brightness and colour regarded as mere physiological activities, and apart from consideration of our perception of coloured objects. It is easy, in dealing with the physiology of the senses, to take no account of the objects we are conscious of. We deal with them as no more than observed manifestations of physiological activity. In this manifestation we find the same kind of co-ordinated maintenance as we find in other manifestations of life; and we cannot define this physically.

What applies to visual activity applies *mutatis mutandis* to other afferent activities expressing the relation of organism to environment. The relation cannot be expressed physically. Hence if we speak of the mechanism of nervous excitation, and compare the working of the nervous system to that of, say, a telephone system, we are only speaking metaphorically, and in terms of physical, and not biological, interpretation. The environment of a living organism is a biological, and not a physical, environment; and it is no more possible to separate a whole organism from a physical environment than it is to separate any living part of an organism from a chemical medium or environment surrounding it. Inside living cells, for instance, we still find a medium, and until we realise what life implies, and that an organism apart from an environment is a mere product of empty imagination, men will still continue to pursue the product of imagination, which, when they consider the co-ordinated internal activity of an organism drives them towards vitalism, and drives them towards physical interpretation when they see that all the phenomena of life depend on an environment which they interpret physically.

Looking at nervous activity as a whole, we can provisionally regard it as a system of interconnected reflex activities. But when we look into the details of anything which we set down as reflex action we find that the conditions of its occurrence are determined not only with relation to what other reflex activities are occurring, but also with relation to all sorts of other simultaneous physiological activities. Thus we cannot separate the reflex activities from one another and from the rest of life. Each is maintained as an expression of the inseparable whole which we call the life of an organism, and how this is so in detail it is the business of experimental physiology to reveal. Upon the wholeness we are always driven back, whether we consider nervous activity or any other form of physiological activity. The wholeness makes physico-chemical description of nervous activity very unsatisfactory in physiological investigation. When we attempt physico-chemical description we need to add that the description only holds when the excitability remains constant. To understand the variations in excitability we must refer back to the wholeness.

I can now pass to the main subject of this lecture. In discussing the fundamental axiom of biology I have endeavoured to distinguish biology from the physical sciences and to illustrate the distinction. But the existence of conscious behaviour makes it necessary also to distinguish biology from psychology, the science, or rather great group of sciences or departments of knowledge, dealing with our experience when it is regarded as actually perceived and an expression of voluntary action.

It is the same world which from the traditional standpoint of the physical sciences is regarded as a world of molar and molecular mechanism, from the standpoint of biology as a world of life, and from the standpoint of psychology as a world perceived and the theatre of voluntary action. Each of these standpoints is of evident practical use; but if we are to avoid confusion we must distinguish them from one another, and not make exclusive use of one of them unless such use is of practical service. Since, moreover, we are only aware of our experience in perception of it, it is evident that the perceived world includes the physical and biological worlds, although in regarding them as physical or biological worlds we neglect the fundamental fact that they are the embodiments of our perceptions and interpretations. The latter fact is what Berkeley called attention to and which has had to be taken account of in all subsequent philosophy worthy of the name.

In natural science we are therefore not attempting to reach ultimate reality, but only interpretations which are practically useful where fuller knowledge is not immediately needed or available. It might be, for instance, that if we knew enough we should have to regard the behaviour of plants, or of individual cells in our bodies, or even the behaviour of atoms or molecules, as conscious behaviour; but it is clearly quite useless to attempt to do so in detail with our present knowledge, though it is necessary to treat as conscious behaviour what we commonly describe as such.

In connection with physiology we have to decide as to where purely physiological or biological interpretations are applicable, and where psychological interpretation becomes necessary. Let us therefore consider the difference between the two standpoints.

In biological interpretation we assume the maintenance and reproduction of specific forms of life, each life being a unity expressing itself in co-ordinated maintenance of detailed structure and activity. This unity is interpreted as constantly maintaining and reproducing itself, but doing so without any display of foresight or retrospect—that is to say, blindly. When retrospect and foresight, or learning from experience, are embodied, whether as perception or voluntary action, in the behaviour we are studying, we interpret it psychologically, or only interpret it physiologically in so far as we leave retrospect and foresight out of account.

We attribute no foresight or retrospect to a cell in which we find constant rebuilding or reproduction of its specific structure by assimilation of food, or in other respects continuous adaptation or active co-ordination in the relation between organism and environment, so that life is maintained; for life itself is just continuous adaptation between organism and environment, as well as between the parts of the organism, so that the unity of life is maintained. Nor do we perceive foresight or retrospect in the development of an embryo. All we can see is blind active reproduction in which the life of the specific stock is maintained. We find that even an embryo is always reacting to the stimulus of the moment, though the response to the stimulus expresses its own life, so that its life is constant adaptation, just as in the adult stage.

It has sometimes been argued that the reproduction of an organism displays memory and foresight. But if we assumed this we should also have to assume that memory and foresight are displayed in the constant adaptation, assimilation, and reproduction of the adult stage. What is actually displayed is neither memory in virtue of which the embryo learns, nor foresight, but simply specific life expressed in each momentary reaction of structural or functional activity. Johannes Müller, who was no less great as an anatomist and embryologist than as a physiologist, expressed himself very clearly as to the difference between conscious behaviour and that of a developing embryo, so far as we can interpret it. We can mutilate an embryo, or otherwise disturb its natural growth, and watch the blind adaptation which still continues to be expressed in its further behaviour. As Driesch in particular has shown by experiment, and as Müller himself inferred, no mechanistic conception will cover the facts. Nevertheless, the mutilated or disturbed embryo behaves simply as if it were responding to the stimuli, or absence of stimuli, of the moment. In this respect Driesch, as it seems to me, failed to see that when a single cell, in the early stage of a developing embryo, is separated from the other cells, there has been an alteration in its environment or the stimuli influencing it. It therefore behaves differently from a cell left in contact with other cells, and as a matter of fact proceeds, or may proceed, to develop in the same way as the original individual ovum would have developed. The hypothesis of an "entelechy" guiding development independently of the influence of environment is thus unjustified. A separated cell tends to revert to the behaviour of the original ovum because its environment has become the same. We see this, not only in separated embryonic cells, but also in separated adult cells cultivated outside the body.

When we perceive things they are perceived as related to a past and future, and as related spatially to one another. An isolated sensation, as Kant saw clearly, is a mere imaginary figment, and denotes nothing. Past, future, and contemporary present are thus given in each experience, and are gradually found to be given in the orderly manner which science describes. This is not all, however, for the perceptions express our interest. In other words, our perceived world is no mere picture independent of our presence in it, but the embodiment of our personal interest which reaches back over the past and forward to the future, so that past and future are represented in the present. Each of our perceptions, and each of our actions, embodies learning from experience, and therefore both retrospect and foresight, since learning implies the guidance of future behaviour in the light of the presence to us of past experience. When we see evidence of this we interpret the behaviour as being conscious. Unity extending over events in time as well as space is expressed in conscious behaviour. In expressing memory it also expresses prediction from memory; but the experiences remembered and anticipated express also our own interest, and are inseparable from the voluntary activity in which our interest is in other respects expressed. The world of conscious behaviour is thus a world of personality.

It also implies irreversibility in an order of time, since a present experience always involves the past experience. We cannot imagine the past as not there, or as undone: it is always implied in the present, so that conscious experience implies the progressive expression of personal interest. The physically interpreted world appears also to be proceeding in an irreversible course, expressed by the second law of thermodynamics if we regard the physical world as a mechanical world, but no less irreversibly if we regard it as ultimately not mechanical. The biological world is also irreversible, since the present in it is the outcome of a past struggle for specific existence of which existing forms of life are the expression.

The fact that perception is an expression of interest, and that personality is the expression of actively maintained interest, shows us at once that we cannot separate perception from conscious volition. Perception itself is active, and the conscious response to it is only a further expression of this activity. Following the analogy of the physically interpreted world, we have become accustomed to look upon perception as the effect of an external cause. Voluntary response is thus regarded as originating in the mind on consideration of the perception, the outcome being usually regarded as an act of free will. To admit that perceptions are incipient actions might be regarded as equivalent to what is called determinism, a view according to which personality is only a flow of sense-impressions and their effects. The view I have presented is, however, very far from being determinism, since the perceptions are regarded as being no less an expression of personality than the voluntary actions with which they are bound up. They are together the expression of personality. We are responsible no less for the motives which appeal to us than for the actions with which they are bound up. Greed for another's money is no excuse for robbery, but an admission of a very mean sort of guilt.

The phenomena of conscious behaviour take us into a differently interpreted world from that of biological interpretation, just as biological phenomena take us into a differently interpreted world from that of the physical sciences or mathematics. Hence biology does not, and cannot, deal with psychologically interpreted phenomena, but can only treat the phenomena it deals with as if psychological phenomena did not exist, or could be left entirely out of consideration. In this respect it is only an abstract science, just as is physical or mathematical science, which disregards the phenomena of life, as well as those of conscious behaviour.

The principle of relativity, as introduced by Einstein into physics, appears to depend on realisation of the fact that all our knowledge of phenomena is based on perception of them, and that perception itself is personal, and appears to us at first as mere individual perception. It follows from this that all our knowledge of the physically interpreted world is primarily relative to ourselves, as if each of us were the centre of the universe. The dramatic results of attempts to measure the absolute velocity of our movements in space, whether with the help of light-vibrations, or with that of what was taken to be gravitational attraction proportional to mass, have established firmly the principle of relativity in physics. Relativity involves also the principle that we cannot separate space from time. That we cannot do so in perception follows from the account of perception which has just been given, since past and future history is involved in every perception, whatever element of spatial relationship it may have to other perceptions.

The world of psychology is the world of interest and values—the world with which history including anthropology, political science, law, art, and literature deal. Nothing but confusion can result if we attempt to interpret psychological phenomena biologically through failure to see that biological interpretation does not embrace the phenomena, and so cannot be applied. To use a technical philosophical expression, we are confusing our categories, and thus making statements or propounding questions which are meaningless. Examples of such questions occur if we ask what the relation is of life to matter, or living to non-living matter, or mind to body. We are treating life or mind as if they could be treated as things existing here and now in space and time, side by side with physically interpreted phenomena.

Memory is also an expression of personality, though if we neglect entirely its psychological character as an expression of personality we can regard it as a mere expression of the results of physical impressions or "engrams" produced in some part of the brain. Up to a certain point this is a useful way of regarding memory, since memory of certain things, such as words and how to pronounce or write them, may be blotted out by a hæmorrhage or other injury in the brain; or when the blood is insufficiently oxygenated the record fades away at once, as if the impression was too feeble owing to the deficient oxygenation. But as soon as we take into account the psychological aspect of memory this way of regarding it appears as totally insufficient.

What and how a man remembers is an expression of his interest and character. In other words, it belongs to his personality, and it is only if we make a false metaphysical separation between mind and body that memory appears to be the mere result of physically interpreted engrams read off by the mind, or reappearing as mental states if we do not wish to postulate the existence of mind as more than a series of mental states. The "association" of memories with perceptions and voluntary actions becomes something quite unintelligible and unpredictable apart from the conception of the personal interest embodied alike in perception, voluntary action, and memory.

We can sum up this whole discussion in the conclusion that a man is a person whose interest reaches out over all that is around him temporally or spatially. He is no mere walking automaton or bundle of reflexes and engrams. The man we see is also the real person, and not simply his physical body. The supposed physical body is nothing but our own imperfect interpretation of our experience of him.

It is with biology, and with physiology as a part of it, that this course of lectures is mainly concerned. Where we are in presence of distinctively conscious behaviour, including perception and voluntary actions, physiology as such has nothing intelligible to say, just as physical science as such has nothing intelligible to say with regard to the distinctive phenomena of life. Thus the distinctive co-ordination in time, as well as in space, which we meet with in conscious behaviour, lies outside physiology. In so far, however, as muscular movements and the activity of the nervous system can be treated as if they were blind unconscious activities, they form a very important part of physiology, and their study furnishes endless useful insight into details which, though they are not treated psychologically, furnish psychology with essential crude material for its own further interpretation.

There is thus a physiological treatment of the nervous system, including all the special senses: of the voluntary muscular system; and of all the bodily activities which we are conscious of. But we are only putting meaningless words together if we endeavour to express conscious activity as nothing but either physiological activity or physical activity plus a mysterious accompaniment of consciousness. I am well aware that this statement is contrary to the beliefs of some zealous physiologists, and of numerous popular writers who mistake such beliefs for realism. The sooner, however, they become aware of the mistake they are making, the better will it be. These ideas will before long be regarded as curious by-products of our time.

We can easily investigate every kind of physiological activity without regard to its psychological aspects. A very apposite example of this is the study of breathing as considered in the previous lecture. We are conscious of breathing, and it is used in the expression of language, emotion, and art. Nevertheless, we can study the manner in which it is regulated physiologically if we leave out of account its conscious employment. To take another example, we can study colour-vision physiologically without reference to the perception of coloured objects as such, or of whether or not they are of interest to us as significant of other things, or as beautiful or ugly. We have only to abstract from what is distinctively psychological, and we are left with an abundance of experience into which physiological study alone can bring the order which is an essential preliminary to psychological interpretation. Though psychological interpretation is much more than biological interpretation, yet biological interpretation is just as essential a preliminary to extension of psychological interpretation as physical interpretation to extension of biological interpretation. Maintenance of interest is just maintenance of life perceived more fully. What appears in its rudimentary form as blind maintenance of life is transformed in psychological interpretation into maintenance of interest; and it is through this transformation that interest becomes wider and fuller. Just, moreover, as life is more than individual life, so interest is more than mere individual interest. All of what we regard as highest and best in us is based on what we can regard from a less adequate standpoint as mere animality; but so regarded it is only imperfectly perceived and interpreted. What may be interpreted biologically as mere blind impulses of hunger, thirst, sexual attraction, parental instinct, or herd-instinct, becomes, when more fully understood, something very different, and quite incapable of mere biological interpretation.

In this last lecture I shall attempt to sum up and survey in relation to the whole of our experience the conclusions reached. I have endeavoured to show that though the fundamental sciences or branches of knowledge are of enormous practical use, the axioms, or fundamental assumptions, on which each of them is based are characteristic for each science and more or less in conflict with one another. This does not prevent our using each science practically in the sphere within which it is found to be useful, but warns us that science is not philosophy, and that we cannot expect to make any science into a system consistent with our experience as a whole. The physicists and mathematicians in particular have been realising this lately. Owing to the brilliant advance made on the general lines formulated by Newton, physics had come, in the latter half of last century, to appear as almost a consistent system apart from the mystery of the physical world being perceived and the theatre of conscious behaviour. Mathematical space and time had also come to be accepted as just something real in themselves apart from other data of experience. Advance in knowledge has very radically altered this situation, though the practical usefulness of the traditional physics and mathematics is greater than ever. Their fundamental conceptions can, however, no longer be taken as representing reality.

Under the general understanding which has been stated I endeavoured to define, and to illustrate by examples, the fundamental axiom of biology. That axiom, as it seems to me, is that in the scientific treatment of biology we assume that the phenomena dealt with, whether they refer to activity, environment, or structure, are manifestations of the unity which we call the life of an organism, and which we cannot define in terms of anything simpler. We can only point to our apparent experience of it in the phenomena we are dealing with, just as, in the traditional physical sciences, we can point to our apparent experience of matter and energy in time and space.

I dealt with the attempts which have been made to interpret the peculiarities of life as being due to the presence within living organisms of an independent influence, the "vital principle," "vital force," or "entelechy." This attempt is that of the so-called vitalists, and it has failed because we can show by observation and experiment that it is impossible to distinguish within the organism any influence not dependent on that of environment, direct or indirect.

I also considered the attempts which have been made to show that life may be regarded as nothing more than a very complex physical and chemical process, and pointed out that we never succeed in distinguishing what we can regard as definite physical and chemical events in the life of an organism. What we actually find is that the life of the organism is an indivisible co-ordinated whole which is constantly maintaining and reproducing itself. The phenomena of life cannot be fitted into the scheme of physico-chemical interpretation.

There is also no definite point at which life begins to interfere with physico-chemical action, since so far as biological phenomena are concerned there is no such thing as physico-chemical action. Assumed physico-chemical action on or by a living organism loses itself in undefinable detail. The supposed effect is found to be dependent on a mysteriously ordered simultaneous influence of innumerable other causes which determine the excitability and the active maintenance of structure in the organism. If we had nothing but physico-chemical conceptions to guide us we should be lost in this maze; and, in particular, it is only into such a maze that chemical investigation, guided only by chemical conceptions, leads us. We make matters no better by calling such investigations biochemistry. The conception of life as a co-ordinated unity maintaining itself throughout what from the physical and chemical standpoint is an indefinite maze enables us to investigate the phenomena scientifically, so that we can use our conception for predicting what will happen under different conditions.

It is the conception of life as fundamental in that part of our knowledge which we call biology that I have tried to stress in these lectures. I have also tried to distinguish biology from all the different branches of knowledge which may be included under the comprehensive title of psychology or applied psychology, since they deal with conscious behaviour. Biology is neither physical science nor psychology. Nor is it philosophy; it does not deal with ultimate questions, but its working assumptions inevitably raise ultimate questions, just as do the working conceptions of other sciences.

When we compare it with the physical sciences it shows us that they are dealing with our experience in an artificially abstract manner, since that experience includes biological phenomena which are ignored by the physical sciences. When, on the other hand, we compare biological science with psychology, we find that biology itself is only an abstract science, since all our experience is also that of conscious behaviour. The physical sciences, biology, and psychology, are all dealing with the same world; but it is in reality always a perceived world of interest and values and corresponding voluntary action. In the natural sciences we disregard, so far as we can, the fact of its being a perceived world and disregard the values, or perhaps treat the perceptions, voluntary actions, and values as if they were only subjective phenomena. By doing so we obtain great simplification and corresponding practical advantages. We cannot, however, do this in the psychological or humanistic sciences, of which the whole material concerns interest and values expressed in perception and conscious behaviour. Thus the world with which any particular branch of knowledge is concerned depends on how we regard it, or how we are interpreting our experience—whether more abstractly or less abstractly.

We are still living in an age which I think our successors will some day look back upon with curiosity and wonder as an age characterised especially by physical realism—an age strangely blind in some, but by no means all, respects to what will then appear as outstanding spiritual reality, and concealing this behind scientific abstractions which it had taken for representations of reality and proceeded to bow down before, though they were only its own creations. In this respect I think that our age will be regarded as an idolatrous one, although our idols are of a different kind from those of relatively uncivilised peoples. The idolatry pervades not only scientific thought, but also, as it seems to me, theology. We have accustomed ourselves to believe at the same time in the reality of a material and a spiritual world, without realising that these two beliefs are ultimately inconsistent with one another.

We can see signs of the passing of this idolatrous age of physical realism or materialism; but how long it will take to pass no one can say. I think, however, that a realisation of the axioms on which biology is based will do a great deal to turn us from our idolatry, and do it perhaps more effectively because it brings us straight up against physical realism, in so direct a manner that there can be no evasion of the issue involved. Once we are in this way brought to see the impossibility of physical realism, further insight will follow much more easily.

The world of psychological or humanistic interpretations has so far been treated as if it were a world of individual, self-centred personalities—of monads, to use the expression of Leibnitz. In his recently published book, *Cogitans Cogitata,* Professor Wildon Carr develops this conception of our universe. When, however, we examine psychological experience, we find that it cannot be interpreted as the mere experience of individual persons. As a matter of fact, nothing would ever convince us that, however true it may be that the manner in which our experience appears to us depends on how we are interpreting it, whether more fully or less fully, the world we perceive is no more than our individual perception of it.

When we examine the interest which unifies our experience we find that it is no mere individual interest. In fellowship with others our mere individual interests are overborne through the existence of what we recognise as truth, right, and beauty, which are not the mere manifestations of individual interest, but unite our individual interests, so that we are much more than separate self-centred monads. It is the recognition of this fundamental fact which we also express when we say that we acknowledge the existence and presence within us of God. Thus it is not to a universe of separate monads, but to a universe which is a manifestation of God, and receives objectivity through this fact, that analysis of our experience finally leads. God is the Personality of personalities. In so far as our perceptions and actions can be identified with the perceptions and corresponding actions of God they correspond with reality; and the presence of God within us inspires the effort to test and realise in our lives the correspondence. It follows that in the effort some degree of correspondence is attained, so that we are always dealing with an objective world, however imperfectly we may be interpreting it, whether mathematically, physically, biologically, or psychologically.

We find that our knowledge, of whatever kind, is always imperfect, in the sense that it never enables us to understand or predict our experience more than imperfectly. Our data are always imperfect. What our existing knowledge does not enable us to predict is constantly happening; and the utility of such abstract knowledge as we possess shows itself only through the extent to which, as mere abstract knowledge, it holds good through actual experiences. It is through experience alone that we discover and come to trust such abstract knowledge as we possess. For instance, it is through actual experience that we have built up physical and chemical theory and are constantly testing it anew. Similarly, actual experience shows us that the life of an organism must be regarded as a whole or participating in a wider whole, and it only shows itself to be a whole through continuous realisation of its unity under circumstances which may vary indefinitely. We should naturally attempt to interpret these circumstances, regarded in isolation from one another, as mere physical events; and it is only when they are perceived in relation to one another that they appear as manifesting the unity of life.

It is the same with psychological unity or personality. It only shows its reality in presence of circumstances which could not be predicted, and which, in isolation from their relation to future and past events, would naturally be interpreted biologically, or else physically. Hence the unity of personality implies an unforeseen element of which we may ultimately only be able to say that it is here and now, and in virtue of which personality is something which is constantly manifesting itself actively and afresh. The here and now is inseparable from personality.

Whether we refer to physical, biological, or psychological interpretation, an element of what cannot be predicted is always present; but without this element the interpretation itself would be meaningless. It is only through the effort to understand an otherwise indefinite world that we realise physical interpretation, and through effort of a wider sort that we realise biological interpretation. Through still wider effort, which also shows us the imperfection of both physical and biological interpretation, we realise psychological interpretation—a world of personality. Finally we realise the interpretation of the universe, in so far as it is ordered or definite, as a manifestation of the perceptions and will of God. There is always present, however, an element which cannot be predicted. Hence we have to walk by continuous effort and faith, not only in science, but also in religion. Personality can only manifest itself in the effort to understand and act accordingly in the realisation of interest; and we only know God through interpretation of what we perceive to be the highest and most unselfish efforts in human behaviour. We realise our personality in the attempt to understand and to act rationally; and in our attempts towards truth, right, and beauty we realise the presence in us of God. It is not to the conception of a perfect God existing apart from what is clearly a very imperfect universe that philosophy leads us, but of a continuously living and acting God, manifested in progressive creation of what we recognise as higher.

However true it may be that each perception or voluntary action sums up present, past, and future experience, yet, as being effort, it is also only here and now, which implies that we are in presence of what we can only understand and predict imperfectly. Nevertheless, the conceptions of the various sciences, abstract and imperfect as they are, afford us invaluable aid in such understanding and prediction as we are able to reach.

They are tools of enormous power. Without them we could not shape our perceptions or actions, but we are prone to misuse them.

We can look back to a time when there were not merely no human beings, but no conscious behaviour or life in such forms as we are at present familiar with; and perhaps it may seem to us as meaningless to imagine that God was then omnipresent, unless we use the word God to signify a mere physically interpreted universe. But what we know about the physically interpreted world then has just the same defect as what we know about the physically interpreted world now. The actual existence of all-embracing life and personality shows us that a mere physical interpretation of our universe is impossible; and it remains just as impossible however far back we go in time, or outwards in space. What we know of our universe from analysis of perception and human activity can never be left out of account either now or at any other time. We are never dealing with anything more than what appears in perception; and the immensities of time and space are still within the world of personality—not mere individual personality, but what individual personality implies, namely, the personality of God.

It has already been pointed out that even when we disregard the existence of life and the fact that our knowledge is only revealed to us in perception, the universe as we represent it to ourselves for the purposes of physical science is not consistent with its representation. The reality behind the representation is therefore something different from it. When we take into consideration, first the existence of life as a manifestation of what that universe is, and then the existence of all-embracing perception and the implied maintenance of values, that reality can only be the reality of personality. The unreality of mere individual personality has, however, been already pointed out, so that our ultimate interpretation of our universe, either now or at any time, must be as a continuous creative manifestation of God's personality.

The conception of evolution as applied to human ideas and institutions including religion, to life, and to our universe generally, appeared at first to many as if it were hostile to religion; and to some persons it appears still in this light. If it were the case that evolution implied that personality, life, and all else that we perceive around and within us, including our conception of the personality of God, can ultimately be interpreted as nothing more than the manifestations of a physically interpreted universe, this hostility would be real. For the latter conclusion, as has already been pointed out, there are, however, no grounds whatever. By tracing back life we never reach what can be interpreted physically, nor do we reach what is not personality by tracing it backwards, although we finally lose sight of what we can at present definitely recognise as individual personality or even life.

On the other hand, the conception of evolution saves us from introducing confusion into our ideas by assuming abrupt and totally unintelligible origins for the reality which we find around us. The fact of evolution shows us that life and personality are no abrupt or artificial introduction, but are inherent in our universe, and belong to its very nature. We can, for instance, trace life back indefinitely, or trace science or religion back indefinitely; but we are only deceiving ourselves if we imagine that we have traced them to some abrupt origin from something else, so that they appear as mere artefacts.

Apart from this, the conception of evolution implies that of progress. In the universe as interpreted mechanically there would be a general tendency towards a condition in which the temperature would everywhere be even, so that heat, in so far as it had not radiated away, could no longer be converted into other forms of energy; and organised life, which on the mechanical conception is everywhere dependent on heat-transference, could no longer exist. The "entropy," which is continually increasing, would have reached a maximum. The only activity left would apparently be that of the cold and solid heavenly bodies if their movements were such that they never collided or produced mutual transference of energy. The general cooling down would constitute degeneration, and not progress. In the light of recent discoveries, however, we might regard as progress the disappearance of chaotic activity capable of being converted into heat, so that only co-ordinated activity was left, such as the internal activity of atoms or the activity of life. This, however, introduces an essentially biological conception into physics.

In the world as interpreted biologically the conception of progress stands out more evidently. Each variety of organism tends to spread itself, and natural selection picks out those most fitted to survive. This fitness depends on inherent maintained co-ordination between organism and environment, so that there is progressive increase in co-ordination.

It is in the world as interpreted psychologically —the world of conscious behaviour—that the conception of progress comes into greatest prominence. For conscious behaviour, whether we call it perception or voluntary action, both the past and the future are expressed in the " now " which is present. Thus present behaviour sums up the experience of the past. The past is not just something which is done with. The co-ordinated interest expressed in present behaviour expresses progress based on past experience, and the new present experience is adding to that experience, and so contributing to progress. From the higher standpoint of religion our universe is the progressive manifestation of God. We can trace advancing civilisation in the history of conscious behaviour, and apart from this, and the consequent light which the past throws on the present, history would become a dull and meaningless record of events, in place of a record of progressive creation.

The conception of God to which the analysis of our experience has led is not that of a perfect being existing apart from the ignorance, sin, and suffering of our own world, but present within and around us, sharing in our struggle. It is only an imperfect theology or philosophy that makes it appear as if the imperfection of the world were inconsistent with the existence of God, since it is only in the continuous negation of imperfection that God is manifested. Our evidence for the existence of God is derived from the recognition in ourselves of the striving after truth, beauty, and goodness, and it is only in presence of what appears to us as error, evil, and ugliness that this divine striving manifests itself. There is no other evidence of any real value; but this evidence is sufficient that throughout all the appearances of chaos our universe is the progressive manifestation of God.

This conclusion or faith is the faith of religion. Our mere individual interests are unreal as such, but in striving after truth and right we find what is real in our world. We are immortal, free, and one with those who have gone before us and will follow after us, not as mere individuals, but through the presence of God within us.

Religion is in reality completely inconsistent with physical realism, though entirely consistent with the use and active development of the physical and other sciences when their uses and the limitations of these uses are realised. It is neither consistent with religion nor with our actual experience to regard ourselves as nothing more than a series of obscure happenings on an obscure planet in a gigantic physical universe. Our universe is not outside of us, because we are not outside of God, and the universe is the progressive manifestation of God. This is the basis of religion; and however often religion may be obscured by mistaken scientific metaphysics or buried in equally mistaken theology, it will return in ever clearer form to guide and inspire humanity as it has done to such a great extent in the past, in spite of the baseless superstitions which have often been associated with it.

While it is true that the physical sciences, and indeed all sciences, are based on what are only abstractions from the reality to which they apply, and to this extent do not represent reality, it is nevertheless the case that the sciences hang together as a whole. The physical sciences have as the basis of their further development crude mathematical data expressed in terms of space and time, these data being then interpreted physically and chemically. Similarly, the biological sciences have as the basis of their further development crude physical and chemical data, which are interpreted biologically. Without the crude physical and chemical data to work on biology would be empty: they are essential to its growth. In the same way, without biological data to work on psychological interpretation would be empty. Thus the abstract interpretations of the more abstract sciences are necessary to the extension of the less abstract sciences, and are indispensable to the growth of knowledge. Since, moreover, as already pointed out, perception and voluntary action cannot be separated as the manifestations of personality, all the sciences contribute, directly or indirectly, to the manifestations of personality.

Hence nothing which I have said about the abstractions of, for instance, physical and chemical knowledge affects its ultimate value. The fault of physical realism or materialism is, not that it embodies our own abstractions, but that it claims to take the place of knowledge embodying wider and more concrete experience. When we regard physical knowledge from the psychological standpoint, it appears as a step towards wider knowledge. In conscious behaviour we make use of physical knowledge in either our individual interest or the wider interest of truth. In so doing we transform physical interpretation into what must be interpreted psychologically.

Philosophical criticism such as that of Berkeley did not come into detailed contact with physical realism; and the same might be said of Kant's philosophical criticism. But the criticism of physical realism from the standpoint of biology makes a more effective contact; and in passing from the physical to the biological interpretation of our experience, and thence to the psychological interpretation, we cannot help realising to how great an extent what we perceive depends on how we are compelled to interpret it when we look closely. The world of physical realism is only an imperfectly perceived world.

We can now give to Berkeley's reasoning a deeper meaning than he was able to reach, though we can still adhere to his central conclusion, which embodied a protest against physical realism. For Berkeley our experience emanated from the acts of God, and it was therefore in the acts of God that he found the source of objective ordered reality. For him the world was a spiritual world —not merely a material world created in time by

God, but a world which is continuously being created and which derives its reality and orderliness from this creation.

Berkeley, however, regarded God as an external source of our perceptions. His psychological conceptions were still those of his time, dominated by the causal conception of physical realism. It is not through causal conceptions of any sort that God is revealed to us, but through realisation of what is implied in the highest values which are presented to us in our conscious behaviour. These highest values are comprised under what we call truth, goodness, and beauty. In recognising them we pass beyond mere individual experience, and realise the presence within us of God as the ultimately real. God is not merely outside us, but within and around us everywhere. Just in so far as we are seeking for truth, righteousness, and beauty, we are identifying ourselves with God's will.

I can only say, therefore, in concluding this course of lectures, that I can see no other ending than what was substantially Berkeley's to our search after reality, provided we realise that in the search after truth God is just as much present in the active perceiver and voluntary agent as in his perceptions. The existence of God must be the central feature in future developments of philosophy. Whether those engaged in scientific work know it or not, God is present, it seems to me, in their pursuit of knowledge. Even though that knowledge has only an imperfect and provisional character, it represents a necessary step in the pursuit of truth. There is no reason why they should not realise this, and thus also realise that in their work they are in no way really separated from others to whom religion is a living reality, even though they cannot accept various outward theological forms which that religion may take.

To those of our own generation it often seems that the progress of science has proved inconsistent with religion. If the reasoning which I have laid before you in these lectures is correct, there is no inconsistency, though the physical realism or materialism which Berkeley criticised is as inconsistent with religion as it is with scientific biology or psychology. It was mainly because of the great importance of realising that scientific thought does not involve physical realism that I chose the subject of these lectures in the College where Berkeley developed his philosophical ideas.

SUPPLEMENT

RECENT BOOKS ON BIOLOGICAL PRINCIPLES

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Since these lectures were originally written, three books dealing with biological principles have successively appeared in England, and I propose to devote this Supplement to some remarks upon them. The books in question are Mr. J. H. Woodger's *Biological Principles,* Dr. E. S. Russell's *The Interpretation of Development and Heredity,* and Professor L. Hogben's *The Nature of Living Matter.*

Since Professor Hogben's book contains many criticisms of my own position, and particularly of my Gifford Lectures on *The Sciences and Philosophy,* I propose to refer to it first. As indicated in the Preface, the book arose out of Professor Hogben's contribution to a discussion on "The Nature of Life," at the meeting of the British Association at Cape Town in 1929.[1] In this discussion Professor Hogben defended what may be called the mechanistic conception of life, and in doing so could not but criticise the non-mechanistic conceptions put forward by General Smuts

[1] Published, with the author's revisions, by Juta & Co., Cape Town and Johannesburg.

and other contributors, including myself. The criticisms are expanded in the book, together with a fuller statement of Professor Hogben's own ideas.

The title of the book foreshadows these ideas. By Professor Hogben a living organism is assumed to be capable of interpretation as a piece of "matter," whether or not it is also conscious. In investigating it we need only therefore apply the methods and ideas of physical and chemical science, as in the case of what we interpret as other material systems. Any different methods or ideas are thrown together as being "vitalism" and denoting nothing capable of objective or intelligible description. Particular stress is laid on the contention that whatever private ideas physiologists may have as to the nature of life, they do not, in their actual investigations, employ any other methods or ideas than those of the physical sciences. No other methods of interpretation or ideas, therefore, are of any real account.

Physiologists have been told this so often by certain well-known teachers that there are undoubtedly many who believe it, even though they also hold that there is an unfathomed and apparently unfathomable mystery about life. Professor Hogben even tries to persuade me that my own experimental work in physiology has consisted of nothing but physics and chemistry applied to the elucidation of what can only be profitably regarded as a physico-chemical system. In the foregoing lectures I have endeavoured to explain why I cannot take this view, but, on the contrary, am quite clear that if physiological investigation had actually been guided by nothing but physical and chemical conceptions, it could only have led to a confused collection of isolated and more or less indefinite observations, to which the name of science could not be applied. To some physicists and chemists this is indeed how physiology appears. It seems to them to deal with indefinite and constantly changing " messes," like blood and protoplasm, and they long to get back to what they regard as definable physical and chemical entities, in dealing with which they know where they are. Physiology, as I tried to show, is redeemed from this reproach by the use of the working conception that the life of an organism is a maintained whole, expressing itself in every detail which can be studied effectively by biologists, and including the relation of living organisms to their environment. If we exclude this conception by assuming, as Professor Hogben does, that in dealing with life we can only be dealing with what must be interpreted as matter, physiology becomes indeed an unintelligible mess.

As an illustration of what he regards as my own devotion to physical and chemical methods, Professor Hogben refers to the investigations of my co-workers and myself on the manner in which oxygen and carbon dioxide are taken up by and given off from blood, and the theoretical explanation, which I gave at the Cape Town meeting, of the linkage of this double process. As was discovered by Christian Bohr, the oxygen which is taken up in the lung by the hæmoglobin in blood is given off again in a very peculiar manner in presence of the lower oxygen pressure in the tissues. The result is that oxygen comes off much more readily and abundantly to the tissues than was generally inferred, in accordance with ordinary conceptions of physical chemistry, to be the case before Bohr's work. He also found that the carbon dioxide taken up by the blood in the tissues helps to liberate the oxygen, while the giving off of carbon dioxide in the lungs helps the taking up of oxygen. Bohr had followed out these facts very fully and completely because he saw the "physiological" importance of what he was investigating—the manner, that is to say, in which the peculiarities which he was investigating contributed to the maintenance of an animal's life. But he had as yet only discovered part of the story of the blood gases.

He was a pupil of the great German physiologist, Carl Ludwig; and Ludwig communicated to him two ideas which he thought might probably be verified, seeing that an organism possesses life. The first was that oxygen turns out carbon dioxide from the blood when the latter is oxygenated in the lungs, the converse process occurring in the tissues. The second was that oxygen may be actively secreted inwards to the blood in the lungs, just as it is actively secreted into the swim-bladder of fishes. Bohr investigated both these ideas, but failed to verify the first of them. He thought he had verified the second; but his evidence, in the form which he gave it, was not confirmed by others. I had studied under Bohr, who handed on Ludwig's ideas to me. Using a quite different, and far more delicate, method, we were able to confirm the second idea at Oxford, and after acclimatisation on the summit of Pike's Peak, as mentioned in Lecture II. The measurements showed no active secretion during rest at normal barometric pressure, but only during muscular exertion or under other conditions, such as life at a high altitude or carbon monoxide poisoning, where the body was undergoing want of oxygen to an appreciable extent.

We also succeeded in verifying the first idea. Two circumstances had prevented Bohr from verifying it. One was that his experimental methods, though very accurate, were rather slow, and he did not realise how quickly blood alters after removal from the body. The other was that he did not realise how accurately the composition of the blood is regulated as regards its capacity for taking up carbon dioxide. Using a new and rapid method, with a fresh sample of blood taken from the same person for each determination, we verified Ludwig's idea quite easily, at the same time showing how extraordinarily constant is the dissociation curve for carbon dioxide of a healthy individual for week after week, and month after month. By means of the curve we could check a faulty blood-gas apparatus, just as we could check a badly graduated gas-burette by analysis of air from the lung alveoli. The new facts explained why it is that there is so little difference in the pressure of carbon dioxide in different parts of the body, or the venous blood coming from them, and why the regulation of pressure of carbon dioxide in the lung alveoli requires to be so exact as we had found that it is.

The constancy of the dissociation pressures of the carbon dioxide and oxygen in normal arterial blood, and the nearness of those pressures to the corresponding pressures in venous blood, would certainly seem very extraordinary to a chemist who regarded blood as an indefinite "messy" fluid, and reflected on the varying amount and composition of the food and drink entering the body day by day. To a physiologist, who instinctively takes in and applies the conception of life, this is, however, no more surprising than the fact that the lungs retain their normal structure or the nose its normal shape. In each case the specific structure or state is actively maintained as a manifestation of the organism's life; and apart from this fact physiology would be mere chaos.

I can at least assure Professor Hogben and any others who share his views that my own work on the gases of the blood was everywhere guided and suggested by the conception that all the phenomena which interest a physiologist interest him just in so far as they are manifestations of the maintenance of life. As a mere physicist or chemist I should never have dreamt of looking for such things as constant dissociation curves or carbon dioxide pressures or hydrogen-ion pressures or chlorine percentages in liquids like blood; and if I had chanced to find one of them it would only have appeared as a very unintelligible fact. It also seems to me that any biologist who does not, either consciously or instinctively, approach the phenomena of life in the light of the biological conception of life as co-ordinated maintenance is just wandering helplessly in a chaos which he cannot understand. It was because Ludwig and Bohr approached the study of life from the biological standpoint that they did so much for physiology.

A physiologist is always dealing with crude data of which, in their isolation from one another, he can give no more than an imperfect and otherwise unintelligible physical and chemical account. But when he brings the data into connection with one another, and with what he already knows of life, he perceives that they express the maintenance of life. This perception constitutes their explanation, and enables him to predict what he will find at future times, just as when we have observed the shape of a friend's nose we can predict from the biological standpoint that it will be the same a year hence, though from a physical and chemical standpoint a very small proportion of the same atoms or molecules may be present in the nose after a year.

Just in proportion as the conception of co-ordinated maintenance has become more and more realised in physiology, so physiology has become more and more a quantitative science, dealing with quantitative measurements of all kinds as expressions of maintained unity. Neither the necessity for nor the significance of these exact measurements in physiology is intelligible to one who approaches life from no other standpoint than that of the physical sciences. These considerations apply no less to the regularities observed in reflex action than to those observed in other biological phenomena.

I do not pretend that in working at blood-gases I have never worked as a pure "biochemist" in the etymological sense. Once, for instance, I noticed in preparing a methæmoglobin solution by adding ferricyanide to diluted blood, that the liquid frothed slightly, and I had the curiosity to find out what the bubbles consisted of. On finding that they were oxygen, and that the whole of the oxygen which had been combined with the hæmoglobin in the blood was set free as gas, my mere chemical interest in the reaction became less. What interested me more was the fact that the reaction offered a ready and simple method of measuring the gases in blood, and so getting more quickly and effectively at the physiology of the blood gases. Originally, however, I was acting as nothing more than a biochemist, corresponding to Professor Hogben's conception of a physiologist.

In connection with his discussion of conscious behaviour Professor Hogben criticises me for not paying attention to what he regards as the special significance of Professor Pawlow's investigations on "conditioned" reflexes. What is known to physiologists as reflex action is described by Professor Hogben as a sort of activity which can properly be regarded as a simple physico-chemical response to a physical disturbance in environment. As a physiologist, I cannot assent to this description for the reasons given at the beginning of my third lecture. But if we pass over this point Professor Hogben's contention is that if "conditioned" reflexes, such as secretion of saliva in response to the sound of a bell, can be established as a result of learning, there is no good reason for doubting that the whole of conscious behaviour may some day become capable of interpretation as a system of similar reflexes.

If we consider almost any act of voluntary activity, such as walking, or eating and swallowing food, we find that involved in it are numerous physiological activities which, when separately regarded, can be treated as reflex actions in response to immediate stimuli. But when we regard them as a whole, it is evident that their stimuli and inhibitions are co-ordinated with the rest of our behaviour, and in a manner which we express, and cannot but express, as the maintenance of our interest, or the manifestation of our character. In the actions both retrospect and anticipation are expressed as well as the presence of contemporary environment. If we neglect the co-ordination expressed in it, the action appears as nothing but an unintelligible and unpredictable chaos of reflex activities. But quite evidently the co-ordination is present, and any such interpretation as the "behaviourism" which Professor Hogben suggests, is simply an ignoring of experience. It is actual experience that must guide us, and not a grotesque attempt, like "behaviourism," to twist it into an unintelligible shape.

The secretion of saliva on expectation of food is one of the co-ordinated reflexes involved in the voluntary taking of food. If the ringing of a bell has previously coincided with the giving of food, the salivary reflex comes to be liberated by the ringing of the bell, no less certainly than by the smell or sight of the food. But the mere fact that reflexes of various kinds are involved in all voluntary action is a matter of such common knowledge to physiologists that Professor Pawlow's experiments do not seem to me of any special significance.

If we regarded reflex action as something which does not participate in voluntary action, then experiments such as those of Pawlow might be taken to indicate that reflex actions originate through a repeated conscious association between the stimulus and other stimuli which normally lead to a voluntary response. The automatic responses by a well-drilled soldier to words of command, and many other similar automatic, or almost automatic, responses might be cited in illustration. Samuel Butler suggested that all reflex action originates in this way from conscious action. Had the salivation which ordinarily occurs when a dog smells or sees food been under direct voluntary control, he would doubtless have accounted in this way for the reflex salivation on ringing a bell, and so traced the reflex action to an origin in voluntary action. His suggestion never appealed to physiologists, since they realised that what, apart from their co-ordination, can be interpreted as reflex actions are involved in all voluntary activity. If there were no reflexes in which conscious co-ordination could manifest itself, conscious behaviour would be meaningless. With nothing to be co-ordinated there would be no co-ordination.

The fault of "behaviourism," such as Professor Hogben aims at, is that it neglects the inherent co-ordinated maintenance which shows itself, not merely in unconscious reflex activity, but in a much wider sense in perception and voluntary action. Apart from the conception of inherent co-ordinated maintenance which we call life, or in its higher forms conscious personality, the phenomena dealt with are nothing but an unintelligible chaos to which the name of science could not possibly be applied.

Professor Hogben argues that the universe as mechanically interpreted is a "public" universe, in the sense that everyone can understand it and communicate ideas about it. The world of such things as moral and æsthetic values, and of what he jumbles together as " vitalism," is only a subjective world, which the victorious advance of " science " is gradually annexing as a world of mechanism. He therefore assigns the ideas of General Smuts and myself, along with those of Sir Arthur Eddington (who took part in the Cape Town discussion), Professor Whitehead, and other physicists and mathematicians for whom the mechanically interpreted world is unreal, to a non-public or subjective universe. It seems to me curious that anyone who looks round and considers the actual world of public interest, and the very diversified branches of what is generally admitted to be knowledge, should propound so quaint an idea. But until the study of philosophy and the logic of different branches of knowledge becomes more definite and serious than it is at present, we must expect to find ideas of this kind put forward.

A chapter is devoted by Professor Hogben to a clear and excellent account of the great progress in our knowledge of various facts connected with the physiology of heredity, commencing with the Abbé Mendel's famous experiments on the subject. The chapter is, however, entitled, " The Atomistic View of Parenthood," and in the course of it the belief is expressed that the new facts discovered constitute a definite step towards a mechanistic conception of inheritance. Such a title, and such a belief, are to me amazing. I can hardly imagine anything more calculated to make men vitalists of the old school than a contemplation of all the orderly facts relating to the behaviour of chromosomes in cell-division and fertilisation, with the related phenomena of hereditary transmission, together with the fact that we cannot form even the foggiest mechanistic conception of how these phenomena are brought about. To regard them as throwing light on any "mechanism" of heredity seems to me to be only ludicrous. It is apparently, however, sufficient for Professor Hogben to know that they are centralised in what he calls pieces of "living matter," and that if so, they must be capable of mechanistic explanation, even though physicists have ceased to believe that any mechanistic explanation can be given of the behaviour of atoms themselves.

Professor Hogben begins his book with the assumption that biology deals with "living matter," and not simply with life. The detailed phenomena of hereditary transmission do not seem to me to take him any farther in showing how his assumption is consistent with biological observation, or how biology can dispense with the "holistic" assumption that life means inherent co-ordinated maintenance of structure and activity, which we can observe, measure, and treat scientifically, but which necessarily eludes us if we attempt to resolve it into mechanism or relate it to a co-existing physically interpreted world. I have, however, already discussed this in the preceding lectures.

As I have sufficiently stated the points on which I disagree with Professor Hogben, I should like also to say where I agree with him. He says that what he calls his "public" interpretation of experience is ethically and æsthetically neutral. While I wholly dissent from his identification of mechanical or physical interpretation with biological interpretation, I am quite at one with him in maintaining that both physical and biological interpretation are ethically and æsthetically neutral. In particular, we cannot base moral, æsthetical, or religious conceptions on biology, nor our conceptions of human society.

There are some biologists, philosophical writers, and theologians who believe that they can find in biological observation a basis for ethics, æsthetics, or religion. It seems to me that in so far as they do so they are confusing biological with psychological interpretation. We cannot regard a man or any higher animal as being simply alive in the same sense as we regard plants or other "lowly" organisms. In so far as we regard them as behaving consciously, we have, however, passed from biological to psychological interpretation. I have endeavoured in the third lecture to distinguish the two kinds of interpretation, and it seems to me that if we mix them up nothing but confusion can arise, just as when we mix up physical with biological interpretation. A biologist has no use, in his descriptions and interpretations, for the conceptions of perception or voluntary action, or for those of right and wrong, or beauty, or truth, any more than has a physicist. An actual physicist or biologist is, however, not one who is living in a restricted inhuman "public" world of physics or biology, but an ordinary person whose actual public world is just that of other persons, though he specialises in the use to which he puts the working hypotheses of his science.

Mr. Woodger's book on "Biological Principles" is mainly critical, and as he carries me with him in nearly all his criticisms, and his references to my own writings are very friendly, I can only express the hope that his book will be widely read by those interested in biological principles and their application. His only complaint against me is of my having been too short in my previous writings dealing with the principles of biology; but I think he has redressed the balance in his own book, which is perhaps rather long.

He stresses particularly the need for critical examination of the general ideas which are applicable to biological investigation, and points out how loose and unsatisfactory have been the guiding ideas commonly applied in the development of biology since the Renaissance. His criticisms of the use of both mechanistic and vitalistic ideas are even more thorough, and considerably more detailed, than my own; and he arrives at a conclusion in which I am in entire agreement with him—namely, that biology must be regarded as an independent science with its own guiding logical ideas, which are not those of physics.

One specially interesting part of the book is where he points out the nature of the step which Galileo, followed by succeeding physicists, took when he concluded that what, since Locke, have been called the "secondary qualities" of bodies may be treated by physicists as unreal, though just these secondary qualities are a prominent element in our ordinary experience, and are of the greatest importance in biology and psychology. At the beginning of my third lecture I tried to indicate the lines on which physiology is capable of giving an orderly account of secondary qualities, fitful and unintelligible as they are from the Galilean standpoint.

I rather think that Mr. Woodger exaggerates the " heuristic " value of mechanistic conceptions in physiology. It certainly seems to me that whatever most physiologists may say on the subject, they are always instinctively guided in their best experimental work by ideas which are not mechanistic, but simply what I should call biological. In this Supplement and in Lecture II, I have tried to illustrate this in the work of such physiologists as Carl Ludwig and Claude Bernard, but many other examples might be taken, particularly perhaps from the work of Harvey. Physiologists deal, not with mere physically or chemically interpreted phenomena, but with those phenomena regarded as a manifestation of life.

As indicated by its title, *The Interpretation of Development and Heredity,* and sub-title, " A Study in Biological Method," Dr. Russell's book does not deal directly with biology as a whole, but only with one side of it. As he points out, however, the phenomena of reproduction and development present a major problem in biology. In reality this problem is present everywhere in biology, if only in the background.

Although Dr. Russell's book, like that of Mr. Woodger, may be described broadly as very strongly anti-mechanistic, yet in certain important points his biological conceptions differ from mine, and I think also from Mr. Woodger's. Professor Hogben may therefore take some comfort from the thought that his opponents do not altogether agree among themselves. Dr. Russell adopts what he calls the "organismal" point of view, and rightly traces it back to Aristotle. We also find it strongly represented among philosophical writers, and it is this point of view which, if I am not mistaken, Professor Whitehead is endeavouring to extend to the physical world generally.

The book is a very scholarly and extremely interesting critical discussion of the theories which have, at various periods in the history of biology up to the present, been held on the subject of heredity and embryology. It is a book which can be very confidently recommended to the careful consideration of all those interested, not only in this subject, but in its general philosophical implications. The conclusion which he reaches is that a living organism represents in Nature a unity or whole which expresses itself in all the bodily parts and activities concerned, so that they cannot be treated scientifically in separation from one another, for the simple reason that their persistent presence and repetition in individual life history is quite unintelligible except as an expression of the nature of the whole. With Aristotle, he insists that it is Nature herself that we are studying in biology, and not the action of a "vital principle" or "entelechy" on a plastic physical basis. He is therefore no vitalist in the historical sense. It is of the essence of his position that certain aspects of Nature cannot be described in terms of physical and chemical theory, and can only be described in distinctively biological terms. Following the example of Ritter, he calls his position the "organismal" one.

At first sight it might perhaps seem that there is no difference between Dr. Russell's position and my own, so I should like to point out the difference. Dr. Russell's standpoint is rightly described as "organismal," and he does not apply his reasoning to the external environment of organisms. When I was a young man I became familiar with the same organismal point of view, as represented in philosophical writings, and particularly those of Hegel; but as a physiologist I also saw that in considering life it is impossible to separate an organism from the external environment with which its life is wrapped up at every turn, and I therefore broke away definitely from the organismal standpoint in favour of the conclusion that in scientific biology we are interpreting the *whole* of the phenomena we are studying from the biological standpoint, and not merely the bodies of living organisms. It is thus the conception of life, and not the mere organismal conception, that guides us in the interpretation of our experience in biology, and environment is not something outside the unity of a life, but within it. We can then interpret scientifically what from the Galilean physical standpoint appears as the mysterious fact that the influence of environment on organisms is always being interfered with in an erratic manner by the influence of organism on environment. Matter seems, for instance, to be endowed with " secondary " qualities of which no physical account can be given; and between afferent impulse and response there intervenes the "excitability" of a living organism.

The organismal standpoint is defective in physiology; but this defect is not so serious in the study of reproduction and development on its physiological side as in the study of adult organisms. An embryo cell carries within it many of the most important elements of environment, and Dr. Russell emphasises the fact that a living nucleus or chromosome apart from its physiological environment is a mere empty morphological abstraction. But it is the intra-cellular or intra-organismal environment which seems most important to an embryologist, or to a morphologist who has thoroughly grasped the fact that organic structure is the expression of constant activity; and not just something given. In all that Dr. Russell says about the impossibility of separating organic structure from intra-organismal environment I am in entire agreement with him, but it seems to me that we must go farther, and regard the whole of an organism's environment from the standpoint of its life as an indivisible and persistent whole. It is true that we may also regard its environment from nothing but a physical standpoint; but we cannot do so without creating an impassable logical gulf between biology and physics. It is not the facts of experience that create this gulf, but our own interpretation of them. The world is just beginning to realise that when Galileo and the early physicists introduced the principles of physical investigation they were not merely launching on new discovery, but also unconsciously shutting out other avenues of discovery. Since Galileo's time biology has been continuously confused by vain efforts to twist physiological and morphological observation into a form consistent with the Galilean postulates; and psychology has been similarly confused through vain efforts to relate a Galilean body and environment to a soul or mind. The writings of Descartes present a specially vivid picture of this confusion.

After these preliminary remarks I wish to say something more about the contents of Dr. Russell's book. He discusses in detail the main facts relating to heredity and embryology, on which I only touched lightly in the foregoing lectures; and at the same time he describes and criticises the various types of explanation or description of these facts which have been given by biologists. With his criticisms I am in entire agreement, and particularly where he points out that the very unsatisfactory attempts to formulate physico-chemical conceptions of reproduction and individual development have failed owing to failure to realise that the physical interpretation of our experience has only a limited validity or usefulness, and is not applicable to our experience of life.

He discusses one by one the various attempts at a physico-chemical conception of heredity since the Renaissance, beginning with the "box-within-box" theory, which had considerable theological support. Since this theory in its crude form was inconsistent with embryological observation, it was modified by Bonnet in the sense that though the form of the adult is not evident in the early embryo, the unfilled outline is nevertheless present. In his celebrated account of the facts of embryology, von Baer hardly mentioned the "box-within-box" theory in any form, and he treated it with deserved contempt. His conception of reproduction is definitely non-mechanistic, and he draws what seems to me the inescapable conclusion that "life cannot be explained from something else, but must be conceived and understood in itself."

Growing knowledge of the microscopical phenomena of embryology and of the cells, male and female, concerned in sexual reproduction, led up to conceptions of which the best known was Weismann's. He assumed that the chromatin of the nuclei of reproductive cells contains "germ-plasma" derived more or less directly from the germ-plasma of the previous generation, and therefore similar to it. The germ-plasma was supposed to be so constituted physically and chemically that in presence of its environment it gave rise to all the amazingly specific details of structure and activity observed in the adult organism, unrolling, as it were, its complications as the nuclear substance divided farther and farther during the course of the organism's development. Dr. Russell points out that this is in reality only a variant of the "box-within-box" theory, an extremely complicated molecular structure capable of producing the adult form being substituted for the original miniature adult. By the use of the word "plasma" where an excessively definite and complex molecular structure was implied, Weismann hid away the difficulty in conceiving how such a structure could reproduce itself indefinitely, or how it could unite with another such structure in sexual reproduction. We can imagine a plasma increasing its volume and then dividing itself indefinitely, but we cannot apply the same conception to an almost inconceivably complex molecular structure. Hence the theory makes nonsense, like the " box-within-box " theory.

The consideration that every structural element in the body is alive, and from the physical standpoint nothing but the expression of continuous exchanges of matter and energy with its immediate environment, has led to other physico-chemical theories on which the germ-cell as a whole is regarded as an extremely definite and complex physico-chemical system, so constituted that in contact with its environment the adult stage is produced. Dr. Russell refers also to these theories, and points out that they are ultimately in no better position, though they do take account of important elementary physiological facts. The difficulty of framing any coherent conception of how an almost inconceivably complex and definite physico-chemical system could reproduce itself by dividing into two, or could fuse with another such system, is just the same as with the reproduction of an excessively complex and definite molecular structure; and the theory again makes nonsense.

In whatever way mechanistic theories of reproduction may twist and turn they never make anything else than sheer nonsense. Yet biologists are constantly returning to them like moths to a candle, because they think that there *must* be some physico-chemical explanation. At the same time they refuse to consider what philosophy has had to say on the subject, since they argue that biology has to do with facts of observation, and not with "metaphysics." They never realise that they are themselves in the grip of metaphysics, and bad metaphysics, when they endeavour to twist biological observation into the form of physical and chemical interpretation. The manner in which, since the time of Galileo, Descartes, and Newton, European culture got into the grip of bad metaphysics when men supposed that they were freeing themselves from metaphysics and going back to facts is something which future generations will laugh over; and particularly over ideas at present current as to what science or "exact science" is.

Dr. Russell has discussed mechanistic theories of heredity much more fully than I ever did, but his conclusions about them are substantially the same as those which I expressed in my address to the Physiological Section of the British Association in Dublin in 1908, and in *Mechanism, Life, and Personality* in 1913. After the discussion of heredity in the latter book, I wrote, " I should as soon go back to the mythology of our Saxon forefathers as to the mechanistic physiology "; and I could say nothing different now.

Dr. Russell does not definitely distinguish biology from psychology, and his treatment of memory and purpose differs correspondingly from mine. In these respects his position is somewhat similar to that taken up by Samuel Butler in *Life and Habit.* In the Third Lecture (page 98) I have tried to explain why we have no reason to attribute to memory and purpose the manner in which an organism develops in one particular way from the embryonic stage. It seems to me that as mere biologists we have no need to make use of the concepts of either memory or purpose. What we observe in all lives is simply their tendency to maintain and reproduce themselves as co-ordinated wholes. An embryonic organism displays this tendency just in the same way as any part of the adult organism displays it; and complexity of structure, whether in the adult or embryonic stage, is a mere detail in the expression of life. In an embryonic organism this complexity is necessarily at a minimum, and it is the absence of normal complexity which, broadly speaking, leads to development, which is the re-establishment, step by step, of the normal complexity. Steps like the formation of organs, such as lungs or eyes, long before they function as respiratory or visual organs, are quite intelligible biologically. Their function as a respiratory or visual organ is only one side of their function as an expression of the whole life of an organism. There is therefore no need to regard their early formation as an expression of purpose. The behaviour of a developing organism is just such as biological theory would assign to it.

Dr. Russell criticises the memory or "mneme" theory of heredity as developed by Hering and Semon. They assume that memory in general is dependent on protoplasmic "engrams," and that germ-cells are furnished with a system of engrams, functioning as guide-posts to all the normal stages of development. This theory, as Dr. Russell points out, has quite evidently all the defects of other attempts at mechanistic explanations of development. How such an amazingly complex system of sign-posts could function by any physico-chemical process or reproduce itself indefinitely often is inconceivable.

In Lecture III (page 104) I have discussed memory from the psychological standpoint, pointing out the central positions which both memory and anticipation occupy; but I did not discuss the inheritance of psychological characters, or in what sense memory can be said to be heritable. The investigations of the latter half of last century revealed clearly the fact that continuity of life in the mere biological sense is always involved in reproduction, and that there is no such thing as spontaneous generation or formation of new cells by any such simple physical processes as Schwann at first imagined when he brought forward what was then called the Cell Theory. We can thus now trace life from generation to generation; but we cannot similarly trace personality. Inheritance of personality is, however, a very evident fact; and the mere circumstance that there is an intervening stage during which we cannot trace it does not alter the fact. There is something very real behind pride of race and descent.

As was pointed out in Lecture III, memory is no mere reading off of a physical record, any more than perception in general is a reading off of physical impressions. The memory which is inherited is the characteristic manner in which records are made, read off, and acted on. This manner can only be interpreted psychologically, and it seems to me that we must conclude that memory in this sense, as well as what else is included in personality, is directly inherited, though certainly not in the form of anything which we can represent to ourselves as mere engrams. I think that my only real difference with Dr. Russell on the subject is that he regards memory in the psychological sense as required to interpret what I would call the purely biological features of embryological development. As regards the psychological features of inheritance I am in agreement with him. It seems to me that there is direct continuity of personality from generation to generation; and this view was also expressed in the last chapter of the Second Edition of my book, *Mechanism, Life and Personality.*

Consideration of the three books referred to in this Supplement has, I hope, contributed towards clarifying the argument running through my Donnellan lectures. Professor Hogben's book represents the direct development of the mechanistic interpretation of biology in the second half of last century. It was not so evident then as it seems to many others as well as myself to be now, that the foundations of this interpretation were entirely rotten. Moreover, physics was apparently almost entirely mechanistic, whereas fundamental mechanistic interpretation is now acknowledged to be impossible in physics. Professor Hogben stands bravely on a burning deck whence others have fled or are preparing to flee. We cannot but admire his courage. The books of Mr. Woodger and Dr. Russell represent critical and constructive efforts to refashion biology on a more secure theoretical basis.

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