Light and Life*

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AS a physicist whose studies are limited to the properties of inanimate bodies, it is not without hesitation that I have accepted the kind invitation to address this assembly of scientific men met together to forward our knowledge of the beneficial effects of light in the cure of diseases. Unable as I am to contribute to this beautiful branch of science that is so important for the welfare of mankind, I could at most comment on the purely inorganic light phenomena which have exerted a special attraction for physicists throughout the ages, not least owing to the fact that light is our principal tool of observation. I have thought, however, that on this occasion it might perhaps be of interest, in connexion with such comments, to enter on the problem of what significance the results reached in the limited domain of physics may have for our views on the position of living organisms in the realm of natural science.

Notwithstanding the subtle character of the riddles of life, this problem has presented itself at every stage of science, since any scientific explanation necessarily must consist in reducing the description of more complex phenomena to that of simpler ones. At the moment, however, the unsuspected discovery of an essential limitation of the mechanical description of natural phenomena, revealed by the recent development of the atomic theory, has lent new interest to the old problem. This limitation was, in fact, first recognised through a thorough study of the interaction between light and material bodies, which disclosed features that cannot be brought into conformity with the demands hitherto made to a physical explanation. As I shall endeavour to show, the efforts of physicists to master this situation resemble in some way the attitude which biologists more or less intuitively have taken towards the aspects of life. Still, I wish to stress at once that it is only in this formal respect that light, which is perhaps the least complex of all physical phenomena, exhibits an analogy to life, the diversity of which is far beyond the grasp of scientific analysis.

From a physical point of view, light may be defined as the transmission of energy between material bodies at a distance. As is well known, such an energy transfer finds a simple explanation in the electromagnetic theory, which may be regarded as a direct extension of classical mechanics compromising between action at a distance and contact forces. According to this theory, light is described as coupled electric and magnetic oscillations which differ from the ordinary electromagnetic waves used in radio transmission only by their greater frequency of vibration and smaller wave-length. In fact, the practically rectilinear propagation of light, on which rests our location of bodies by direct vision or by suitable optical instruments, depends entirely on the smallness of the wave-length compared with the dimensions of the bodies concerned, and of the instruments.

The idea of the wave nature of light, however, not only forms the basis for our explanation of the colour phenomena, which in spectroscopy have yielded such important information of the inner constitution of matter, but is also of essential importance for every detailed analysis of optical phenomena. As a typical example, I need only mention the interference patterns which appear when light from one source can travel to a screen along two different paths. In such a case, we find that the effects which would be produced by the separate light beams are strengthened at those points on the screen where the phases of the two wave trains coincide, that is, where the electric and magnetic oscillations in the two beams have the same directions, while the effects are weakened and may even disappear at points where these oscillations have opposite directions, and where the two wave trains are said to be out of phase with one another. These interference patterns have made possible such a thorough test of the wave nature of the propagation of light, that this conception can no longer be considered as a hypothesis in the usual sense of this word, but may rather be regarded as an indispensable element in the description of the phenomena observed.

As is well known, the problem of the nature of light has, nevertheless, been subjected to renewed discussion in recent years, as a result of the discovery of a peculiar atomistic feature in the energy transmission which is quite unintelligible from the point of view of the electromagnetic theory. It has turned out, in fact, that all effects of light may be traced down to individual processes, in each of which a so-called light quantum is exchanged, the energy of which is equal to the product of the frequency of the electromagnetic oscillations and the universal quantum of action, or Planck's constant. The striking contrast between this atomicity of the light phenomena and the continuity of the energy transfer according to the electromagnetic theory places us before a dilemma of a character hitherto unknown in physics. For, in spite of the obvious insufficiency of the wave picture, there can be no question of replacing it by any other picture of light propagation depending on ordinary mechanical ideas.

Especially, it should be emphasised that the introduction of the concept of light quanta in no way means a return to the old idea of material

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particles with well-defined paths as the carriers of the light energy. In fact, it is characteristic of all the phenomena of light, in the description of which the wave picture plays an essential rôle, that any attempt to trace the paths of the individual light quanta would disturb the very phenomenon under investigation; just as an interference pattern would completely disappear, if, in order to make sure that the light energy travelled only along one of the two paths between the source and the screen, we should introduce a non-transparent body into one of the paths. The spatial continuity of light propagation, on one hand, and the atomicity of the light effects, on the other hand, must, therefore, be considered as complementary aspects of one reality, in the sense that each expresses an important feature of the phenomena of light, which, although irreconcilable from a mechanical point of view, can never be in direct contradiction, since a closer analysis of one or the other feature in mechanical terms would demand mutually exclusive experimental arrangements.

At the same time, this very situation forces us to renounce a complete causal description of the phenomena of light and to be content with probability calculations, based on the fact that the electromagnetic description of energy transfer by light remains valid in a statistical sense. Such calculations form a typical application of the so-called correspondence argument, which expresses our endeavour, by means of a suitably limited use of mechanical and electromagnetic concepts, to obtain a statistical description of the atomic phenomena that appears as a rational generalisation of the classical physical theories, in spite of the fact that the quantum of action from their point of view must be considered as an irrationality.

At first sight, this situation might appear very deplorable; but, as has often happened in the history of science, when new discoveries have revealed an essential limitation of ideas the universal applicability of which had never been disputed, we have been rewarded by getting a wider view and a greater power of correlating phenomena which before might even have appeared as contradictory. Thus, the strange limitation of classical mechanics, symbolised by the quantum of action, has given us a clue to an understanding of the peculiar stability of atoms which forms a basic assumption in the mechanical description of any natural phenomenon. The recognition that the indivisibility of atoms cannot be understood in mechanical terms has always characterised the atomic theory, to be sure; and this fact is not essentially altered, although the development of physics has replaced the indivisible atoms by the elementary electric particles, electrons and atomic nuclei, of which the atoms of the elements as well as the molecules of the chemical compounds are now supposed to consist.

However, it is not to the question of the intrinsic stability of these elementary particles that I am here referring, but to the problem of the required stability of the structures composed of them. As a matter of fact, the very possibility of a continuous transfer of energy, which marks both the classical mechanics and the electromagnetic theory, cannot be reconciled with an explanation of the characteristic properties of the elements and the compounds. Indeed, the classical theories do not even allow us to explain the existence of rigid bodies, on which all measurements made for the purpose of ordering phenomena in space and time ultimately rest. However, in connexion with the discovery of the quantum of action, we have learned that every change in the energy of an atom or a molecule must be considered as an individual process, in which the atom goes over from one of its so-called stationary states to another. Moreover, since just one light quantum appears or disappears in a transition process by which light is emitted or absorbed by an atom, we are able by means of spectroscopic observations to measure directly the energy of each of these stationary states. The information thus derived has been most instructively corroborated also by the study of the energy exchanges which take place in atomic collisions and in chemical reactions.

In recent years, a remarkable development of the atomic theory has taken place, which has given us such adequate methods of computing the energy values for the stationary states, and also the probabilities of the transition processes, that our account, on the lines of the correspondence argument, of the properties of atoms as regards completeness and self-consistency scarcely falls short of the explanation of astronomical observations offered by Newtonian mechanics. Although the rational treatment of the problems of atomic mechanics was possible only after the introduction of new symbolic artifices, the lesson taught us by the analysis of the phenomena of light is still of decisive importance for our estimation of this development. Thus, an unambiguous use of the concept of a stationary state is complementary to a mechanical analysis of intra-atomic motions; in a similar way the idea of light quanta is complementary to the electromagnetic theory of radiation. Indeed, any attempt to trace the detailed course of the transition process would involve an uncontrollable exchange of energy between the atom and the measuring instruments, which would completely disturb the very energy transfer we set out to investigate.

A causal description in the classical sense is possible only in such cases where the action involved is large compared with the quantum of action, and where, therefore, a subdivision of the phenomena is possible without disturbing them essentially. If this condition is not fulfilled, we cannot disregard the interaction between the measuring instruments and the object under investigation, and we must especially take into consideration that the various measurements required for a complete mechanical description may only be made with mutually exclusive experimental arrangements.

In order fully to understand this fundamental limitation of the mechanical analysis of atomic phenomena, one must realise clearly, further, that in a physical measurement it is never possible to take the interaction between object and measuring instruments directly into account. For the instruments cannot be included in the investigation while they are serving as means of observation. As the concept of general relativity expresses the essential dependence of physical phenomena on the frame of reference used for their co-ordination in space and time, so does the notion of complementarity serve to symbolise the fundamental limitation, met with in atomic physics, of our ingrained idea of phenomena as existing independently of the means by which they are observed.

(*To be continued.*)

Phases in South African Locusts

THE theory of phase variation in swarming locusts was first put forward about ten years ago, since when a considerable amount of data has been accumulated in its support. Most of the evidence, however, was either based on direct field observations, or on small-scale experiments which served only to prove the fact of the transformation from the solitary to the gregarious phase, and vice versa, but were insufficient for analytical study of the phenomenon and of its underlying causes. This gap has now been filled by a paper by Prof. J. C. Faure recording the results of four years' experimental studies on the phases of four species of locusts occurring in South Africa.*

The bulk of the experiments refer to the well-known brown locust of South Africa (*Locustana pardalina*, Wlk.), and most of them were repeated on the tropical migratory locust (*Locusta migratoria migratorioides*, R. and F.) which swarmed over enormous areas of the African continent last year; some corroboration of the results was obtained also from studies on the desert locust (*Schistocerca gregaria*, Forsk.) and the red locust (*Nomadacris septemfasciata*, Serv.).

The main result of the numerous breeding experiments made under a great variety of conditions is a final proof that the phase transformation is a scientific fact which can no longer be doubted. Indeed, Prof. Faure succeeded in producing the swarming phase from the solitary one, and vice versa, in the case of every species experimented upon.

Turning to the problem of the mechanism and the causes of the transformation, Prof. Faure's experiments confirm beyond doubt the importance of the density of the population in a given space. Locusts raised in crowded cages invariably assume the colour and structural characters of the swarming phase, and those kept in isolation become typical of the solitary phase. The factor responsible for the transformation appears to be the greater activity on the part of locusts in crowded cages, where every movement of an individual disturbs the others and the mutual excitation practically never dies down. This excessive activity results in an abnormally high rate of metabolism, and the striking reddish (or yellow) and black coloration of the hoppers of the swarming phase may be ascribed to the deposition in the chitin of some products of this abnormal metabolism; these unknown products are called 'locustine' by Prof. Faure. Structural differences by which the two phases can be separated may be explained also as a result of greater development of certain muscles in gregarious hoppers as compared with the solitary ones. This theory was tested in a series of experiments in which hoppers kept in isolation were forced to excessive activity, but unfortunately this proved to be a very difficult task, since none of the several very ingenious methods of stimulation applied to hoppers produced the desired degree of activity. Nevertheless, the results show clearly that a change towards the gregarious phase occurs in isolated but active hoppers, and there remains little doubt that solitary hoppers if forced to lead an excessively active life would produce a locust of the swarming phase.

A supplementary factor of the transformation is temperature, since the gregarious phase is obtained more easily and is more typically developed at higher temperatures. This is also in keeping with the above theory, since the general activity of hoppers is greatly affected by temperature conditions.

The results of some experiments suggest that transformation is caused not only by direct environmental influence on the developing individual, but that the conditions of adult life may also have an effect on the characteristics of the progeny. Thus, the progeny of adults of the gregarious phase show certain characters of that phase already in the first instar; Prof. Faure suggests that this is not a case of the inheritance of phase characters, but that the phenomenon may be due to the 'locustine' being handed down to the progeny in the nutritive yolk of the eggs. Indeed, a series of crossing experiments proved that phase characters are not Mendelian characters, and disposed effectively of some earlier suggestions in that direction.

An interesting point is raised by Prof. Faure's experiments on the coloration of solitary hoppers. As a rule, such insects are rather variable in colour but often exhibit a close correlation with the colour of the surroundings. The breeding of hoppers in uniformly painted boxes resulted in many cases in excellent general imitation of the background, even of the white, or black one.

* "The Phases of Locusts in South Africa". *Bull. Entom. Res.*, **23**, pt. 3, 1932, 112 pp., 25 pls., map.