ARCHIMEDES

OR

THE FUTURE OF PHYSICS

TO-DAY AND TO-MORROW

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OR

THE FUTURE OF PHYSICS

BY

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CHAPTER I

The Sciences Converge

One of the most fascinating features in the history of thought is that on several occasions an important new idea has come simultaneously to independent minds. Thus after Euclid's geometry had remained without a rival for two thousand years the conception of an alternative non-Euclidean system was reached separately by Gauss, Lobatschewsky, and Bolyai during the years 1820-30. Bolyai's father, while ignorant of the fact that Gauss had already made the same discoveries, wrote to his son urging him to publish his results and used the following prophetic words:

"There is some truth in this, that many things have an epoch, in which they are found at the same time in several places, just as the violets appear on every side in the spring."

Another example of the simultaneous emergence of an idea in the minds of different thinkers is given by Darwin in his introduction to the *Origin of Species*. He there calls attention to the fact that in 1794-5 the broad idea of the evolution of species—though not its cause—was simultaneously formulated by Goethe in Germany, St Hilaire in France, and his own grandfather, Dr Darwin, in England. Moreover Darwin himself had the remarkable experience of finding in an essay submitted to him in 1858 by A. R. Wallace a complete summary of his own unpublished theory of natural selection as the chief cause of the evolution of species.

The last few years constitute another critical period of a similar kind, since an idea, which when made precise will transform scientific thought, has already come independently to many thinkers. Since 1922 many scientists have felt that in studying the emission and absorption of light physics has come near to the problem of life.[1] Others have proposed that in order to straighten out its atomic problems physics will have to take a hint from biology, but what this hint should be has not yet been indicated. The following pages suggest a definite line of advance for physics, and interpret these isolated flashes of intuition as evidence of a special feature in the present situation of the sciences.

We stand at the eve of a new epoch. Physics, biology, and psychology are converging towards a scientific synthesis of unprecedented importance, whose influence on thought and social custom will be so profound that it will mark a stage in human evolution. For centuries science has concentrated its highest genius on the study of inanimate matter; to-day the three great sciences are at last reaching the problem of life. For their researches on matter, life, and mind are now overlapping at one common issue: the nature of the fundamental electrical processes which underlie radiation and chemical combination.

Thus physics is at present occupied with the changes that occur when an atom emits either light or electricity. Biology is at the same problem in studying the electrical processes which are the basis of all organic behaviour, whether in primitive forms of protoplasm or in the highly developed central nervous system of man. Meantime psychology is dealing with an identical process when it analyses the structure of mind, and considers the elementary changes of consciousness which are produced when light of a given colour falls on the retina and sends its influence to the brain.

As the result of these convergent researches, life and consciousness will soon be subject to the first stages of a theoretically-grounded control, compared with which the present tentative efforts of medicine and psychology will be looked back on much as we remember the haphazard work of the alchemists before the foundation of chemistry. But this development of human knowledge and powers will carry with it great responsibilities, and scientists have to prepare themselves for the new tasks that will very soon fall to them. By indicating the main ideas through which this broad scientific synthesis may come about, this essay aims at showing that this possibility has to be taken seriously. We shall first examine the situation in physics and then turn to consider the influence which future developments of physical theory may have on biology and psychology.

Two main types of process defy interpretation within the present scheme of physical conceptions: life itself, and the atomic processes of radiation and the building up of stable compounds. In organic processes on the one hand, and the energy-interchanges of atoms on the other hand, we find something happening which cannot adequately be explained as a change in the *structure* of the system considered. By structure is meant a spatial pattern of particles, which are supposed to be permanent and to move about like cricket balls or planets. Systems with a structure of this kind could not display the purposive quality of organic behaviour, and when we try to make a structural model of the atom we find that it fails to explain why the atom radiates energy in the abrupt packets which are called 'quanta', instead of in a continuous wave. We shall return presently to the question of organisms, after making an endeavour to discover why the atom cannot be described in terms of a particle structure.

In 1911 Rutherford achieved remarkable success in accounting for the results of his own researches in radioactivity by adopting a model of the atom as a miniature solar system, with planetary electrons rotating rapidly around a nucleus. But in order to explain the fact that the spectrum of the light emitted by an atom shows a characteristic series of lines, Bohr suggested that an electron inside an atom could emit light only by making a discontinuous jump from one possible orbit to another quite distinct orbit. This apparent discontinuity in the motion of electrons has intrigued physicists for more than ten years, and the following interpretations have recently been offered for this puzzling behaviour:

1. Nature is made up of electrons,

but neither space nor time is fundamentally discontinuous. The electron appears to have some freedom of choice, and to be able to reappear unexpectedly at forbidden places.

2. Nature is not discontinuous or arbitrary, but nevertheless something prevents us determining all the things we should like to know about an electron. For instance, if we try to determine exactly where it is, it behaves so that we cannot simultaneously measure its exact velocity. (Heisenberg.) This view may perhaps be interpreted to mean that we have made the atom model more complex than the atom itself is, and that consequently we have been using more quantities than are necessary for describing all we can observe of its behaviour.

3. Nature is not made up of electrons, but of waves. The atom must be considered as a system of electric waves spread over its whole volume. 'Electrons' are merely an inaccurate way of describing some of the properties of these waves. The wave picture of the atom

is, however, to be considered only as a temporary expedient to be used until some better description of the atom can be invented, in which both the wave and the corpuscular properties of atoms will appear as aspects of some more profound physical property. (Schrödinger.)

The first alternative is a mere cry of despair, since it does not propose any line of advance. But the other two suggestions may be combined thus:

4. The view of the atom as a structure of Newtonian particles is wrong since it gives rise to discontinuities, and provides more quantities than we at present need. A new formulation of atomic processes must be found using fewer quantities which will explain why we find wave properties, and why sometimes the electron does behave like a small billiard ball though really it is some different sort of thing.

Now since the Newtonian mathematics of moving particles is inadequate for describing the changes that go on in the atom—just as it is for describing organic processes—there must be some assumption implicit in Newton's laws which is valid neither for atom nor for organism. Such an assumption can be found very easily, though physics has never given it much attention. It is that the elementary processes in nature are *reversible,* or would be if they could be isolated. By reversible is here meant that the laws governing the process remain unchanged when the direction of time is reversed, i.e. when $-t$ is substituted for $+t$. If the law is changed by this substitution so that the reversed process never occurs or is recognizably different, then the process is called irreversible. An irreversible process can therefore be used to yield an objective criterion of past and future, when these terms have been once defined.

To take an example. If I am standing behind a hedge and take a cinematograph film of a stone which suddenly rises in the air and disappears from sight, I could not tell from an examination of the film which way to wind it. Thus if it is wound one way the stone appears to rise, and if wound the other way to fall from the sky. To tell which was the right way I should have to use my subjective sense of the direction of time, i.e. remember the fact that I saw the stone low in the air before I saw it high up. This case, like every gravitational process, is reversible, and motions of this kind have provided the basis for modern physical conceptions.

But suppose that instead I had taken a film of a cup of tea as it was cooling. One end of the film would show the steam above the cup and the spoon changing in length as it changed in temperature. Passing along the film these effects would grow less marked until the successive photos showed no variation when the temperature of the tea was nearly that of the surrounding air. It would be obvious which way to wind this film, without using any subjective criterion supplied from memory of the individual process which had been photographed. This process is irreversible, but physics has hitherto assumed that all such processes are merely the statistical result of a chaos of molecular motions each of them perfectly reversible.

The assumption of reversibility seems to some physicists so fundamental that they think there could be no science without it. But that is a mere prejudice arising from the fact that Newton conceived one particular way of giving mathematical formulation to the measurable features of physical processes. By suggesting that all the laws of nature might take a form similar to his law of gravitation, he made the implicit assumption that all elementary processes were reversible. Gravitational motions are so, at any rate within the accuracy of Newton's law, and as a consequence of the confirmation of his law and the fact that it has been taken as a model for the whole system of modern physical conceptions, the latter are only appropriate for reversible processes.

Apparent irreversibility, such as the cooling of a cup of tea, is attributed to statistical effects, and the second law of thermodynamics, which asserts that temperatures tend to uniformity, is treated as merely a statement of what is highly probable. This is probably quite legitimate, but even where no statistical effect can enter and the process is clearly irreversible physics usually adopts any measure rather than assume that a fundamental elementary process is irreversible.[*] We cannot be surprised at this, since if physics once admitted that any elementary process was irreversible it would have to give up the whole system of Newtonian conceptions. Matter, force, energy, action, and wave properties are all unsuitable for the treatment of irreversible effects since they all ultimately depend on Newton's reversible law.

An entirely new set of ideas is necessary for describing processes which necessarily proceed in one direction, so that one particular state of the system must precede another state. It appears conceivable that an alternative set of conceptions to replace the Newtonian might be established by demanding the irreversibility of all natural laws, as well as the demands hitherto made by physics, i.e. the permanence of matter and the conservation of energy.

The question of the reversibility of natural processes provides the key to a great intellectual struggle which is now in progress behind the complexities of philosophic and scientific thought. The issue can be formulated thus:

Is there a real temporal process in nature? Is the passage of irreversible time a necessary element in any view of the structure of nature? Or, alternatively, is the subjective experience of time a mere illusion in the mind which cannot be given objective expression? These are not metaphysical questions that can still be neglected by science with impunity. For just as Einstein made his advance by analysing conceptions such as simultaneity, which had been thought to be adequately understood for the purposes of empirical science, so the next development of physical theory will probably be made by carrying on the analysis of time from the point at which Einstein left it. Moreover, the above questions may be put into precise scientific form by asking if the causal relations which are studied by science are symmetrical and reversible so that we cannot obtain from them any criterion by which to distinguish past and future. If, on the other hand, they are asymmetrical and irreversible, the laws of nature lead us on necessarily from what went before to what comes afterwards.

CHAPTER II

A modern duel: Einstein and Eddington v. Bergson and Whitehead

In this battle over the importance of time and process great names stand out as representatives of the two opposed views: Einstein and Bergson, with their lieutenants, Eddington and Whitehead. The two leaders use very different methods. Einstein, as mathematical physicist, suggests that physical laws can best be expressed if we assume that space and time are so similar that physics can make no absolute distinction between them. Thus in relativity theory the symmetry of space involves the symmetry of time, and therefore the reversibility of physical laws, as has been shown by Birkhoff. Bergson, as biologist and philosopher, denies that the view of time which is implicit in relativity mathematics is adequate when a wider range of experience is taken into account.

Einstein starts by excluding all but a very narrow range of physical experience, and finds that he can make successful predictions about light and gravitation by treating the irreversibility of the passage of time as of no importance for scientific measurements. Bergson, by studying a wide range of biological and subjective experience, comes to assert the existence of a creative process, though the inherent limitations of the intellect and of science may leave the essence of this process outside their reach.

Both protagonists have left their flanks exposed, by omitting to present their view as a consistent logical system, Einstein because he is concerned only with the equations that can be empirically tested, and Bergson because his chief interest is non-intellectual. It is here that their lieutenants step forward to develop the two points of view, and hence to intensify the conflict.

Eddington provides a logical basis for the theory of relativity and reveals that the significance of physical laws is not quite what we used to think. They are, he argues, identities which the human mind discovers in its search for something permanent that it can call *matter* beneath all the changing appearances of the world. We have made matter the real thing by demanding permanence or indestructibility as the basis of physical reality. Now that we know that we have done this it need not trouble us too much to find that absolute unchanging matter doesn't exist, since this merely means that we started out with a demand that nature cannot fulfil. Unfortunately Eddington doesn't discuss what alternative demand we might now make in order to build up a more satisfactory system of scientific ideas. But in spite of his enthusiastic support of Einstein's theory, with its implicit assumption of reversibility, Eddington hesitates at least once in his advocacy of reversible laws, for facts are turning up which suggest that this undiscussed presupposition may not prove valid.[a]

Meantime Whitehead has been at work on the other side, and by sharpening his logic till few can understand him has made the idea of temporal process the basis of all intellectual and scientific thought, whereas up to now process has always presented many difficult problems for the intellect. He proposes that since the conception of matter has been found to be unsatisfactory we must start from the basic idea of process in building up a new physical theory. As a consequence of his line of thought, Whitehead found it necessary to reject some of Einstein's arguments and to show that Einstein's law could be reached from quite different postulates. For instance, Whitehead assumed that the motion of light was irreversible, and that light did not travel with the same velocity in the two opposed directions.

So much for one aspect of the conflict, its logical and philosophical basis. But the issue must be decided by appeal to experimental confirmation over the widest range of phenomena. Orthodox physics still assumes reversibility, and has on its side the explicit statement made by Einstein in 1925,[4] but by doing so it excludes at the start any reference to organic processes. Conceptions based on this assumption could never be legitimately applied to life, and all attempts made hitherto to explain the central controlling processes of organisms in terms of classical physics have necessarily failed. We know now that this failure could have been foreseen.

The same objection cannot be made

against the basic ideas of Bergson and Whitehead, nor against the new atomic physics as interpreted by Born, as we shall see in a moment. To Bergson and Whitehead, as to many others amongst whom Lloyd Morgan must be mentioned, the process of nature is creative, i.e. it involves the coming into being of the new, the appearance of new combinations essentially precluded before. This probably means that the laws of physics which are to describe what is actually happening in the world must be given irreversible form. For reversible equations make no distinction between to-day and to-morrow, and cannot express the fact that at later moments new forms may emerge, either in the evolution of organisms or of stars. On the other hand irreversible laws can be arranged so as to display time as an active factor in causation, i.e. to emphasize the fact that a certain period of time necessarily has to pass before some new combination can be attained.[6]

The upholders of a real process in nature can appeal to the facts of organic life, human memory, and to biological and stellar evolution. But their case is still weak because fundamental irreversibility has not yet received explicit mathematical formulation suitable for experimental test. When this has been done the intellectual battle will be brought to its decision, and if irreversibility wins the day biology and psychology will find themselves in possession of a physical basis well suited to the facts with which they have to deal.

There is reason to believe that the decision will be made very soon. We saw that the implicit assumption of reversibility underlies all Newtonian conceptions. It may therefore be that the reason why we cannot interpret atomic behaviour in terms of particle motions is that electrical and radiational processes are essentially irreversible. Particle motion and wave propagation—the two ideas on which all modern theories of matter are based—are both represented by mathematical expressions which are essentially reversible since time enters only through the square of 'dt'. If the quantum processes should prove to be irreversible, we have already found a reason why the old conceptions of particles and waves must be inadequate.

This speculation may indeed be found correct, since Born, one of the leading experts in Quantum Dynamics, asserts that all quantum processes are irreversible and that the apparent reversibility of classical processes is only an approximation due to the fact that their irreversibility happens to be negligible.[4] We may therefore hope that the atomic physicists will soon formulate the quantum laws in a clearly irreversible form which admits of precise experimental test.

But this may take some years, and in the meantime we must look around and see how this issue is affecting current thought. We find the doubt about process presented by Mr Sullivan (in *Gallio*), who has not yet made up his mind to which side science will grant the victory. Thus on one page he writes: " it seems to be true that events do not really take place, we come across them " and suggests that process may be " a totally irrelevant idea when applied to reality ". But later we learn to our surprise that " it seems likely that (in scientific theory) the world will have to be regarded as an evolutionary process, where patterns of value emerge ". However, this inconsistency need not bother us, since we are told that " the teachings of science so far as the spiritual problems of man are concerned are merely irrelevant ".

These views reflect perfectly the uncertainty of the time, and will be looked back on as a precious record of the state of mind which preceded the scientific synthesis. Perhaps the most interesting feature of the essay is the indecision it displays with regard to the spiritual importance of science. This is a relic from the days when there were two worlds, the world of science and the world of religion and art. No one ever knew which of these worlds they were living in, and this is no wonder. For the division was made only because at one time it looked as though the scientific method could only deal with *quantities*, and therefore that science could have nothing to say about values or qualities. This view is no longer tenable. For instance, there is a quality in organic integration which most of us value, and without this and many other such conceptions biology and psychology could not get far.

Before proceeding any further it is necessary to correct a common misunderstanding with regard to the significance of Einstein's theory of relativity. This theory is mathematical, and is based on a series of postulates which rule out any claim to present an ultimate theory of space and time. One of these postulates* asserts that all our physical knowledge can be reduced to the space-time coincidences of pairs of point-events, or in other words the intersection of the world-lines of electrons. No respect for the supreme genius who predicted two experimental results and eliminated the chief discrepancies remaining in Newtonian theory should restrain scientists from pointing out that this postulate assumes something that has never been known to occur, and has no valuable reference to the world of physical experiment. The confirmation of Einstein's final equations cannot give any validity to this postulate. For it is difficult to think of any physical experience considered by theoretical physics which does not involve the perception of light or colour, and one cannot assume that the perception of light is a perception of coincidences.

Light varies in colour and intensity; coincidence in space is too abstract to account for an effect which is subject to variation. Moreover all physical experience requires a certain amount of time, and this fact is neglected if perception is reduced to the recognition of instantaneous coincidences. Even if these two criticisms are left on one side we still have to notice that Einstein's postulate rules out from the range of physics the important fact that many processes are irreversible. For instance, if we accept Einstein's definition of physical experience, then the interesting fact that radioactivity is only observed in the form of disintegration, and not also as the reverse process of a spontaneous building up of heavier elements from lighter, has to be left over by physics to be dealt with by some other science.

It almost always happens that the formulations of genius are exaggerated and form the basis of a pernicious orthodoxy, and it has certainly happened to relativity theory. Against a tide of exaggerated praise Whitehead, Larmor, and Bridgman, as well as some Continental astronomers, have debated the general assumption that the theory of relativity is adequate to its task, but those in whose hands the power of orthodoxy lies have not yet answered their criticisms in print. Neglect has always been the weapon by which orthodoxy has unknowingly hindered the advance of new ideas. But while this neglect is easy to understand, it is really remarkable that the postulates of relativity theory were not subjected to closer examination before it was made the basis of wide philosophical speculation. The experimental confirmation of Einstein's law of gravitation does not guarantee his postulates, since Whitehead has reached a similar law (identical within the accuracy of the observations) from different assumptions.

Einstein's profound creative intuition

and use of a difficult technique compel our deepest respect, but his work should never have been regarded as a *general* theory of time and space. Not only does he neglect the question of irreversibility but it is very doubtful if periodic processes can be made to fit into his scheme, as has been pointed out by Russell and Bridgman during the last year. Probably Einstein himself has never regarded his theory as more than a stage in the attempt to create a still wider physical synthesis, and we must not interpret in a broad sense his statement that one of the demands of his theory "takes away from space and time the last remnant of physical objectivity".[*] This could only be true if physical time shared the absolute symmetry of space, i.e. if physical processes were all reversible. But there are processes from which we can obtain an objective criterion of the direction of time, and hence time does retain an element of physical objectivity as distinct from the absolute symmetry of space. One of the most interesting features in the future of physics will be the explanation of the fact that Einstein reached a correct law from postulates of limited validity, and in this connection Whitehead's alternative derivation may prove to be of importance.

CHAPTER III

Time in Astronomy and Physics

The real discrepancy between the world of physics and that of life lies in the fact that physics has never recognized the irreversibility of time, while this is fundamental to life. We may even feel a doubt if the 't' of physics has the same significance as the time of biology, evolution, history, and human experience. The physical conception of time arose from the practical utility of clocks for describing natural processes, and finally took the form of defining astronomical time in terms of the rotation of the earth. The day was in fact taken as an absolute measure of time, and this remained quite satisfactory so long as the laws of physics were found to take a simple form with reference to the time so defined.

But then a complication arose. The study of the moon's motion suggested to astronomers that the earth's rotation was slowing down, i.e. to account for the apparent motion of the moon they had to assume that the day was increasing in length. The theory of the tides revealed a possible cause for this slowing down in the tidal friction on the bottom of shallow water basins, for instance the rush of the Atlantic tides into the Irish Sea provides an appreciable frictional force retarding the spin of the earth. In addition to this slowing down there appears to be a very slow periodic variation in the length of the day such as would be accounted for by a rhythmic expansion and contraction of the earth's crust.

The astronomers declare that our old measure of time is not only getting slower and slower, it is even varying rhythmically! It is clear that they have thrown over the earth as their definition of equal time intervals and have surreptitiously substituted something else. Yet one cannot discover any formal announcement of this, or find out if they realize that by doing this they have altered the theoretical significance of all physical measurements. In earlier days physics defined time in terms of a selected clock, and then set about finding the laws of nature. But the old ways aren't good enough for the modern astronomer who gives us our time and sets the clocks of our physical laboratories. He has reasons for disapproving of the earth, and has almost reversed the procedure. In order to save the laws of inertia and gravitation in connection with the moon's motion—and to a lesser degree in the cases of the planets and the sun—he has made these laws his standard of equal time intervals in place of the earth's rotation.

It is a curious situation, especially in view of the fact that Einstein's law, which has superseded Newton's, is not very suitable for use as an astronomical clock, as has been pointed out by Larmor. Perhaps the physicist will soon be able to use the atom as the theoretical clock for physics, and we can go on using the corrected rotation of the earth as our practical standard. There is a faint chance, for instance, that if physics can invent some way of measuring the minute time intervals along the track of an electron, then electrons might be used as giving the fundamental measure of time. Thus if the velocity of an electron were first measured by some indirect method the electron itself might then be used as a clock. But in the meantime the astronomers should make a formal announcement to the Royal Society of what they have been up to. It then might be found necessary to appoint a commission to discover exactly what physics is now doing. For by using an astronomical clock of the new type it is assuming classical laws while researching on processes which are already known to undermine the absolute validity of these laws. Theoretical physics cannot hope to clear up its fundamental problems until it has considered exactly what is involved in this suspicious procedure.

Like most professions, physics includes a good deal of bluff, but unlike the others physics is now occupied on a campaign to get rid of all pretence. For instance, physical text-books have been filled for twenty years with phrases of this kind: "an electron with a velocity of so many cms per sec." Yet the professors omitted to tell their students the awful secret that this hypothesis of electron velocities is one that has never yet received direct experimental confirmation. To-day a reaction has set in and the demand is being made that physical theory shall not make use of conceptions that do not correspond to directly observed quantities. Thus the latest theories of the atom have eliminated the idea of electron orbits because it was realized that these were nothing more than a mathematical trick for calculating something quite different: the wave-length of the light an atom can emit. In place of the orbits it is hoped to substitute something which only makes use of the directly-observed features of the atom, but this new picture is not complete.

Yet physics still makes use of ideas that have not been adequately justified. For though the idea of moving electrons has been removed from the latest atomic model, no substitute for it has yet been proposed for the case of electrons outside the atom. It therefore becomes very important for the experimental physicist to discover whether he can measure the distance travelled by an electron in a measured fraction of a second. As yet we have no proof that nature has not confused us by making electrons behave rather like moving particles, though really they are something different. In fact we have not yet made enough direct experiments to know even whether the dimensional system which is used for electrons is correct. Since no electron velocity has ever been directly measured we cannot be sure that the dimensions of the new constant ' h '—called Planck's constant—are really what we suppose, energy multiplied by time. Until a way has been invented of making a direct measurement of some *time* involved in electronic motions, it is impossible for physical theory to know how it should deal with the quantum processes.

When we realize how uncertain are the conceptions on which the whole of electron theory is based, we may wonder what is really known about the atom itself. Yet it is possible that we know more about the atom than we think, and that what are talked about as facts concerning electrons and radiation may really be better viewed as information about individual atoms and the way in which they influence one another. The emission of light is an atomic process, and we only know about light when it has reached some atom and been at least partially absorbed. Some un-understood change of condition occurs in an atom when it radiates and passes this changed condition on to another atom. The absorbed energy may cause chemical change, as on a photographic plate. But if a human mind is to become aware of this change of condition, then sooner or later, directly or indirectly, its influence must be passed on to an atom in the retina. We know very little about this change of atomic condition, and though it is usually called a change of the internal electrical energy of the atom this supposes more than we really know until some electron velocity has been directly measured. The dimensions of electrical energy are taken as those of kinetic energy, i.e. mass times square of velocity, but we do not yet know if this describes atomic changes correctly. Since no one has ever measured a *time* involved in an electronic process, the scale of time in the atom might be quite different from that given by our calculations.

Our ignorance of what this change of atomic condition really signifies is so profound that some writers have begun to treat the atom as though it were an organism, alive when the atom is excited, and dead when in a state of minimum energy. Thus Whitehead proposes that we should call the atom an organism, though this of course may only muddle us since we know even less about life than we do about the atom.

Yet we do know one very interesting thing about this change which happens to atoms but cannot be reduced to a change of structure. When light reaches an atom in the retina, an electrical stimulus passes up a nerve and alters the condition of the protoplasm somewhere in the brain. This change in brain condition is known to us directly as the perception of colour. Therefore in one sense we know more about this change of atomic condition than we ever did about 'electric fields' or 'gravitational potential' or any other of the mathematical conveniences used by physics in correlating observed quantities. The change in a sodium atom when we put salt in a flame is not a change in the consciousness of the sodium atom, because it is not part of a complex nervous system with the same high co-ordination as is found in the human being, and therefore the atom has no consciousness. But when an atom in the brain undergoes the same change we may become conscious of it, and the changes in matter which occur when light is absorbed are undoubtedly associated with the problem of consciousness.

Thus we are led to ask: how are single atoms built up into complex systems which have the characteristics of life, and finally into still more complex systems which have human consciousness?

CHAPTER IV

An Evolutionary Experiment

Questions are often made unnecessarily difficult by their being expressed in an abstract or theoretical form, and instead of asking What is life? it will be more valuable to put forward a practical issue for discussion: Could an infinitely wise physicist order the necessary chemicals to-day, and to-morrow put together a synthetic man? If not, why not? What are we really up against, that seems to put some aspects of life beyond our control?

Let us watch this ambitious physicist as he enters his laboratory. He has started quite easily and has in a moment prepared some simple molecules from their elements. Now he has completed the first colloid that he will require, and is starting on his first organic synthesis. But his infinite wisdom does not give him eternity within a minute, and we notice that he is getting on more slowly. While the actual combination of the first molecules took only about a thousandth of a second, once he had the apparatus ready, the simplest colloid took about a second. The organic colloid has taken him about a minute; it seems that nature won't work faster than that. She has her own rhythm and won't be rushed. If we wait patiently till the end of the day our friend may have his first speck of protoplasm, and all the skill in the world would only have helped him to make more of it, not to have got any further in his game of evolution.

But look at him now! He is making a hasty calculation as though he had just realized some great secret of nature, and knew that he could never create his homunculus. We look over his shoulder and read:

Estimated minimum time required by the synthetic processes of nature to attain various evolutionary stages.

Starting from the elements, to	Minimum Time
Simple inorganic compound	1/1000 sec.
Simple colloid	1 sec.
Protein	1 hour
Primitive protoplasm	1 month
Simplest uni-cellular organism	10 years
Flagellate	1,000 years
Mammal, including *Homo sapiens*	1,000,000 years

This highly speculative estimate is based on suggestive facts. A certain amount of time is necessary for two atoms to approach one another and form a molecule. The time required will be greater if many atoms have to settle down together into some special arrangement. For instance, the metal silver is normally crystalline, but if silver vapour is condensed too quickly the atoms will not have time to arrange themselves, and it is found that they pile up anyhow into an amorphous mass.

Colloidal processes require even longer periods, because great clumsy molecules have to arrange themselves on the surface of the colloidal particles. In elementary forms of protoplasm the molecular patterns are still more complex, and yet more time must be necessary to get the molecules properly adjusted.

It is probable that only our ignorance prevents us from building up protoplasm, but that we shall require rapidly increasing amounts of time for each successive stage of evolution. This will certainly be the case when we have reached organisms which can only be rendered more complex by controlling their environment while they reproduce themselves for many generations. A higher organism cannot be built up directly; the molecular arrangements in its body can only be reached through the synthesis of some simple form of life which must then be allowed to evolve through countless generations. Organic heredity resides in molecular patterns which can only be built up by this very slow process of repeated reproduction. Thus it is *shortage of time* that our ambitious scientist is up against in his haste to create a homunculus. Only the synthetic alchemy of time can build up organisms, each bearing within itself a long heredity.

The estimates given for the minimum time required in each case are about a thousandth of the actual time taken in a laboratory experiment or in the history of evolution as known from geological records. It may have taken a million years or more for the first mobile cells to have developed from inorganic materials and a thousand million years for the mammals. Yet perhaps these processes might have gone on more quickly. The times given are mere suggestions of a minimum time which may be necessary under ideal conditions. We waste a lot of time adjusting the apparatus in a laboratory experiment, and in evolution there may have been stationary periods with little or no new development. But it seems likely that when we know more about it we shall discover that a certain time is required for the formation of organic systems of given complexity. In this sense we may say that then human spermatozoon and ovum carry within them the synthesis of at least a million years.

Only an International Institute of Evolutionary Research under the most stable of Leagues of Nations could hope to create an artificial man, and even then man could hardly take the credit, for Time would have done more than man. But with sufficient consistency of purpose man could do this, provided he learnt how to make use of every moment of the creative power of time, and never made a slip by which the accumulated treasure of the years (i.e. heredity) might be broken. How man would learn to value life, and how profoundly such an experiment might alter his view of human beings, each one a priceless miracle, fruit of a million years!

In twenty years' time scientific knowledge will be adequate for the beginning of this giant task, and we shall be subscribing our guineas for the foundation of the Institute. Time has created man; man may use time to create man once more. With a million years ahead of us before we reach the sensitive mammals, we need hardly fear criticism from the Society for the Prevention of Cruelty to Animals. We are simply going to allow life to evolve itself under ideal conditions with Switzerland as the State for Evolutionary Research.

It may happen that under such perfect conditions life will evolve more swiftly than it did on this rough-and-ready planet. But equally well we—or rather our descendants—may find that the Darwinian struggle for survival is essential for evolution, and then the nations would have to debate on the morals of reproducing the 'cruelty of nature' inside the World's Evolutionary Zoo. Perhaps a wrathful god will seek to punish mankind for attempting to build this ladder to the secret of life, this modern Tower of Babel, and amuse himself by watching the community of scientists stricken by a plague of inconsistency amongst their weights and measures.

The possibilities of such grand schemes have to be taken seriously. We are now highly self-conscious beings with a tremendous technique for research. Men with genuine creative imagination who reverence life must shoulder the responsibilities of the twentieth-century consciousness, and use scientific technique for creative not life-destroying purposes. One can imagine a growing fraction of the interest now given to war, other people's adultery, and greyhound racing, turned towards Switzerland, whence at critical moments wireless bulletins would announce that the first amoeba had just successfully taken nourishment. If we wish it, the future of science can be such as to recompense for its recent occupation with gunpowder. Governments would be powerless to make war if the physicists refused to make the guns and the Royal Society called upon scientists to go on strike until each war crisis had been settled by arbitration.

The problem of life may be seen in a new light if the speculations of the last section are accepted and we assume that a definite period of time is necessary for the building up of any living organism. For if this is so the laws which govern life must involve the age of the organism since some definite moment in its history. We might choose for this moment the instant when the parent spermatozoon entered the ovum in the case of a higher

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organism, or in the evolutionary experiment just described the age might be reckoned from the moment when the first elementary chemicals were combined into molecules. The point is that this whole evolutionary process must be described by laws which take into account the age of the system under consideration.

Let us take a very simple, indeed the simplest possible, example. If two hydrogen atoms having just the correct total energy for the formation of a hydrogen molecule have approached one another and combined, the law describing what has happened must indicate that at a definite moment the combination was complete and the process at an end. This is an example of an irreversible process, since the molecule does not *spontaneously* break up again. Moreover, the mathematical formulation of this process must include the definite age of the system at which the process was complete, this age being measured from some selected initial moment.

This process provides an interesting limitation to a principle put forward by Maxwell as the basis of physical science. He suggested that the laws of physics must be considered to be eternal and unchanging and that therefore they must be expressed in a form which does not contain the time explicitly. This means that for physical laws there can be no difference between to-day and to-morrow. The laws are concerned with small changes which systems undergo in small time intervals, and need not express any fundamental distinction between one moment and another.

Such laws cannot express the fact that anything sudden ever occurs which makes an essential change in the system as when two systems become one, or when one system breaks up into two. The laws of organic growth or the evolution of individual systems must display the fact that at a certain age of the system special things happen, such as the combination of two hydrogen atoms, or the attainment of maturity by an organism. Maxwell's principle puts a limitation on the form of physical laws which precisely eliminates the laws that would be appropriate for organisms. But there is no reason why a broader physics should not try to frame this new type of law that would be applicable to the history and development of individual systems, and it is probable that if this could be done the reversible laws of Newton, Maxwell, and Einstein would appear as approximations which were valid when nothing of special interest was happening, i.e. when only spatial movements were involved without synthesis, disintegration or the emission of light.

Laws of the Newtonian type which Maxwell had in mind assume that one can adequately describe the present state of a system without specifying its past history. But we cannot say anything very precise about the inside of a living organism, and it is found far more efficient to describe what is known of its past history. We do not try to say where atoms are in an organism; instead we mention its species, age, etc. Organisms might be defined as systems whose future behaviour is more easily estimated from their past history than from what can be known about their immediate internal structure. The most convenient formulation of organic laws will therefore be expressed in terms of the age of the organism and take account of how its life has been spent. These laws are necessarily irreversible, since the assimilation of oxygen or food is always going on in a manner which can never be reversed. Life is like a function which must always alter in one direction; when this development ceases life has disappeared.

The contrast of living and dead now

appears less important than the following classification of natural processes:

1. Processes which are reversible and whose laws can be expressed independently of the age of the system, e.g. gravitational and mechanical motions which do not involve light or heat.

2. Processes which are irreversible, the laws being best expressed in terms of the total time which has passed since some initial state, e.g. chemical combination, growth, evolution, radioactivity, and all changes involving light or heat.

Physics has always asserted that processes of the first type were fundamental in nature, and astronomy provided the ideal example in planetary motion. It was this assertion that gave rise to the essential issue behind the conflict of mechanism and vitalism. But if Born is right, and the fundamental atomic processes are irreversible, then the situation is completely altered. There is no longer a question of life being an arbitrary irruption in a world of mechanical law, since the laws of gravitation and mechanics must then be looked on as the limiting case, when the irreversibility is vanishingly small, of a whole series of irreversible processes which constitute the most important examples of the fundamental order in nature. This series would include the atomic processes connected with heat, light, and electricity, chemical combination, colloidal effects, organic growth and evolution, and the highly co-ordinated electrical processes which form the physiological basis of consciousness.

If this view is correct the atomic processes of radiation and chemical combination should be just what the biologist needs to build up organisms. Instead of a chaos of little particles obeying inverse square laws, the modern physicist offers to the biologist a new kind of atom with electrical and magnetic properties which cause it to build up stable compounds.

The biologist may reply: "Yes, but organisms have four chief characteristics, their behaviour is irreversible, and displays growth, memory, and purposiveness. If you tell me that your atoms obey irreversible laws, so much the better, because my organisms certainly do. But your crystals grow very differently from my cells and organisms, and you can't explain away the apparent purposiveness of all life."

To which the physicist may answer: "Suppose that two hydrogen atoms are some distance apart with the total energy necessary to make a molecule. If they begin to move towards one another under some attractive influence which they exert we display no surprise. But they are moving towards a final end, which is an end, even though they are of course unconscious of it; and provided that nothing interferes they will reach one another, form a molecule, and the process will be consummated. The atoms move under an irresistible law of attraction towards a final condition which is unavoidable unless outside influences prevent it. The system of the two atoms develops necessarily towards a consummation, and the process has in this sense a teleological quality, though this need not mean that any god or man had consciously planned the end for these particular hydrogen atoms.

"This quality was not present in Newton's law of gravitation precisely because it failed to say what happens at the end of any process, for instance when a meteorite hits the earth. Newtonian laws avoid the responsibility of dealing with all the exciting events, like the wedding of the atoms or the death of the meteorite. On the other hand it appears probable that all irreversible laws can be interpreted as leading either from or to some critical end condition. Thus all heat processes tend towards an approximate uniformity of temperature, and chemical reactions also move towards a final condition.

"Such systems as these display the rudiments of unconscious purpose. One must imagine these systems made much more complex so that it takes a long time and considerable nourishment before their unconscious purpose is fulfilled, whether this be the instinctive reproduction of their kind or any other biological function."

"Maybe. I like the unconscious purpose which you have revealed in irreversible physics, because I am troubled by colleagues who see conscious mind everywhere.

"But if I grant that your view of the atom, and hence of molecules and colloids, allows me two of the four features I find in life, i.e. irreversibility and unconscious purpose, you have still to deal with growth and organic memory."

"Yes. Growth and memory are things that physics has as yet little to say about. But we have at any rate reduced the problem of life to smaller proportions. It is no longer the question what is life? but, how do colloidal processes build themselves up into continuously-active, developing systems which can react to their surroundings so that some distant condition can ultimately be attained? This is a much less difficult question. Moreover, since the problem of radiation underlies all the chemical processes which are associated with the maintenance of life, we may expect considerable assistance when physics has cleared up this crucial problem."

CHAPTER V

Physics and Mind

If a psychologist who was not a behaviourist had been listening to this conversation he might break in:

"Does the physicist seriously propose that we should try to leave mind out of our picture of the human organism? Even if we can eventually explain the unconscious purposes of the lower organisms as ends towards which they are driven by physical laws, yet man has the supreme distinction of a conscious mind, he can select his aim, and if he likes renounce it again for something else. You must therefore allow in your picture for the emergence of mind at some point during the course of evolution."

"Wait a moment," replies the physicist. "Your whole outlook towards consciousness betrays not only an anthropomorphic standpoint, but one limited to a single stage in man's development. There is no single condition adequately described by the word 'conscious'. There are in fact a great many different states of awareness which may grade into one another, or may form a series of distinct conditions. We do not know much about them yet, but their variety is most striking. There is the dim sentience as we awake from chloroform, the awareness of the dreaming state, the passive experiencing that accompanies any intensely rhythmic activity such as running. Again, quite different states are known in day-dreaming, intellectual concentration and the delicately-balanced semi-consciousness of creative thought.

"Consider especially the states of awareness associated with love, or with the supreme creative activities of the mind. Free-will, or the deliberate choice of a purpose, is completely lost in a whole-natured falling in love, as it is also in the artist's need to follow some dimly-conscious intuition of a task he must attempt. At these important occasions free-will disappears before a sense of inner organic necessity.

"These examples seem to me to make it clear that 'conscious purpose' is not in any sense the ultimate or highest criterion of human behaviour, and that free-will need not be taken necessarily to mean the power to over-ride any laws of nature. In my view 'free-will' is simply the apparent characteristic of organic behaviour when no complete integration of the personality has been achieved and the mind seems to be able to oscillate from one purpose to another. We really have to deal in human beings with a whole series of forms of behaviour of increasing complexity and integration: reflex and instinctive actions, deliberate activity, and finally the intuitive whole-natured creative functioning which leads to ends which could not have been intellectually foreseen. To each of these must correspond a certain type of awareness, and in my view, a brain process of a definite degree of complexity. By analogy with our own experience of different modes of consciousness, we may be able to infer from the structure of the central nervous system of an organism what sort of awareness it can experience.

"Eventually we must expect to be able to give a complete scheme of all organic behaviour in terms of the organic processes and their laws, but none the less it will remain a great deal more convenient in some cases to refer to what happens to human beings by using words that suggest their conscious experience. The behaviourist denies the scientific significance of all but the very barest elements of conscious experience, but of course he has to start from the human perception of light and colour. Science cannot get on without ideas which obtain their whole meaning from the qualities of conscious experience, and hence the extreme behaviourist position merely arises from a prejudice which prevents clear thinking. But as a campaign to put more stress on the direct observation of what really happens to living beings in terms of physical movements, behaviourism can only do good by bringing more unbiassed knowledge about life.

" My own interpretation of the question may be put in this way. The thing that is given in nature is a process in time. According to its complexity and degree of co-ordination an organic process has different degrees of awareness. There is no one condition called human consciousness, because the human organism can function with different degrees of co-ordination, and if we ask if an atom in absorbing light is conscious, the question has no definite meaning. But in a few years those who are studying the physiology of the central nervous system will be able to indicate how many steps of synthesis and integration occur between the simplest cell and the creative thinker, and to each of these stages will be ascribed a mode of awareness. But below a certain degree of organic complexity this 'awareness', will cease to be anything that can be consciously imagined by man, e.g. below the dimmest sentience one might allow an undifferentiated knowledge of mere continuance, based in turn on the rhythmic pulsation of the elementary cells."

"Your scheme is of course still rather vague, but in its main outlines it appears satisfactory", replies the psychologist. "But tell me outright, can mind influence matter? If I understand you rightly, you suggest that matter certainly influences mind."

"On the contrary, I do not! You are back at the meaningless questions on which philosophers have wasted much time. To ask if mind can influence matter does not mean anything until you know what you mean by mind and matter, and to a scientist that means knowing the laws they obey. Now, on the one hand, relativity and modern quantum theory indicate that there is no matter in the old sense of particles made of some unchanging stuff, and physical science recognizes atomic and other *processes* as fundamental in the place of 'matter'. On the other hand, you really mean by 'mind' one particular form of conscious activity: the deliberate selection of a purpose. Therefore to give your question real meaning I have to ask instead 'Does the conscious selection of a purpose alter the physical processes going on in the human organism?'

"But that is an absurd question. It is like asking: Does a dint in the outside of a hat *cause* an alteration in the shape of the inside of the hat? To which the only reply is that the dint on the outside is merely another way of describing the dint on the inside. There is no *causing* of the one by the other any more than if you fold a bit of paper you can say that the crease on one side causes the crease on the other side. They are identical and the double method of description used in the question creates a meaningless problem.

"'Conscious selection of a purpose' is one way of describing a particular process, and after this process has occurred the brain will be different from before. The old theories of the correlation or interaction of mind and matter presupposed that they were separate things in themselves. The important questions become quite different when one realizes that mind and matter do not exist independently, but that they are both somewhat inadequate ways of describing certain *aspects* of one organic process.

The spatial aspect of organic process is called the physical organism. The temporal aspect of organic process corresponds to the content of its consciousness. The physical body is a group of spatial characteristics. Consciousness is a system of temporal elements; memory, anticipation, deliberate repetition, creative longing, hope and fear are all things set in time.

"Professor Alexander has said 'Time is the mind of Space.' He attempts to explain space and time by an anthropomorphic analogy. It is a very suggestive idea, though for the searcher whose goal is the nature of consciousness itself it is more valuable to put it the other way round: mind is the temporal aspect of process, body the spatial aspect. But it is very important indeed to notice that we have not yet found the adequate terms for describing these two aspects of process. Matter is unsatisfactory for the spatial aspect, because there are no unchanging particles. But nor is mind sufficient for the temporal aspect, because there is a temporal aspect to the combination of hydrogen atoms and to chemical and colloidal processes, and yet we must not speak of these as having mind. When the new words for these two aspects are invented they will form the foundation of the scientific synthesis which I am expecting."

To which the psychologist may answer: "Well, at heart I have always been a thorough-going determinist like you, at least in dealing with my patients. Moreover I find it works, because I have always included in my picture of the patient a life-impulse of some sort, which can be influenced by my personality. Thus if the behaviour of my patient is absolutely determined, the conditions which determine what happens to him include some inner life tendency, and also the effects produced on him by all the people he meets.

"But if one attempts to formulate such an absolute determinism, or to apply it to oneself, one gets into deep waters, and I haven't the courage to try it. It seems you must be right at bottom, but that only a god could believe it without its upsetting his mental balance or his sense of moral responsibility."

"There I agree," replies the physicist, "as long as one does not simultaneously revise one's whole view of life in terms of this new organic knowledge. That is a very big task, but I should like one day to attempt it. Two things especially would attract me to such a revision of human values. One is that people who ought to know better still go about making moral judgments about their acquaintances. Now that we know how profound is the influence on a child of the treatment it receives during its first five years of life, moral judgments become rather old-fashioned and only show that the person making them has himself not yet learnt to find emotional fulfilment in healthier ways. An analysis of human behaviour along the lines of organic determinism might do something to show that moral condemnations, whether of bolshevism or of the sins of one's children, are never effective unless immediately accompanied by positive example or creative suggestion.

"But there is another more attractive reason why I should like to attempt this transvaluation of values. If organic determinism is valid, then the artist's aspiration to create is a natural consequence of some organic law. Creative aspiration may then be looked on as the natural destiny of certain human beings, though they no more know where they are going than did the two hydrogen atoms. But organic determinism allows us to understand why it is of no importance that the artist doesn't know what he is going to create before he does it. It seems that in some matters our organic body is wiser than ourselves, or rather wiser than our very immature consciousness. When we have developed our consciousness by the discovery of the organic laws of our own natures we may be able to make human life more beautiful."

CHAPTER VI

The Future of the Sciences

The preceding pages have very broadly indicated the way in which current physical researches may influence the scientific outlook on the problems of matter, life, and mind. The view has been put forward that we are on the eve of a profound scientific synthesis of which the main outlines are already determined. These general suggestions will now be made more precise in order to offer to anyone who is interested the opportunity of testing for himself some definite prophecies regarding the future of scientific thought. The forecast made here does not involve any supernatural reading of the future, but is based on tendencies already inherent in the different departments of science. For convenience it is expressed in the form of separate assertions concerning the future of physics, biology, and psychology.

1. Before 1940 a very remarkable simplification will be made in atomic theory, which will indicate that in quantum processes physics has 'touched bottom' and that—for the time being—we may consider that nature is not infinitely complex within the heart of the atom. The proof of this apparent if not absolute limit to the micro-structure of nature will take the form of the discovery of simple relationships between the fundamental constants of atomic structure, e, m, M, c, and h. (The electronic charge and mass, the mass of the hydrogen nucleus, the velocity of light, and Planck's constant.) Such relations are already known but are considered to be of no significance since they are ruled out by the accepted theory of electrical dimensions.

Yet this dimensional system is not based on direct observation, and the importance of these relationships will soon be recognized in consequence of experiments aimed at a direct determination of an 'electron velocity', in a curved track. 'Electron velocity' as calculated from deflection experiments will be found not to be the same as the directly measurable cms. per sec., and in the case of straight electron tracks, the measured velocity may be found to be always that of light, though this does not mean much since the velocity of light in one direction has never been measured.

As the result of the study of individual radiation tracks, for instance in the reflection of electrons by crystals, and particularly of any *time* measurements that can be made, a new system of physical conceptions will be built up appropriate to irreversible processes, which will be substituted for the Newtonian reversible system. The new scheme will probably be based on the conception of the atom, with its radiating electron tracks, as a natural clock which not only can be used to measure out equal time intervals, but also to yield an objective criterion of past and future. In order to make this idea, or at least one part of it, capable of empirical test the following hypothesis is put forward: The time-interval between any two point-events on any electron track is a simple function of the length and curvature of the part of the track between the two points. This hypothesis contradicts the current interpretation of electron theory on a point which has never yet been subjected to experimental test.

The conceptions which will be built up on electron velocity experiments will very quickly bring within one simple theory the facts of chemical combination and colloidal processes. For these depend upon irreversible effects connected with radiation and electrons, and will therefore be amenable to treatment by the new conceptions for the very reason which necessarily puts them beyond the scope of Newtonian laws.

2. As the result of the alteration in physical conceptions biology will soon cease to draw a definite line between inanimate and living systems. The normal characters of life will be recognized as appearing in steps as one passes up the series atom, molecule, colloid, protoplasm, cell, and through further stages to mammal and man. In each class of organism a central controlling process will be discovered and its laws formulated with some precision, in terms of irreversible electrochemical processes. The process which in each organism represents the co-ordinating factor and is the life of the organism considered as a unit may for instance be described in terms of a quantity which we shall call 'f'. 'f' would be such that so long as 'f' keeps on increasing the organism is alive, while if 'f' stands still the organism dies. The rate of increase

of 'f' indicates the tempo or intensity of the organism's life. In a simple case 'f' might be directly related to the intake of oxygen or food, and just as respiration and assimilation are irreversible, so is the change in 'f'. 'f' must go on increasing, or else cease to represent any quantity in nature; as soon as it ceases to increase the process to which it corresponds cannot be identified any longer.

The most important factors which influence the life-function 'f' (i.e. which affect the central controlling process in any organism) will be known before about 1950, with the result that local rebellions such as cancer will not only be controllable, but easily prevented. Harmless methods for increasing the rate of change of 'f', i.e. for increasing the *élan vital* of the organism, will be discovered, so that, for instance, the duration of child-birth will be reduced to a natural minimum. If child-birth sometimes takes very long nowadays, this is presumably because the woman's body is tired, exhausted, or partially poisoned by her mode of living, and by raising her vitality at the critical moment we may expect to be able to let the process go on at its natural speed. There must be some minimum time necessary for the act, since a vast number of complex organic processes have to complete themselves in a certain order, but probably this time is considerably shorter than that during which many women in this country have to suffer.

It is already known that the Mendelian *genes* which determine heredity are related to the rates of development of special processes in the organism, and a control over the life-tempo, or rate of increase of ' f ', in any organism or group of cells within an organism, will provide a new method of tackling the practical problem of heredity. It is possible that hereditary tendencies to specific weakness or disease will be overcome by accelerating or retarding the rate of development of the human system at some special moment between conception and maturity.

Rejuvenation will soon be safe and efficient, but not as a means for attempting immortality. It will be socially recognized as healthy and legitimate only when undertaken to compensate for premature ageing due to specific repressions, illness, or anxiety.

The elimination of known diseases by a genuine science of life does not mean that other diseases will spring up perhaps worse than before. A theoretical science of life will know the meaning of all disease, and will not prevent one in such a way as to give rise to another. Instead of making campaigns against influenza or any other one disease, it will determine the conditions in which no disease can survive, and thus gradually eliminate all the organic diseases which attack the body.

But this does not mean the attainment of a hygienic Utopia in which human life necessarily fulfils itself. A balance will be made to the disappearance of cancer and syphilis, not by the arising of other diseases but as a result of the consequent increase in the sensitiveness of the human brain.

The supremely difficult task of the next hundred years will be to keep the mind of the race healthy and stable through a period of critical sensitiveness. We are in a transition stage of violent instability, of intense cruelty coupled with compassion (America), of blended love of liberty and need of discipline, of emotional religions and of wars—but we must hope that it will lead to some mode of life with greater inherent stability.

3. Psychology is now occupied with the discovery that the human response to perceptions is not additive, i.e. that the effect made by a group of sounds or colours depends on the pattern in space and time in which they are arranged. (*Gestalt-theorie.*) For instance, the effect made on a man by the individual notes

of 'God save the King' when played in the wrong order is negligible, and bears no relation to his response when he hears the tune played in a cinema, and it reminds him of 'patriotism' and the War. So far no scientific method has been found of describing when a group of elements is to be treated as a 'whole' for the purposes of psychology, and this is where the greatest advances may be expected.

Most scientific conceptions have been based on the method of spatial analysis, i.e. the reduction, where possible, of a thing to its smallest spatial elements. Physics, biology, and psychology have all lacked the equipment to describe what makes the atom, organism, or the pattern function as a unit, and how we are to know if some group is a unit or not. The analytical method is fully developed, but we lack even the basis for a synthetic treatment. This leads some hard-headed scientists of the materialistic school who will 'stand no nonsense' to assert that there is no such thing as 'synthesis', that this is a mystical idea left over from primitive anthropomorphism. Yet to any mind that is guided not by prejudice but by a simple search for truth, the fact of synthesis is obvious, though not yet properly formulated.

Here modern physics can supply a clue. Analysis is the method required in a search for instantaneous spatial structure; the synthetic method which we need must deal with the temporal history and behaviour of systems. The fact that the human being reacts in the ways he does to a tune as a whole is evidence of something in his history, that he has heard the tune often under certain emotional surroundings. The unity of any synthesis, whole, or organism is not an instantaneous fact explicable in terms of structure, for we can recognize this unity only from a continued observation over a period of time.

Physics can invent one law to describe

the approach of the two hydrogen atoms to form a molecule, and in doing so treats the two together as a unit. This suggests that the fact of organic unity is to be defined and formulated in terms of an irreversible law which governs the system as a whole. Thus a group of atoms, cells, or any other elements is to be called a unit when, and only when, one irreversible law can be found which expresses the behaviour of the different elements as contributing towards some common end, like the formation of the molecule in the case of the hydrogen atoms.

We can now draw a practical conclusion for the future of psychology, which is in great need of a moral principle to guide its treatment of disintegrated human personality. On the analogy of the two atoms, a human being is to be considered as a unity when his whole behaviour displays continuous co-ordination towards some end. But there is an important difference in the two cases: the atoms move towards an end which we know because it has already happened in history, whereas man's development is creative, that is it proceeds towards an end we cannot know exactly before it comes into being. Thus the parent or psychologist need not trouble if he cannot understand what his child or subject is aiming towards; so long as some consistency and harmony of functioning is apparent, the 'end' can be left to nature to look after, because such harmony *means* that the organism is tending towards some ultimate condition.

The psychologists of the future will therefore have to follow some principle such as this: their only legitimate aim is the maintenance and restoration of harmonious co-ordination of all the human functions, and no concern need be paid to ultimate intellectual or spiritual ideals. Of course if the person considered is apparently tending towards some degenerate condition, that is known to the onlooker because it is *not* new but a repetition of what many human beings have done before, then this tendency can be altered. At least, it can be altered if the onlooker can use his intuition to discover signs of repressed conflict which show that the immediate tendency is not whole-natured, but based on the repression of some more profound aspiration or desire. Then by bringing this repressed aspiration back into consciousness the degenerate tendency may be arrested. But this control over the lives of others can only be effectively exercized by the intuitive discovery that their present tendencies are not whole-natured.

Prophecy can never be scientific, and forecasting in the realm of science is perhaps the most dangerous form of intellectual acrobatics. Science must be thorough, and all vague speculation is its enemy. But there are moments when a profound revision is necessary, and amidst the responsibilities and rich appeal of daily life no one will undertake this task who does not believe that it offers an adequate reward to science and to man. To-day prophecy can call attention to unjustified limitations inherent in current scientific thought, and encourage the students of matter and of life to get together and try to discover the single system of natural law which we must believe covers both realms. It may even help them to find crucial experiments by which to guide their search.

The reward is certainly great. The indifference to the destruction of life which has marked recent years is no cause either for surprise or for despair after an epoch of orthodox and insincere religion coupled with an abstract science of matter. One thing only can guide humanity to a saner and richer life: the recognition and valuation of life. This can be assisted by science and art both revealing life in all its significant forms. But the roots of art have been destroyed by the domination of a science which had not recognized the significance of life within the realm of natural law. For great art can only arise from a profound reverence for life, whereas to the scientific mood of this period life appeared as an arbitrary impulse in continual conflict with the laws of matter.

Physics is now studying light. The radiant influence of light nourishes life and within human body forms the fabric of consciousness. We are alive and conscious, but our consciousness is immature for we do not yet know the laws that govern our own lives and thoughts. Yet it is certain that light, life, and consciousness are bound together by some undiscovered law. This secret of nature's alchemy is still hidden from us within our own bodies. By revealing it physics will create a new hope for man.

NOTES

1 Whitehead, *Science and the Modern World*. Eddington comes near to the same idea in an essay in *Science, Religion, and Reality*, 1925. See also Weyl, *Was ist Materie?* 1924, p. 84. It has also been expressed by others quite independently, though I do not know of other published references.

2 E.g. the irreversible motion of an electron in the field of a bar magnet is rendered formally reversible by the assumption that the magnetic field is due to moving electrons. Yet this assumption is highly artificial since it postulates electronic movements that have never been observed. In other cases irreversibility is eliminated by the choice of special co-ordinate systems. Some physicists now hold the view that irreversibility may be inherent in atomic as it is in organic processes.

3 *Internal Constitution of the Stars*, 1926, p. 56. Compare note on p. 44.

It may be convenient here to summarize the processes that give at any rate superficial evidence of their irreversibility: processes involving heat changes, or the radiation of light, or mass; the production of energy in a star, the motions of electrons in magnetic fields, certain types of atom-ion collision in mixed gases, processes dependent on retarded potentials, radioactivity, organic growth and evolution, and consciousness itself. Eddington deals only with the case of the emission and absorption of light, but suggests that the direction of time can only be deduced from statistical processes. This is the orthodox view, though it is very doubtful if it is valid now that the quantum processes are receiving formulation. In this connection, see note 4.

4 Einstein. Berlin Akad., *Sitzungsberichte*, 1925, p. 418. But Einstein's view must be revised in view of recent experimental results (e.g. Harnwell, *Phys. Rev.*, vol. 29, 1927. pp. 683 and 831), if these have been correctly interpreted. See Born, *Zeitschr. für Physik*, vol. 40, pp. 177-8; and Jordan, *Naturw.* 1927, p. 792.

5 The idea that time may be an active factor in causation has the mathematical significance that 't' (for the system in question) must appear explicitly in the formulation of the law, and not merely as the square of a time-differential found convenient for the correlation of a standard clock with a reversible process which is being observed. A law whose mathematical formulation involves 't' measured from some moment in the history of the system, gives an entirely new meaning to 't', though one consistent with the properties of the reversible Newtonian differential 'dt'. Such a law may claim to express the fact of historic, irreversible, duration, a feature in nature which is neglected by laws involving only 'dt' squared.

6 Einstein, *Annalen der Physik*, vol. 49, pp. 776-7, 1916.

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