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PHYSICS AND VITAL PROCESSES[1]

NEVER before have I attempted to give a lecture on a subject about which I know as little as I do about the physics of vital processes. Those who did me the honor of inviting me to speak should, however, be better acquainted even than I am with the probable extent of my ignorance, so that I hope you will follow the custom of a certain English college which, when one of its members invited a guest to its dining halls, recorded to the credit of the host any offenses committed by his guest, and fined him accordingly.

I should indeed hesitate to attempt any critical discussion of special fields of biophysics in the presence of an audience many of whose members are far more competent to discuss these matters than I am. Nevertheless, when a physicist turns his attention to the mechanism of things which pertain to life he is apt to be impressed by certain aspects of a general nature which may have seemed of secondary importance to the biologist, but which, nevertheless, in his own eyes play a very fundamental rôle. This is particularly the case in these days when the physicist has become humbled in the matter of materialistic dogma by his endeavors to understand the actions of the most capricious thing in all nature, not excepting the things which live, nor even the female sex thereof, by his endeavor to understand the atom.

We may divide the activities of living things into three classes as regards their relation to physics. First, we have the class which is understandable to us in terms of physics or chemistry, without the invocation of laws other than those which have become familiar to us in the laboratory. Thus, when I expand my chest, I require no further knowledge than the fact that the pressure in a space decreases when the volume increases to explain why my lungs fill with air. When I observe that the boundary of the protoplasmic interior of the cell allows certain things to pass through and stops others—when I find that the cell can build up within itself a hydrostatic pressure greater than that in the medium in which it is placed, I am not surprised, because I can duplicate such phenomena with various membranes in the laboratory. Even though I may be unfamiliar with the complete theory of osmosis in its molecular aspects, I am ready to accept the facts as understandable in

[1] Presented at the American Chemical Society Institute, Northwestern University, Evanston, Illinois, August 11, 1928.

terms of physical laws, just as I am satisfied as to the reason for the transmission of vibrations through this table when I strike it, although, until we have a more satisfactory theory of cohesion and of the nature of intermolecular forces than we have at present, I shall not see in all its details the ultimate reason for the transmission of motion from one part to the other.

One of the first questions which must confront the biophysicist in the examination of any class of phenomena is that of deciding how far these phenomena can be explained as regards their detailed action without the invocation of processes other than those which can be produced in the laboratory with non-living matter. I may cite one or two illustrations of this kind.

I was once consulted by a biologist concerning the conductivity which appeared to be imparted to a solution by the presence of certain spores in suspension. From the point of view of the physicist, the first thought is that the phenomenon may have a very simple explanation; for, if we should place a number of small conducting spheres in a liquid, they would distort the flow of the electric current and would so alter the apparent conductivity to an extent depending upon their size and number. Even if the spheres were insulating, or imperfectly conducting, they would produce an apparent alteration in the conductivity calculable in terms of the relative conductivities and dielectric constants of the materials of the spheres and medium, and in terms of size and number of the spheres per cc. By making measurements of different kinds it is possible to dissect out the values of the various quantities which would thus participate in a physical explanation of the phenomenon and make a test of the consistency of our hypothesis.

But it was found that the effect of the spores on the conductivity changed when they died. At first sight this fact would seem to imply some phenomenon having to do with the life of the cell. A closer examination of the situation showed, however, that the size of the spores changed at death, so that before one is driven to the necessity of postulating anything out of the realm of his physical understanding, it is necessary to see whether this changed size alone is sufficient to account for the change of conductivity, or if there is any change in the conductivity or dielectric constant of the spores' interior which is sufficient to account for the change observed.

The quantitative aspect of physical phenomena is one which should not be lost sight of by the biologist. When one speaks of organisms as being charged and seeks to account thereby for certain lively motions which they exhibit in relation to each other, it is well to remember that, in the simple sense of our understanding of the phenomena, a charged body placed in a solution of the conductivity prevailing in the solutions in which these actions usually take place would lose 90 per cent. of its charge in a small fraction of a millionth of a second. It is true that a body can acquire a charge when placed in a liquid, this charge being associated with the difference of potential which becomes set up between the body and the liquid. But the charged body becomes surrounded by a layer of opposite charge in the liquid in its immediate vicinity, so that the electric field of its charge does not extend out in the simple manner associated with a charged body in empty space. The story of its motion under the influence of electric forces is not a very simple one. It would therefore seem that in all discussion drawing upon the repulsion of charges in liquids, matters should be pushed to their quantitative conclusions, at any rate as far as the knowledge of the physical data will permit.

The second class of phenomena comprises those which have not been duplicated in the laboratory in such a manner as to provide a quantitatively satisfactory explanation of the actions of the organism, but in which an appeal is made to possible specialized conditions of matter in the living cell as the cause of the enhancement of activity of the purely physical mechanism.

Thus, many chemical reactions which take place in the non-living protoplasm occur with increased velocity in the otherwise indistinguishable living protoplasm.

Again, while osmosis is not a phenomenon peculiar to the living state, the osmotic properties of the cell membranes are profoundly modified when the cell is living.

In this class of phenomena it remains to be definitely proved as to whether we need invoke any principles other than complexity of chemical or physical structure to account for the apparently special characteristics of living matter.

Finally, we have the third class, if indeed there be such a class, which comprises those phenomena of life which require a definite appeal to a wider system of laws than those comprised under chemical or physical laws in the ordinary sense of the words.

Speaking of cohesion, Sir Oliver Lodge once remarked that it was as yet an inexplicable fact that when one end of a rod is pushed the other end moves, to which *Punch* retorted that it was an equally inexplicable fact that when one end of a man is trodden upon the other end shouts. Now as to whether the phenomenon cited by the famous comic periodical is more or less wonderful than that cited by Sir Oliver Lodge is a function of what the other end says. Insofar as the action is purely reflex, I suppose it is no more wonderful. Even if the victim should say damn from force of habit it is no more wonderful. But if he says damn for the first time, then I think the phenomenon is more wonderful, because it includes as much as was included in the problem of the rod and also something more: it means that a definite physical phenomenon, the production of the state of air motion associable with the propagation therethrough of the objectional expletive which I have already cited twice was brought about as the result of an intention initiated in the brain.

From the standpoint of the physics of the last century, at any rate, such a phenomenon attains the status of a miracle, whose degree of remarkability can be gauged only by a detailed tracing of the physical mechanism back step by step to the origin of its inception in the brain.

The very essence of a physical law in the sense of a half a century ago lies in its providing a definite statement of the subsequent behavior of a system when the condition of the system is appropriately stated at some instant. Consider, for example, the Newtonian law of gravitation as applied to a number of bodies moving about in space. I know that if I should come upon these bodies in certain positions and start them off afresh with certain velocities, their subsequent history for all time would be determined by the Newtonian law. The answer given by the law to a question asking the state of the system at any subsequent instant would be perfectly definite. It might even be wrong, but it would be definite.

Now in order to give these bodies the velocities which I actually imparted to them I had to do something. If, at the instant when I was about to touch those bodies, I had refrained and left them to themselves, the velocities which they would have had at the next and subsequent instants would have been those determined for them by the law of gravitation as a result of their previous history. To postulate that they of their own accord would suddenly change their velocities in a manner which disregarded what the law of gravitation had to say about the matter would be to postulate a miracle—a temporary suspension of the activities of the general law. The new state of motion resulting from the miracle would not itself be inconsistent with the general law once it had been produced. The inconsistency would be confined to the act of its production.

I temporarily relieve myself of the necessity of postulating a miracle by saying that I took hold of the bodies and threw them into space with the velocities in question; but having committed myself thus far, I must now go on and trace again by some appropriate laws the actions of my hands in approaching these bodies, of catching hold of them, and of imparting to them their velocities. I can go back into the history of the matter for some distance without encountering any grave philosophical difficulty. This motion of my hand and the subsequent grip upon the bodies was determined by forces brought into play on account of my muscles, so that granting the contractions of the muscles there is a train of laws providing in continuous manner for the history of the matter up to and including the impartation of the motion to the bodies, the continuity being thereafter perpetuated through the law of gravitation. But I dare not stop at the contraction of the muscles without relating that to something else, for, if I do, I introduce a miracle, which I wish to avoid, so I look further into the mechanism of the contraction.

I see that it is associated with certain chemical changes in the muscles, so that the path from the chemical changes to the contraction of the muscles is probably understandable in terms of physical and chemical processes. But the chemical changes were not of the kind which took place spontaneously, as, if they were, it would be a fact that all beings possessing muscles would be involuntarily constrained by those muscles to do the same experiment that I have imagined myself to have done. And so I invoke the nerve stimulus to the muscle as a link to continue the train of law action back from the muscle. Then I refer the nerve stimulus back to the brain, and there I must pause; for, at this point, two courses are open to me. I may suppose that the action in the brain was the outcome of what occurred before and that, pursuing this matter back step by step to its logical conclusion, there was somehow or other contained in the state of the universe a thousand years ago the inevitable consequence that to-day I should carry out the experiment which I have cited.

Now such a picture of the habits of the universe is not one which lends itself to our liking. It represents the doctrine of predetermination which the philosophers have wrangled over for many a long year. Yet, the only alternative is the postulation of a sudden suspension of the ordinary physical laws, by which new "initial conditions," as the student of dynamics would call them, are created, leading by subsequent operation of the general law to actions of the individual different from those which would have occurred if there had been no discontinuity in the state of the system. Perhaps it would be better to avoid the use of the term "suspension" of the ordinary physical law and widen our concept of what a physical law is to include the possibility of such discontinuities as part of it. In such a conception of the actions of the universe we would think of the condition of a system as being determined by some general law in the step-by-step fashion, each step being governed by its immediate previous history, but we should think of its being determined in this way only over finite intervals of time, these finite intervals being separated from each other by sharp boundaries of discontinuity in which new alignments of the quantities which specify the system take place, these alignments being provided for in general by conditions quite apart from the general continuous law which guides the system over the intervals between its discontinuities.

I do not wish to imply that these discontinuities are necessarily unrelated to anything, but only that they are not to be expressed in a unique manner or as an inevitable consequence of the previous state of the system. Were they so expressible our laws would simply revert to the old doctrine of predetermination in a more elaborate form.

The essence of the assumptions involved in the introduction of these discontinuities is that, at any given state of the system, there shall be not one but many different kinds of discontinuity which may occur, and that if the state of the system plays any part in the matter at all, it is in determining the relative probabilities of the occurrence of the different kinds of discontinuity.

There may be discontinuities which are spontaneous in the sense that the probability of their occurrence is not related in any obvious manner to the state of the system. One is naturally tempted to associate spontaneous thoughts with such discontinuities. My decision to do the experiment which I cited earlier is a case in point. If I do the experiment because you ask me to, we have a case where the spontaneous discontinuity which represented the thought in your brain produced a physical phenomenon, your speech, for example, which increased beyond its normal amount the probability of that discontinuity in my brain which is to be associated with the initiation of the experiment.

The element of probability as distinct from certainty in the matter of the initiation of these discontinuities is illustrated by what would happen if you should tread on my toe. The discontinuity may be such as to give rise by a train of continuous processes to actions in my muscles which will cause me to knock you down. Or it may be of such a kind as to lead ultimately to the muscles of my lungs and tongue and cause me to swear at you.

Spontaneous thoughts, *i.e.*, those associated with discontinuities which have no simple relation to the state of the system or to physical causes resulting from discontinuities in external systems, are naturally to be associated with free will actions. The philosopher may object that if they are purely spontaneous they deny by their very nature the doctrine of free will. The question here involved is, however, merely one of words. The essential thing about free will actions is their unrelatedness to anything, or at any rate the lack of uniqueness in any relation which they may have to external causes. I may strike you or hurl maledictions at you when you tread on my toe, but there is no certainty of either, that is all. The additional aspect which presents itself, and concerned with whether I could have done anything other than what I did do, has to my mind no meaning. Of the various possibilities, one has happened. The occurrence of that one is not the result of my choice, it is my choice. Of course we must admit that developments may take place in my system which cause the probability of some discontinuity A to be greater than that of B. I may even develop to a state where I fail to respond at all to a certain stimulus in the matter of initiation of discontinuities of certain kinds. I may neither swear nor fight when you tread on me. And this development may even be initiated by outside stimuli—the attempt on your part to convert me to a righteous behavior.

According to the foregoing views then, these discontinuities which symbolize the initiation of the various actions—the blow, the emission of bad language, the intention to perform an experiment, and so forth—constitute the essential distinctions between living and non-living matter; and the vital feature of these discontinuities is that they are not related to the state of the system or to outside influences in such a manner as to make the occurrence of any one of them a certainty under any specified conditions. All that the outside influences or the state of the system can determine for any kind of discontinuity is a certain probability of its occurrence.

I should like to illustrate some of the foregoing remarks by considering a simple example which may serve as a crude parallel in discussing some of the questions pertinent to living matter.

Suppose I have a set of balls moving about in this room, subject only, let us say, to Newton's law of gravitation. The types of motion which I shall observe will depend upon that law and upon the particular state of the system at some instant; or, put more crudely, upon the particular types of motion which were started. It may be that I shall find all the balls arranged in concentric rings about a central ball, each of them whirling around the central ball as planets whirl about the sun. Suppose that in another room I have another set of identically similar balls moving under the same law of gravitation, but started off in a different way. It may be that I shall find those balls separated off into little groups, each of which is like a miniature solar system of its own, and possibly some of the balls may dance around these groups like comets visiting various solar systems. In other words, I may have in rooms A and B identically similar balls, obeying the same general law, but resulting in conditions which are entirely different in the two rooms. Some of the phenomena in A may be entirely unknown in B, for the reason that they could not have evolved by continuous application of the gravitational laws out of the particular state of the system originally initiated in B. It would not be anything about the general physical law which determined the difference between the conditions in A and B, but simply what the mathematician calls "the initial conditions." Indeed, we may have an infinity of different systems of identically similar objects all agreeing with one and the same general law which is sufficient to determine their state at any instant from that at a previous instant, and yet showing properties which have no apparent relation to each other. Suppose now that there should occur in one of our systems A and B a miracle, or, to use a less disturbing phrase, suppose that there becomes initiated one of those discontinuities in state to which I have already referred. Then it is possible that, following this discontinuity, the system will continue to obey the same laws as before, but show characteristics quite different from those which it had formerly exhibited.

In this crude example of the balls moving under gravitation may we not have a possible, even though a remote, parallel to the difference between dead and living matter, and may we not see in a series of discontinuities of this kind a parallel with the initiation of different kinds of activity in living matter. Death would constitute as it were the master discontinuity or group of discontinuities following which the history of the organism would go on according to the ordinary continuous laws of physics without the occurrence of any further discontinuities of the kind under discussion.

The secret of the greater chemical activity of living protoplasm as compared with dead protoplasm would be sought not in any difference in the laws of chemical activity when extended to their detailed specification in terms of atomic processes, but to a difference in the state of the system resulting from considerations of the kind I have sketched. In speaking of chemical action in this connection, I desire to emphasize the extension to an interpretation in terms of ultimate or atomic processes, because if we confine ourselves to chemical laws as stated in crude macroscopic form we may well include in their formulation statements such as would deny to a certain chemical reaction the possibility of its having more than one rate. To cite a parallel situation, a primitive statement of the laws of impact of billiard balls which treated them as perfectly smooth, elastic spheres would deny the possibility of certain phenomena which arise from the more detailed consideration of their actions in relation to the roughness of their surfaces or the rise of temperature which they may suffer at impact.

In the case of the chemical processes associated with living and non-living matter the thought is that, if we could view the chemical processes in each case in terms of the ultimate atomic processes, we could understand them both in the sense that they would obey the same ultimate laws. There would, however, be certain differences in the configuration of the system, conditions in every way consistent with the previous states in each case, but of such a kind that one could never evolve out of the other by an evolution controlled by the continuous law. We must guard against a temptation to believe that on account of the huge complexity of animal organisms they all necessarily go through all states which the general law would permit. I have only to remind you that the ultimate elements of which the matter is composed do not lose their identities in the complexity of the organism. A certain characteristic state may, while operating by continuous processes through the general law, impress itself on the whole organism without getting lost in the complexity of the organism, just as, in the hodge-podge of the city dump, the individual electrons and protons of the atoms retain their relation sufficiently to permit the permanence of the elements which they compose. They do not get lost sufficiently ever to form a new element which was not to be found in the dump originally.

One of the most astonishing things in biology is the handing on of minute characteristics such as a crooked finger or a pointed nose from generation to generation; and the fact is still more astonishing when we realize that at one stage in each generation the potentialities of each of these characteristics are contained in the apparently simple structure of the germ cell. It is only by enhancing the importance of a dependence of characteristics upon the particular system as distinct from the general laws which all the systems follow that we are able to understand the remarkable perpetuation of the characteristics shown by a study of heredity.

If now I proceed to trace the possible consequences of some of the foregoing conclusions in some of their major aspects, I fear I shall incur the censure of certain of the orthodox. We know that certain abnormal developments which take place in the human body are to be traced to abnormal types of cell division whose initiation is not very clearly understood. Indeed, I believe I am correct in stating that the initiation of normal cell division is not very thoroughly understood. At any rate, we have, in the cases of which I am speaking, at least two different types of development, the normal and the abnormal. On a view which associates vital phenomena with the discontinuities of which I have spoken, either one or the other process of development may occur. The fact that the normal development takes place more frequently than the other is simply a consequence of the fact that the probability of occurrence of the type of discontinuity associated with that development is greater than the probability of occurrence of the discontinuity associated with the abnormal type of development. It is, of course, quite within the realm of reason to suppose that the relative probabilities of the two kinds of discontinuities might be affected by the physical or chemical state of the system—put crudely, the probability of disease is a function of the state of health of the body. Moreover, it would not be inconsistent with logical reasoning to admit that the relative probabilities of the two types of development might be controlled by the state of the system as determined by the discontinuities in the brain which we associated with thoughts, so that even the faith healer might find some basis in scientific fact for the results of the exercise of his art.

Cell division may be artificially initiated by injury; and even if I should bring it about by means of a knife, the action is one originating in the thought associated with my intention to perform the injury, and differs only from the apparently more subtle phenomenon associated with the partly unknown processes in the spectacularness of its nature.

I have no desire to force the facts in this connection, but simply to state that if the facts exist they will find their place in an extended idea of the nature of physical laws of the kind I have sketched. Perhaps a theory of faith healing based upon such a concept as I am discussing would be less open to orthodox objection than would be the more fanatical claims of the over-confident. For it is the essence of our present line of reasoning that merely the probability of the action one way or the other would be the thing that was affected. The difference between that kind of a faith cure in which a man keeps fit by not allowing himself to become depressed and that in which some one claims that he has, by meditation, mended one of his bones which had become broken, is that the former class would be one in which the probabilities of the occurrence of the different kinds of discontinuities concerned were greatly influenced by the state engendered by the thought, while in the second class the probabilities concerned would be influenced to an unimportant degree by the corresponding mental activity.

In speaking of probabilities of occurrences, physicists are familiar with the statement that once in an eon it may happen that a piece of ice placed in a furnace will cause the furnace to become hotter while it itself becomes cooler; and the improbability of such an event has its parallel in the improbability of the effect of thought on those properties of the living organism which experience has shown to be affected to a negligible extent, if at all, by mental activity.

In principle, therefore, the possibility of the effect of thought on the probability of all kinds of development may be admitted, so that even the optimism expressed in referring to the "faith which moveth mountains" may be allowed to stand, but I fear with a very small probability factor to warrant us in relying upon it.

It may be argued that in introducing the element of chance, the element of a certain amount of unrelatedness to its previous state in the development of a system, we depart fundamentally from what, formerly at any rate, was regarded as the essence of a physical law, the prediction of the future state with certainty in terms of the past. It is well to realize, however, that even in the matter of phenomena which without question we would class as physical, in thermodynamics, in the theory of heat radiation, and in many branches of atomic theory, we have found it necessary to introduce the laws of probability, the laws of chance, into the discussion; and indeed there is much in the part played by probability in these purely physical phenomena which has a close counterpart in some of the applications I have cited in relation to vital processes.

Thus, in a system in temperature equilibrium, the radiation which passes to and fro between the different elements of matter comes, of course, from the atoms. We think of certain of these atoms as being in certain energy states from which they may pass to lower energy states with the emission of a radiation of frequency characteristic of the change of energy from one state to the other. Now statistical considerations enter in specifying the probability that any one of the atoms may be in any one of the assigned states. Then, considering all of the atoms which are in any one state, there exists a certain probability that the atom may make a change from that state to any one of several others, just as for a living organism in any one state (not necessarily characterized by its energy as in the analogue of the atom) there exists a probability that it may make any one of the transitions which may carry it to another possible state. In the case of the atom, we are accustomed to think of the probability of a transition as composed of two parts, one depending simply upon the atom itself, and the other determined by the density of radiant energy of the appropriate frequency in the space in which it exists, this density of radiation being of course determined in turn by combined probabilities of transitions in all the other atoms. We have in vital processes a parallel to the first type in the part of the probabilities associated with some spontaneous discontinuity experienced by a living organism, and a parallel to the second type in the part of the probability which is controlled by the general state of the system or perhaps by the sum total of all the other discontinuities which are continuously taking place. To one who would complain that the introduction of statistical considerations into vital matters constitutes the invocation of non-physical processes, we must point out that here, in one of the most important fields of pure physics, in the theory of heat radiation, we have just this very type of reasoning, and one calling for as drastic a departure from the popular concept of a physical process as is involved in supposing that the physical condition of an individual may be controlled in part by his own thoughts.

But one may contend that the introduction of statistical considerations into physics is only a makeshift, pending the more complete formulation of the detailed laws in whose terms there would be no necessity for statistical considerations. It is quite true that this has been the prevailing view. Its significance can be illustrated by a consideration of the following.

Suppose that this room were covered with a flat plate of ground-glass exposed to the sky and that I had been born in the room and had never gone out of it. Suppose further that, by some optical system, the motions of the heavenly bodies had been projected on this ground-glass screen. I should know nothing about the heavenly bodies, and should confine my thought to these bright dots on my ground-glass screen. I should see them move about and should proceed to study their orbits on the screen, for I should be unconscious of any third dimension to be associated with them. You who were conscious of this third dimension would know that if I would only use it in my calculations I should greatly simplify my work, even though I should not know what it referred to and should eliminate it at the end of the work by the process of what you would call projecting the planetary motions on the ground-glass screen. But there is something more important than this. Occasionally I should see two points of light come together on my screen and result in an explosion—you would say that a certain comet collided with a planet. On another occasion I should see two spots of light come together and nothing would happen. You would say that on this occasion one body simply passed behind the other; but, to me, "passing behind" would have no significance. I should have to be content with the statement that sometimes when two spots of light came together there was an explosion, and sometimes nothing happened. I should be driven to introduce considerations of chance, considerations of probability, into the matter, and should endeavor to impart some regularity into my observations by this means. You would, of course, know that if only I would introduce that third dimension all would be so simple. You would know that if, instead of attaching two numbers x and y to each spot of light I should attach three numbers x, y, z, I could set up appropriate laws such that an explosion would be symbolized by the equality of x_1, y_1, z_1 for one spot with the corresponding x_2, y_2 and z_2 for the other. And so, in this case at any rate, the necessity of introducing statistical considerations would be the symbol of the postulation of an insufficient number of coordinates to represent our spots of light. In the last analysis, the number of coordinates which it is appropriate to attach to the entities whose relations we wish to discuss is the number of numbers which we have to attach to the individual entities in order that it shall be possible to establish relations between the numbers in such a manner as to enable us to express with certainty, *i.e.*, without leaving elements of chance, all we are interested in expressing about the system.

However, to return to the illustration in which I supposed myself to have been born and to have lived all my life in this room, the third dimension which you would have me introduce to discuss the motion of my spots of light, the third dimension which is so simple a concept to you, would be a thing of mystery to me. It would seem to me to have no reality, and predictions made in terms of it, even if I found them correct, would border in my mind on the predictions of the astrologers.

And so, while one can not say that, granting the ideas of discontinuities and considerations of probabilities in our laws as applied to vital processes, it may not be possible to reformulate the laws in a more abstract way in such manner as to avoid these probability considerations, the fact remains that the reformulation in this way might involve such a remoulding of our whole thought structure as to make the old physical laws with their discontinuities and chances provide a more satisfactory picture to our minds than the more abstract formulation to which I have referred.

As a matter of fact, even the subconscious belief prevalent among physicists to the effect that laws of chance as introduced into their own subject were merely makeshifts for something more fundamental has, in the last two years, received a severe blow. For, in the most modern developments of atomic structure, the old idea of the universality and definiteness of the laws which control the actions of the most fundamental entity in all physics—the electron—have had to give way to laws of chance. No longer do we say that if an electron finds itself in an electric field a certain consequence will definitely follow. We say only that there is a certain probability that such and such will take place. No longer do we rest in the belief that the velocity of an electron will remain constant so long as it is not under the influence of an electric field. It may suddenly change its state of motion. From being at rest, it may suddenly decide to move about like a dog which is tired of inaction.

From the standpoint of one who admits the concept of discontinuous changes of state as an element characteristic of certain vital processes, it becomes of importance to trace the laws which govern the probabilities of occurrence of these discontinuous changes. Those changes which are not related in an obvious manner to any of the others, or to the physical state of the system, form one class, and the remainder form the other class, although it is not impossible that the difference between the two classes may be simply one of degree. Into the former class fall, of course, all those discontinuities which are to be associated with free-will actions.

An interesting problem presents itself in the possible effect of the living state upon the general laws applicable to non-living matter. I have already referred to this question in connection with the effect of life on the rate of chemical action associated with vital processes. In line with what I have already said, the influence of the vital state would not affect the continuous parts of the laws, but would concentrate itself on the introduction of discontinuities. It might well be, therefore, that those laws of the physics of non-living matter which have in the past invoked, and depended for their existence upon, the statistical aspect would be the most liable to an influence of the vital state. The most outstanding of these physical laws is the second law of thermodynamics. It would, therefore, seem particularly appropriate to test in all possible ways the conformity of living organisms to this law. Each of the consequences of the second law provides one avenue for the test, and some of these consequences concern experiments which are possibly not incapable of application to living organisms.

When the physicist sets out to examine a new field, he usually consciously or unconsciously seeks for something which is conserved. The physics of a century ago saw in mass something which was conserved. In the more recent developments, this view has had to give way as an exact statement of fact, and we now look to electric charge as the thing which is conserved in the various activities participated in by matter. The growth of the science of dynamics pointed to another entity which should be thought of as conserved—the total energy of the universe.

It is a matter of some interest to speculate on whether, as we learn more about vital processes, we shall find some measurable quantity concerned with them which may be thought of as conserved. As yet we see no candidate for the position. The number of living cells in the universe is certainly not conserved. The number of atoms forming part of living substance is not conserved. If we are to believe that life originated on our planet from non-living matter, it would seem rather improbable that we should find evidence of a conservation of anything concerned with it. And yet, it is not inconceivable that there may be some processes at work tending towards a situation in which, to use a phrase whose very vagueness is properly symbolic of the vagueness of the concept involved, a situation in which the quantity of life in the universe, or on our earth at any rate, seeks to attain a steady value.

It is by no means as fantastic as might appear to suppose that the elements peculiar to life exist at all times but in relatively insignificant amount in so-called non-living matter, so that in the sense in which we may associate life with the discontinuities of which I have spoken we may, perhaps, on rare occasions find a chunk of copper which is, in a certain sense, for an instant, alive.

One who pictures our globe in its geological antiquity may well find it hard to think of its dead substance of a thousand million years ago as having any elements of life in it. But physics presents us with strange phenomena as regards the rarity of existence of certain things and states which nevertheless play a potent part in the doings of nature.

In each cubic centimeter of this room at the present time there are about a thousand molecules which are in a peculiar state. They have lost or gained an electron. They are what are called ions. I could bring into this room a comparatively simple apparatus and measure the number of these ions in a cubic centimeter in a few minutes. Yet think how few there are of these ions in relation to the number of molecules. For in a cubic centimeter of the air there are about ten million million million molecules. In other words, for every ten thousand million million molecules, only one has lost an electron. If a molecule were to go about saying that it had once seen one of its brothers which had lost an electron, it would be less likely to be believed than would the story of a miracle which had been claimed to be seen by only one person since the dawn of history. Yet these ions play a very important part in certain aspects of atmospheric electricity. Similar remarks may be made about most of the phenomena which are vital to modern physics. An X-ray is generated when an electron traveling with high speed penetrates an atom and suffers a change in its velocity. Yet, from the standpoint of the individual atoms, even of the atoms of the X-ray target, the phenomenon is so rare that if you lived on an atom you could never be made to believe that it had ever occurred. The photoelectric cell, which is responsible for the wireless transmission of pictures, owes its action to the effect of light in ejecting electrons from the atoms of a sensitive potassium surface on which it falls. Yet, if you lived on one of the atoms of the layer of potassium, it is probable that you could never be persuaded that such an emission of an electron had ever occurred, so rare is the phenomenon to the individual atom.

And so the fact that vital phenomena do not make themselves immediately evident in so-called non-living matter is no criterion as to the certainty of their complete absence. It is, in fact, not inconceivable, that the existence of completely non-living matter as such would be unstable, and that the living activity might increase, perhaps slowly at first, but possibly at an increasing rate, until, at any rate in the presence of suitable conditions and environment, it finally attained a steady state in which there was a definite equilibrium between the living and the non-living matter.

In bringing to a conclusion a lecture which, I realize, many of you will consider highly speculative, I will utter one word of warning to the effect that before we make a statement that such and such a type of phenomenon would be inconsistent with physical principles, we should first weigh with care the question of what we are going to exclude under the head of non-physical principles. For, in these days of such radical developments of the abstract point of view in physics itself, it may well be that, if he is not careful, the biologist will seek to be more materialistic than the physicist would ever dream of being, and will bar from his realm of philosophy as unphysical, doctrines far less revolutionary to the thought of fifty years ago than those which the physicist himself has found it necessary to admit in the fields of his own immediate interests.

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FRACTURES AND FIORDS IN THE FAEROES

THE Faeroes constitute an archipelago, spreading sixty-five miles east-west in the north, trailing 110 miles to the south, and including over twenty islands which have been carved out of an upstanding part of the vast Thulean basalt field of the northeastern Atlantic. They have been beautifully mapped by Danish topographers on seventy-two sheets, 1: 20,000, and on two sheets, 1: 100,000. They have lately been described as to structure and form by Peacock,[1] who visited the archipelago in 1925 as a Carnegie research fellow of the University of Glasgow. The basalt flows lie about horizontal in the north, but dip 15° or 20° to the south or southeast in the south; and are estimated to have a total thickness of over thirteen thousand feet, although the highest summit now rises only 2,894 feet above sea-level. The islands have been heavily glaciated except on their highest parts, and are of massive form. They are separated by smooth- and steep-walled fiords, generally trending northwest-southwest, as if consequent upon the dip of the lavas; but certain islands are incompletely divided by two opposing, collinear fiords which are continued inland in great, trough-like valleys to low, open cols. Similar cols are found in the submerged floors of the through-going fiords where they are narrowest and shallowest. The smooth fiord walls are repeatedly cut back in cirques which, according to J. Geikie, frequently open in hanging relation to the fiord level; and the discordance is in some cases over one thousand feet; but the walls are little dissected by normal side valleys, although side streams abound. The outer headlands are steepened into great cliffs by wave work.

The islands are traversed, without faulting displacement, by a system of profound, east-west fissures, which are ascribed by Peacock to torsional stresses caused by an inferred Postglacial subsidence, and on which erosion, chiefly weathering, has recently opened many a V-shaped cleft, called by the Scotch (Caithness) modification, *goe,* of the Danish original, *gjov;* over eighty goes are located on an outline

[1] Peacock, Martin A., "Recent Lines of Fracture in the Faeroes in Relation to the Theories of Fiord Formation in Northern Basaltic Plateaus," Trans. Geol. Soc. Glasgow, 1926–27, xviii 1–26.