Light and Life*

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THIS revision of the foundations of mechanics, extending to the very question of what may be meant by a physical explanation, has not only been essential, however, for the elucidation of the situation in atomic theory, but has also created a new background for the discussion of the relation of physics to the problems of biology. This must certainly not be taken to mean that in actual atomic phenomena we meet with features which show a closer resemblance to the properties of living organisms than do ordinary physical effects. At first sight, the essentially statistical character of atomic mechanics might even seem difficult to reconcile with an explanation of the marvellously refined organisation, which every living being possesses, and which permits it to implant all the characteristics of its species into a minute germ cell.

We must not forget, however, that the regularities peculiar to atomic processes, which are foreign to causal mechanics and find their place only within the complementary mode of description, are at least as important for the account of the behaviour of living organisms as for the explanation of the specific properties of inorganic matter. Thus, in the carbon assimilation of plants, on which depends largely also the nourishment of animals, we are dealing with a phenomenon for the understanding of which the individuality of photo-chemical processes must undoubtedly be taken into consideration. Likewise, the peculiar stability of atomic structures is clearly exhibited in the characteristic properties of such highly complicated chemical compounds as chlorophyll or hæmoglobin, which play fundamental rôles in plant assimilation and animal respiration.

However, analogies from chemical experience will not, of course, any more than the ancient comparison of life with fire, give a better explanation of living organisms than will the resemblance, often mentioned, between living organisms and such purely mechanical contrivances as clockworks. An understanding of the essential characteristics of living beings must be sought, no doubt, in their peculiar organisation, in which features that may be analysed by the usual mechanics are interwoven with typically atomistic traits in a manner having no counterpart in inorganic matter.

An instructive illustration of the refinement to which this organisation is developed has been obtained through the study of the construction and function of the eye, for which the simplicity of the phenomena of light has again been most helpful. I need not go into details here, but shall just recall how ophthalmology has revealed to us the ideal properties of the human eye as an optical instrument. Indeed, the dimensions of the interference patterns, which on account of the wave nature of light set the limit for the image formation in the eye, practically coincide with the size of such partitions of the retina which have separate nervous connexion with the brain. Moreover, since the absorption of a few light quanta, or perhaps of only a single quantum, on such a retinal partition is sufficient to produce a sight impression, the sensitiveness of the eye may even be said to have reached the limit imposed by the atomic character of the light effects. In both respects, the efficiency of the eye is the same as that of a good telescope or microscope, connected with a suitable amplifier so as to make the individual processes observable. It is true that it is possible by such instruments essentially to increase our powers of observation, but, owing to the very limits imposed by the properties of light, no instrument is imaginable which is more efficient for its purpose than the eye. Now, this ideal refinement of the eye, fully recognised only through the recent development of physics, suggests that other organs also, whether they serve for the reception of information from the surroundings or for the reaction to sense impressions, will exhibit a similar adaptation to their purpose, and that also in these cases the feature of individuality symbolised by the quantum of action, together with some amplifying mechanism, is of decisive importance. That it has not yet been possible to trace the limit in organs other than the eye, depends solely upon the simplicity of light as compared with other physical phenomena.

The recognition of the essential importance of fundamentally atomistic features in the functions of living organisms is by no means sufficient, however, for a comprehensive explanation of biological phenomena. The question at issue, therefore, is whether some fundamental traits are still missing in the analysis of natural phenomena, before we can reach an understanding of life on the basis of physical experience. Quite apart from the practically inexhaustible abundance of biological phenomena, an answer to this question can scarcely be given without an examination of what we may understand by a physical explanation, still more penetrating than that to which the discovery of the quantum of action has already forced us. On one hand, the wonderful features which are constantly revealed in physiological investigations and differ so strikingly from what is known of inorganic matter, have led many biologists to doubt that a real understanding of the nature of life is possible on a purely physical basis. On the other hand, this view, often known as vitalism, scarcely finds its proper expression in the old supposition that a peculiar vital force, quite

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unknown to physics, governs all organic life. I think we all agree with Newton that the real basis of science is the conviction that Nature under the same conditions will always exhibit the same regularities. Therefore, if we were able to push the analysis of the mechanism of living organisms as far as that of atomic phenomena, we should scarcely expect to find any features differing from the properties of inorganic matter.

With this dilemma before us, we must keep in mind, however, that the conditions holding for biological and physical researches are not directly comparable, since the necessity of keeping the object of investigation alive imposes a restriction on the former, which finds no counterpart in the latter. Thus, we should doubtless kill an animal if we tried to carry the investigation of its organs so far that we could describe the rôle played by single atoms in vital functions. In every experiment on living organisms, there must remain an uncertainty as regards the physical conditions to which they are subjected, and the idea suggests itself that the minimal freedom we must allow the organism in this respect is just large enough to permit it, so to say, to hide its ultimate secrets from us. On this view, the existence of life must be considered as an elementary fact that cannot be explained, but must be taken as a starting point in biology, in a similar way as the quantum of action, which appears as an irrational element from the point of view of classical mechanical physics, taken together with the existence of the elementary particles, forms the foundation of atomic physics. The asserted impossibility of a physical or chemical explanation of the function peculiar to life would in this sense be analogous to the insufficiency of the mechanical analysis for the understanding of the stability of atoms.

In tracing this analogy further, however, we must not forget that the problems present essentially different aspects in physics and in biology. While in atomic physics we are primarily interested in the properties of matter in its simplest forms, the complexity of the material systems with which we are concerned in biology is of fundamental significance, since even the most primitive organisms contain a large number of atoms. It is true that the wide field of application of classical mechanics, including our account of the measuring instruments used in atomic physics, depends on the possibility of disregarding largely the complementarity, entailed by the quantum of action, in the description of bodies containing very many atoms. It is typical of biological researches, however, that the external conditions to which any separate atom is subjected can never be controlled in the same manner as in the fundamental experiments of atomic physics. In fact, we cannot even tell which atoms really belong to a living organism, since any vital function is accompanied by an exchange of material, whereby atoms are constantly taken up into and expelled from the organisation which constitutes the living being.

This fundamental difference between physical and biological investigations implies that no well-defined limit can be drawn for the applicability of physical ideas to the phenomena of life, which would correspond to the distinction between the field of causal mechanical description and the proper quantum phenomena in atomic mechanics. However, the limitation which this fact would seem to impose upon the analogy considered will depend essentially upon how we choose to use such words as physics and mechanics. On one hand, the question of the limitation of physics within biology would, of course, lose any meaning, if, in accordance with the original meaning of the word physics, we should understand by it any description of natural phenomena. On the other hand, such a term as atomic mechanics would be misleading, if, as in common language, we should apply the word mechanics only to denote an unambiguous causal description of the phenomena.

I shall not here enter further into these purely logical points, but will only add that the essence of the analogy considered is the typical relation of complementarity existing between the subdivision required by a physical analysis and such characteristic biological phenomena as the self-preservation and the propagation of individuals. It is due to this situation, in fact, that the concept of purpose, which is foreign to mechanical analysis, finds a certain field of application in problems where regard must be taken of the nature of life. In this respect, the rôle which teleological arguments play in biology reminds one of the endeavours, formulated in the correspondence argument, to take the quantum of action into account in a rational manner in atomic physics.

In our discussion of the applicability of mechanical concepts in describing living organisms, we have considered these just as other material objects. I need scarcely emphasise, however, that this attitude, which is characteristic of physiological research, involves no disregard whatsoever of the psychological aspects of life. The recognition of the limitation of mechanical ideas in atomic physics would much rather seem suited to conciliate the apparently contrasting points of view which mark physiology and psychology. Indeed, the necessity of considering the interaction between the measuring instruments and the object under investigation in atomic mechanics corresponds closely to the peculiar difficulties, met with in psychological analyses, which arise from the fact that the mental content is invariably altered when the attention is concentrated on any single feature of it.

It will carry us too far from our subject to enlarge upon this analogy which, when due regard is taken to the special character of biological problems, offers a new starting point for an elucidation of the so-called psycho-physical parallelism. However, in this connexion, I should like to emphasise that the considerations referred to here differ entirely from all attempts at viewing new possibilities for a direct spiritual influence on material phenomena in the limitation set for the causal mode of description in the analysis of atomic phenomena. For example, when it has been suggested that the will might have as its field of activity the regulation of certain atomic processes within the organism, for which on the atomic theory only probability calculations may be set up, we are dealing with a view that is incompatible with the interpretation of the psycho-physical parallelism here indicated. Indeed, from our point of view, the feeling of the freedom of the will must be considered as a trait peculiar to conscious life, the material parallel of which must be sought in organic functions, which permit neither a causal mechanical description nor a physical investigation sufficiently thorough-going for a well-defined application of the statistical laws of atomic mechanics. Without entering into metaphysical speculations, I may perhaps add that any analysis of the very concept of an explanation would, naturally, begin and end with a renunciation as to explaining our own conscious activity.

In conclusion, I wish to emphasise that in none of my remarks have I intended to express any kind of scepticism as to the future development of physical and biological sciences. Such scepticism would, indeed, be far from the mind of a physicist at a time when the very recognition of the limited character of our most fundamental concepts has resulted in such far-reaching developments of our science. Neither has the necessary renunciation as regards an explanation of life itself been a hindrance to the wonderful advances which have been made in recent times in all branches of biology and have, not least, proved so beneficial in the art of medicine. Even if we cannot make a sharp distinction on a physical basis between health and disease, there is, in particular, no room for scepticism as regards the solution of the important problems which occupy this Congress, as long as one does not leave the highroad of progress, that has been followed with so great success ever since the pioneer work of Finsen, and which has as its distinguishing mark the most intimate combination of the study of the medical effects of light treatment with the investigation of its physical aspects.

Food Storage at Low Temperature

SOME of the problems involved in the preservation of food for transport and storage have been discussed by Sir William Hardy in two recent lectures*. The abandonment of the earlier agricultural civilisation by many races for an urban culture required the transportation for long distances of foodstuffs destined for the peoples of the cities. Non-perishable foods such as oil, honey and grain required no special treatment; meat and fish, however, were preserved by drying or curing with salt, and root vegetables for winter use as jams made with honey. It was not until the eighteenth century that the growth of winter vegetables was developed and another hundred years passed before low temperature began to be employed to preserve perishable food in the fresh condition.

The modern period began about fifty years ago, when the first cargo of meat was successfully brought from Australia in the frozen condition. That was made possible by mechanical refrigeration, and, at first, research and invention were occupied in perfecting the machinery, the insulation and the design of cold stores, in wagons or in ships. The properties of the material to be stored were, on the whole, neglected until more recently, when the importance of defining the exact conditions under which the stored foodstuffs survived for the longest time was realised and the science of biological engineering became differentiated from mechanical engineering.

The heavily insulated rooms at the Low Temperature Research Station at Cambridge are cooled by pipe grids through which cold calcium chloride brine is pumped. The first approximation to the required temperature is arrived at by regulating the temperature and rate of flow of the brine. The fine adjustment is made by treating the chamber as an electrically controlled thermostat.

Stored foodstuffs undergo changes in cold storage, the nature of which must be fully understood if the food is to be stored at the optimum temperature and if the store is to function efficiently. Fruit, for example, is alive, consuming oxygen and giving off carbon dioxide and heat. The heat production is greater the higher the temperature and is also increased by disease, for example, fungus rot. A rise of temperature in the store thus sets up vicious circles, with shortening of the storage life of the fruit. In addition to removal of heat from the store, the engineering problems involve the maintenance therein of an atmosphere with a constant content of oxygen, carbon dioxide and water vapour.

A further complication arises from the fact that storage life also varies, under the same conditions, with the earlier history of the fruit. The following variables have been found to affect the storage life of apples: variety, rootstock and age of tree, maturity of fruit on tree, its size and position on the inflorescence, the soil, manuring and climate, and finally orchard sanitation.

The rate of output of carbon dioxide on storage varies with the temperature, but the curves at different temperatures all have the same shape. The output falls continuously while the apple is growing and maturing on the tree. It then rises for a short time after picking and again decreases

* The Hurter memorial lecture before the Liverpool Section of the Society of Chemical Industry on November 18, 1932 (*Chem. and Ind.*, 52, 45; 1933). The Sir William Trueman Wood lecture before the Royal Society of Arts on February 22, 1933.