121

Indeterminism and Natural Selection

BY

R. A. FISHER

ABSTRACT

The historical origin and the experimental basis of the concept of physical determinism indicate that this basis was removed with the acceptance of the kinetic theory of matter, while its difficulties are increased by the admission that human nature, in its entirety, is a product of natural causation. An indeterministic view of causation has the advantages (a) of unifying the concept of natural law in different spheres of human experience and (b) of a greater generality, which precludes the acceptance of the special case of completely deterministic causation, so long as this is an unproved assumption. It is not inconsistent with the orderliness of the world, or with the fruitful pursuit of natural knowledge. It enriches rather than weakens the concept of of causation. It possesses definite advantages with respect to the one-sidedness of human memory, and to the phenomena of aiming and striving observable in man and other animals. Among biological theories it appears to be most completely in harmony with the theory of natural selection, which in its statistical nature resembles the second law of thermo-dynamics.

In an indeterministic world natural causation has a creative element, and science is interested in locating the original causes of effects of special interest, and not merely in pushing a chain of causation backwards *ad infinitum.* These contrasting tendencies are illustrated by a critique of the mutation theory, and by an attempt more closely to define the sense in which indeterministic causation should be thought of as creative.

THE ancient philosophers seem to have thought that with few or no observational facts, but guided solely by their intuition, and the power of exact deductive reasoning, it was possible to arrive at a valid and scientific view of the nature of the world around them. In some civilisations, science, or philosophy, seems never to have passed beyond this speculative phase, and in our own intellectual tradition there are many centuries in which speculation was pre-

Philosophy of Science, 1: 99-117, (1934).

dominant, and the direct, inquisitive scrutiny of things, neither encouraged nor respected. In the last few centuries a certain uneasy compromise may be observed, between inventing the world *a priori,* and looking to see what it is like. The framework of our thoughts, our preliminary concepts, or basic ideas, have been supposed to be given by philosophy; it was the business of observational science to fit into this framework its missing details, in all confidence that whatever could really be found, had already its place prepared for it in our conceptual framework of ideas about what the world is like.

One of the most remarkable things about the science of our own generation is that, at one point after another, we are coming to recognise that the observations will not necessarily fit into their assigned places. What we had imagined must be, is found not to be so in truth. The limitations of the unguided human imagination are found not to be limitations of the surrounding world. We must let the facts sink into, and inform, ideas more deep-seated in our nature than we could have thought amenable to their influence. Of these examples of the dissolution of the axioms none perhaps carries more far-reaching consequences than the present questionable predicament of the doctrine of determinism. We may consider briefly the character of this predicament in its relation to the history of physical science, before turning to some parts of biological theory, in which the release from this doctrine, as from a dogmatic restraint, seems to open up fresh and fertile possibilities.

What has been called the "principle of indeterminacy" has been much discussed in recent years by writers on pure physics. We need not here discuss it, beyond noting that in spite of its name it does not, however true it may be, settle the problem. In the present state of knowledge it *may* merely define a necessary limitation of human powers of observation; but, again, it may imply that the exact specification of the state of a physical system, in sufficient detail for its subsequent behaviour to be inferred with exactitude, itself corresponds to no physical reality prior to this subsequent behaviour. We must take it as leaving the question open, though it, and the wave mechanics in which it appeared, have sufficed to bring to the forefront the question: Why should determinism have ever been regarded as necessary, or even as a reasonable assumption?

We must go back to the seventeenth century for the formation of the existing concept of physical causation, which has governed scientific thought on the subject over the intervening period. Terrestrial and astronomical mechanics were given at that time a scientific basis and, what is equally important, a mathematical form. In the mathematical form adopted, the future state of a system could be calculated rigorously, supposing its initial state were known with absolute precision. The prediction did not involve a plurality of future possibilities, having determinate probabilities, although this mathematical form, appropriate to indeterministic predictions, had been developed in connection with games of chance, almost as early as had been the laws of mechanics. During the eighteenth century the methods of mathematical physics were found to be applicable not only to the mechanical properties of matter, but to those of heat, light and electricity; so that the simple notion of completely deterministic causation seemed to be applicable in the whole physical realm, and the task of science seemed to be merely to ascertain the form of the equations by which effects might be expressed in terms of their causes. Some uncertainty was felt, it is true, as to the extent of the physical domain. As late as Hertz, in the latter half of the nineteenth century, a cautious physicist might set living matter deliberately aside, in formulating the universal laws of mechanics. On the other hand Descartes, in the seventeenth century, had not hesitated to propose that all animals, with the sole exception of man, were mechanical automata without feeling or will; and at the beginning of the last century Laplace had found it necessary to conclude that the development of the solar system, including the whole course of human history, could have been computed by a sufficiently able calculator from the positions and motions of the particles of a primitive nebula.

The equanimity with which a deterministic theory was accepted as applicable to lifeless matter, and to organisms lower than man, was undoubtedly facilitated by the belief that the human race was separated from the rest of creation by differences, not of degree but of kind, and of a kind which transcended in importance the differences which distinguish all other beings, whether living or not living. Man knew himself to be capable of reasoning, and felt himself to be capable of choice. He could, it appeared, act at will, and thereby to some extent control his surroundings. The fact that the physical sciences had so far stripped the non-human world of these attributes added much to the repugnance that was felt to admitting, as it was inevitable he should soon be forced to admit, that man himself was but an animal, descended from lower animals, and owing his evolution from them to the same great causes, which had brought the rest of the animal creation into existence.

The strength of the deterministic position did not only rest on its power of comprehending the most diverse physical phenomena, but on a much more insistent fact. As, in each branch of research accuracy was increased, as disturbing causes were eliminated or allowed for, as purer materials were used, and as more refined methods of measurements were discovered, so were the physical laws more and more exactly verified. The mathematical formulae were constantly found to be more accurate than the observations upon which they had first been based, or, when their form had to be modified, they were found to be so much the more comprehensive. It is not to be wondered at that experimenters and theorists alike should have regarded it as axiomatic that there *were* laws of causation, similar in form to those already established, which controlled the happenings of the world with perfect rigour. The argument was an extrapolation from experience. The physicist might say:—"By taking precautions against observational error I have reduced my errors to a tenth of those that used to be committed. By further refinements of the same kind, the errors that remain could be still further reduced, and so *ad infinitum*. But, though the argument went further than experience can ever proceed, the simplicity of the axiom, and the insistence of the verification that the argument should certainly be carried further than experience had formerly proceeded, made its acceptance well-nigh universal.

How firmly rooted was this conviction may be judged from the fact that when its experimental basis was removed, the change was scarcely noticed. For the experimental basis fell away, not with the advent of the wave mechanics during the last few years, but a full half century earlier, with the acceptance of the kinetic theory of gases, and of the more general statistical mechanics, as a means of explaining the properties of matter. The experimenter who, up to that time, might have imagined that the precision of his instruments, and the exactitude of his observations could be increased indefinitely, by precautions of the same kind whereby they had reached their existing state of perfection, had now to recognise that this was only true so long as he did not approach, in geometrical magnitude, the size of a single molecule, and so long as the energy of a single molecule was negligible compared to the quantities he was measuring. On the other hand, the accurate predictability of the physical behaviour of systems involving much larger quantities than these, was guaranteed on statistical principles by the large number of independent particles, of the aggregate, or average, of the actions of which this behaviour was the outcome. There was nothing in this to prevent one believing what was, indeed, generally believed, that the behaviour of these individual particles was strictly determinate. But, equally, there was no experimental basis for believing it, and no reason for doing so except the continuity of habit. That determinism would be rediscovered behind the molecular chaos, was, though unrecognised, a new axiom, to which the reliability of physical law in larger masses—the basis of all previous experience of determinism—could, by its nature, give no support. Consequently the interest of the new physics, dealing with single electrons, and quanta of energy, is not that it has discovered an indeterminate system, as to which we must remain, for a time, in doubt; but that it has conspicuously failed to discover the deterministic laws (in the sense of the explicit formulation of future in terms of past experience) which were for long sought with unswerving confidence.

It is a revolution in theory only. Technically, since technique must always stick close to the facts, the difference it makes is trivial. If we take the view that all laws of natural causation are essentially laws of probability, we are only recognising in theory what we have always known to be true in our daily affairs. Theoretically, it is of interest that the reliability or predictability of a system has the same basis now in the "Natural" as in the "Social" sciences. We have the same reason to be confident that a physical system will behave as it should, as we have for predicting approximately the number of marriages which will take place next year in London—the reason that the result depends on the aggregate of a large number of independent actions, the average character of which has been determined by previous observation. And if a trade depression affecting millions simultaneously, should temporarily affect this average behaviour, just as the chilling of a beaker will retard a chemical reaction taking place within it, this only shows that the average is conditioned by the environment, and not that the argument from the approximate determinism of the aggregate to the exact determinism of the individual is any stronger in the one case than in the other.

Besides unifying the concepts of natural law held in diverse spheres of human experience the view that prediction of future from past observation must always involve uncertainty, and, when stated correctly, must always be a statement of probabilities, has the scientific advantage of being a more general theory of natural causation, of which complete determinism is a special case, possibly still correct for special types of prediction. Consequently the man of science who is determined to abide by Descartes' precept never to accept anything for true which he does not clearly know to be such, has no option, in the absence of cogent evidence for determinism, but to set this aside as an unproved assumption, which, in spite of its familiarity, is unnecessary to a rational and coherent approach to scientific studies.

Biologists, perhaps, as this view becomes more familiar, will be more inclined to elaborate independently concepts appropriate to their own field of study, and be less inclined to assume that all improvements in method must be those introduced from the "exact" sciences of physics and chemistry. They may also come to wonder what the controversy between "mechanism" and "vitalism" can have been all about. In sociology, as I had occasion to illustrate last year in the Herbert Spencer lecture,[1] it may be of real importance to recognise that some links in the nexus of social causation are more rigorous, owing to their dependence on numerous independent actions, than others, which are influenced much by fluctuations in public opinion or in public policy, in which far fewer main agencies may be discerned.

The *appearance* of social determinism evinced in the history of the rise and decadence of many great civilisations, which has impressed, though not always convinced, the most philosophic of historians, would seem to be capable, on this view, of a new interpretation. It would appear that the political efforts of so many generations had expended themselves to so little real effect, merely because they have been usually devoted to pretentious futilities. To sweeping back, as it were, a rising tide with a broom instead of building a dyke, or to making the sun rise by crowing at the approach of dawn. Man, it would seem, has not yet laid hands on the levers which control his sociological destiny, but has instead exerted himself to retard or accelerate the belts and wheels by which existing causes are bringing about their necessary effects. The course of social evolution in the history of civilised man, gives the appearance of being controlled by necessary and unintelligent causation, merely because intelligence has not in fact yet been applied to its guidance. Things which are allowed to drift will naturally appear to be at the mercy of the current.

The author is conscious that it is probably, at the present time, premature to forecast the effect of an indeterministic view of the world upon biological opinion on the theory of evolution. We can note the framework of tendencies amidst which this reaction will be worked out, and bring into at least a preliminary perspective the majestic proportions which the concept of evolution itself assumes; and the status, from our new standpoint, of the different causative processes which have been invoked to explain it. The first point to be emphasized, perhaps, is that an indeterministic theory does not in the least imply an anarchy of causelessness. It implies only that certain limitations, once regarded as

[1] The social selection of human fertility. Herbert Spencer Lecture, 8 June 1932. Oxford: The Clarendon Press.

rigid and necessary, will appear now as conditioned or even as casual. The existence of order and harmony in the world, difficult to define as these conceptions are, is as much an observational fact on one theory of causation as on another; natural law is none the less real if, when precisely stated, it turns out to be a statement of probability: causation is none the less recognisable, and an action is just as much an effective cause of subsequent events, if it influences their respective probabilities, as if it predetermines some one of them to the exclusion of the others.

In connection with the effectiveness of causes there is a point of still greater importance which will be easily appreciated only by those who have entered unreservedly into the logical consequences of the deterministic position. To the complete determinist that action which the common man regards as a cause must itself be regarded as wholly predetermined. It could not have been different. And since to the common sense of mankind it is the property of a cause, *qua* cause, that it might have been different and have had different effects, the supposed cause, if completely predetermined, is recognised not to be a true cause at all, but must yield place to some prior event, of which it is itself one of the consequences. But the determinist cannot stop there, nor indeed anywhere within the realm within which determinism is assumed to be complete. If he ascribes to any act the full sense of causation, it can only be to the act of creation by which his deterministic universe was brought into existence. Within the history of this universe there is neither cause nor effect, but only a predetermined pattern of events which for some reason unexplained by deterministic theory is perceived by men as ordered in a time sequence with memory running in one direction only. Those known first are only conceived to be the causes of those which follow, through the illusion that they might have been different, in which case, logically impossible as it is, the deterministic scheme would, it is supposed, have required a modification of the subsequent events. It is obvious that there can be no observational basis for studying the consequences of what can never happen, and to the determinist, who perceives the logical consequences of his theory, causation is as non-existent as free-will. In other words only in an indeterministic system has the notion of causation restored to it that creative element, that sense of bringing something to pass which otherwise would not have been, which is essential to its commonsense meaning.[2]

The fact that our consciousness has in what we call memory a mode of access to past experience which does not extend to experiences to come, is to the determinist not merely an inexplicably arbitrary limitation of man's outlook on the world picture, but one that is in positive contradiction of the view that the state of our consciousness is governed by the instantaneous condition of a physical system following a predetermined course. For the instantaneous state of such a system must be related to its subsequent states by equations identical with those which relate it to its previous states. That this is not the case with the human mind is, like the existence of the power of effective choice, universally verified by subjective experience. Unlike this latter belief, however, it is also directly demonstrable by objective experiment. One has only to make a series of random drawings from a pack of playing-cards, recording each card as it is drawn, and between each pair of drawings to allow the subject to record the best opinions he can form as to (a) the card last drawn, and (b) the card to be drawn next, to demonstrate experimentally that the opinion recorded under (a) correspond more closely to the facts than the opinions recorded under (b). It may be noted that the cogency of this demonstration would not be impaired even if the subject showed some degree of clairvoyant prediction, unless he could foresee the future correctly no less frequently than he could remember the past, as would be the case if the two series of events were connected with the instantaneous state of the consciousness by identical equations.

The creative element in the relation of cause and effect makes an essential difference to the view we take of the spectacle of indi-

[2] It is necessary to emphasize this aspect of causation since so revered a leader as Max Planck has referred to physicists who adopt the statistical method as "setting aside the principle of causation" *('Where is Science Going'* p. 64). Clearly here the principle of determinism is intended. It would be more just to speak of the statistical formulation of physical laws as reinstating the principle of causation.

viduality among organisms, and of the associated phenomena of aiming and striving. It is possible to imagine that man is an automaton, and that the verb "to choose" exists in all languages only because he is an automaton predestined to the illusion that he has a power of choice. The biologist must then decide (or at least his nervous mechanism must go through motions which seem to him like deciding), when he sees apparently purposeful effort in other organisms, whether they also share the same illusion, or whether it is a peculiar product of the evolutionary process in the case of man. It would, indeed, be perfectly possible to argue that, since certain purposes connected with survival and reproduction have to be achieved by any organism which is to maintain its place in the world, a purely deterministic world would, in fact, evolve creatures which behaved as though their actions were purposive. But the *illusion* that they could act or refrain from acting spontaneously, since what really happens is not affected by it, can be of no selective advantage, and the appearance of this illusion in mankind must be postulated as a purely fortuitous accident; feelings analogous to those experienced by man in choice and intention must be denied, unless the accident be required to have occurred repeatedly, to all organisms not closely related to man.

An indeterministic world, then, is one in which the human qualities of aspiration, planning and foresight, are rationally possible and may be advantageous, and in which we can recognise the primitive precursors of these qualities, not as an epiphenomenon, but as having a real part to play in the survival or death of the organisms that evince them. Biologically it might be said that purposive action by the organism as a whole is the crowning stage of an evolutionary process by which relatively large masses of living matter have come to achieve that co-operation of parts and unity of structure which we call individuality. For, on a statistical view of causation, spontaneity or creative causation is at its highest only when perfect unity is achieved.

In the childhood of our race creation had to be regarded as a single catastrophic event. The imaginative faculties were insufficiently developed to conceive it as a continuing process still active in the midst of its incredible duration. It was Darwin who first opened men's eyes to the marvel that causes already known were effective in the creative process of fashioning living things. His mind had set itself to ponder, in a rational spirit, on the adaptive characters of animals and plants, that is on those qualities which distinguish them most conspicuously from the non-living world; the adaptations of the internal structure, and the intricate physiological mechanisms by which the co-operative functioning of the whole body is made possible; the complex interaction of growing parts by which the different structures of the body are formed; the external appearance, and morphological adaptations to exploiter escape from other organisms; and finally the nervous mechanism which gives them instinctive guidance, emotions and incipient reason.

The only other serious attempt which has been made to explain these qualities of living things, either before Darwin's time or since, had been made some 60 years earlier by the speculative zoologist Lamarck. Lamarck had suggested that the desires and efforts of animals had the power of inducing in them heritable changes which should enable, by an imperceptibly gradual process, corresponding desires and efforts in their descendants to be more perfectly satisfied. In the case of plants, where the driving force of will could not be (or at least was not) postulated, Lamarck fell back on the unsatisfactory expedient of ascribing their evolution to heritable changes induced by their environment. Lamarck had no satisfactory explanation to give as to how the appropriate hereditary changes were to be induced by the volition of animals ignorant, as most must be, of their own adaptive requirements and potentialities; and in the case of plants, was perhaps unaware of the existence of numerous and intricate adaptations to the habits and properties of other organisms, which these habits and properties could not possibly have induced. Darwin, from an early age, was familiar with too many facts incompatible with the Lamarckian hypothesis, to gain from it the least assistance in convincing himself of the reality of evolution; and he unquestionably found that the rejection, by biologists of the two previous generations, of Lamarck's uncritical speculations, had prejudiced the case against all evolutionary doctrines. It is not that Darwin was in theory at all averse from the inheritance of acquired characters. On the contrary, as I have pointed out elsewhere[3] in more detail, on the theory of inheritance accepted by him, the environment ought constantly to be modifying the heritable constitution. It was only his unceasing and impartial study of observational facts that led him constantly back to the view that, as evolutionary agencies, such modifications had in fact achieved very little. How could the existence of hairy or woolly animals have induced the seeds of plants to grow hooks, fitted to be entangled in the hair, and facilitating the dispersion of the seeds? How could the instincts and special structures of worker bees have been evolved by a Lamarckian process, through a series of queens who never attempted the actions for which these instincts and structures are adapted?

It was, therefore, not until Darwin had satisfied himself that differences in the rates of death and reproduction would alone suffice to ensure a constant improvement of all adaptations, that he became a convinced evolutionist. This theory postulates nothing more than the existence of heritable variability, and need make no assumptions about the causes by which new variations (mutations) arise. It ensures, moreover, the improvement of adaptations of all kinds, throughout the entire life-history, by which the rates of death and reproduction may be beneficially modified.

Two characteristics of Darwin's evolutionary thought which, in the writer's opinion, give it its supreme and lasting value are, first, that while an active theorist, willing to follow long chains of reasoning if he felt their foundations secure, he constantly brought his speculations into contact with a candid and thoughtful scrutiny of the living things themselves; and, secondly, that he was never willing to curb or limit his thought by theoretical considerations brought in from other fields of study. Thus his theory of evolution made demands upon the age of the earth beyond what the physicists, for many years after his death, regarded as physically possible. We now know that the evolutionists were

[3] The Genetical Theory of Natural Selection. Oxford: The Clarendon Press, 1930.

right and that it was the physical theory that was faulty. Again, in regard to man and his mental and moral characteristics, (his Soul in all but the meaning given to the word by theological theory), Darwin did not shrink from the plain meaning of the facts that fighting cocks could be bred for courage, or dogs for fidelity, and that the amazing plumage and ornaments of many male birds indicated a discriminative choice on the part of the females, which only an anthropocentric prejudice would hesitate to call aesthetic appreciation.

Both on the Lamarckian and on the Darwinian theories creative causation is centred in the organisms themselves. Each living thing has a part to play in the process; though few can achieve so much as that intrepid explorer, the first vertebrate who voluntarily left the water. The contribution of each is made effective, however, on the Lamarckian view by willing and striving only, on the Darwinian view by doing or dying. The selective value of choice and spontaneous action must always lie in its harmony with the world around, its capacity to utilise its advantages, or penetrate its undiscovered possibilities. An active animal above all requires to establish a sensory and emotional contact with all its dangers and opportunities. Conscious and more or less intelligent mental life would seem to have played an increasing part in the adaptation of the higher animals to their surroundings, and the diversity and intricate possibilities of these surroundings seems to have provided a necessary and sufficient condition for such mental development.

Darwin's selection theory is alone among the theories of evolutionary change in locating the driving force of the evolutionary process in this manifold contact between the inner and the outer worlds. It is alone, in fact, in placing no reliance on the manner in which hereditary changes—mutations—come to happen. About the causes of these mutations and about their nature, whether generally beneficial or predominantly deleterious the theory of selection need postulate nothing. It is sufficient that they should maintain some hereditary variability in structure and in behaviour, and that some forms of structure and some types of behaviour should be, in fact, more successful than others.

All alternative views of evolutionary causation have attempted to locate the driving force in the origin of hereditary variations, that is in the process of mutation itself. Thus, though the term "mutation" was not used in its modern sense at the time the Lamarckian theory was developed, that theory postulated that it would be sufficient to produce evolutionary change if the action of the organism in willing or striving could induce in itself the appropriate mutations. Again a considerable body of doctrine under the name of "Orthogenesis" postulates that a long sequence of progressive evolutionary changes may be brought about by purely internal causes producing a constant succession of mutations in a predetermined direction. The least common measure of all this group of theories, in the sense of postulating least, and explaining least, is the so-called mutation theory, held by some geneticists, which, when stripped of its earlier and more ambitious extravagances, seems to assert no more than that the process of mutation is the effective cause controlling the direction of evolutionary change.

Even this bare residuum of the many attempts which have been made to place the effective causes of organic progress in circumstances far removed from the vital activities and interests of the individual organisms, is in contradiction with a substantial body of well-ascertained fact. A knowledge of how hereditary factors are inherited makes it possible to calculate, with rough but sufficient accuracy, how rapidly fresh variation must be supplied by mutation, in order that the variability may be maintained. Under a particulate scheme of inheritance, such as is now known to prevail, this rate is many thousands of times smaller than under the blending theory of inheritance, which was assumed, prior to the rediscovery of Mendel's work. Until that rediscovery it was quantitatively reasonable to put forward hypotheses involving mutations occurring with sufficient abundance to cause, of themselves, an appreciable rate of evolutionary modification. On the Mendelian theory it has become several thousand times less reasonable to do so.

Moreover genetical workers, especially with the fruit fly *Drosophila* and with maize, have found it possible to examine sufficient material to detect the occurrence of the more frequent and striking mutations, and to estimate the mutation rates with which they occur. This work indicates that, though some mutations, especially, perhaps, some of the lethals, may occur with mutation rates of more than 1 in 1,000,000 in each generation, yet that this is a relatively high rate of occurrence, and that mutation rates exceeding 1 in 100,000 are quite exceptional. It is easy to show that mutation rates of this order would be entirely inoperative, in causing evolutionary change, if they were opposed even by very minute counter-selection.

These are quantitative considerations: they can carry their full conviction only when the grounds of calculation have been examined and the relevance of the quantitative evidence assessed. This I have attempted to do elsewhere.[4] For the present purpose it is sufficient to notice that all theories which ascribe the effective guidance of the evolutionary process to the agencies which cause mutation are exposed to this quantitative difficulty, which has not yet, in any case, been resolved. We must ask the proponents of all forms of mutation theory, though we must at present ask in vain, whether they are willing to postulate mutation rates many thousands of times greater than such as are known to exist, and if so, whether they have an alternative theory of inheritance reconcilable with these hypothetical mutation rates. The difficulties of the mutation theory, however, are not only quantitative. The kinds of mutations which are observed to occur are equally difficult to reconcile with the view that these indicate the direction in which evolutionary change is proceeding, for of the many hundreds of mutations which have now been studied none can be claimed as definitely advantageous to the organism in its wild environment, and the great majority are definitely pathological deformities. Indeed the largest class of all comprises the so-called 'lethal' mutations, which render the organism incapable of living to maturity. If these mutations pointed the direction of evolutionary change there would be no escape from the conclusion that all the species so far sufficiently studied by geneticists were in a state of rapid degeneration. It may, indeed, be argued that

The Genetical Theory of Natural Selection. Oxford: The Clarendon Press, 1930.

the mutations studied by geneticists are not a random sample, and still less an exhaustive catalogue, of the mutations which are capable of occurring, and which are occurring occasionally among the thousands of millions of individuals which constitute most species. The geneticist can only study conveniently mutations which have a relatively great and distinct effect on the external appearance. Again the mutations which are observed to occur must be, preferentially, those which are occurring with the highest frequency. For these reasons, the mutations upon which genetic experience is based may be expected to produce larger effects, and to have higher mutation rates, than many others which more frequently escape observation, or fail to occur in the stocks under examination. There may therefore, in addition to what has been studied, be a multitude of mutations having effects smaller than can readily be observed, and these if deleterious, will naturally on the whole be less deleterious than those whose larger effects are more easily studied. Some of these inconspicuous mutations, indeed, may not be wholly disadvantageous at all, but may be capable, in particular environmental circumstances, or possibly in particular genetic combinations, of conferring a benefit upon the mutant organism. To recognise this, however, is by no means to admit the possibility that the causes of mutations are the effective causes of evolutionary change; for if, in some cases, slight or rare mutational changes lead to a beneficial modification of the species in which they occur, such as other more drastic and more frequent mutations are incapable of doing, the determining cause must lie not in the production of mutations, but in the selective process, (the net result of the vital activities of the living population), which determines that the beneficial mutations shall be effective, and the deleterious mutations, more powerful and more numerous as they are, shall be inoperative as causes of evolutionary change.

There are, therefore, in the facts which have been so far observed, both as to the frequency and as to the nature of the mutations whose occurrence has been studied, obstacles to the acceptance of the mutation theory of evolution which there seems at present no prospect of being overcome. In studying or speculating upon the causes of mutations we are paying attention to a process which apparently can exert no appreciable control over the evolutionary progress of organic nature; and this although the occurrence of mutations itself, like the physical conditions necessary to sustain life, is a necessary condition of future evolutionary change, and may be regarded as supplying the ingredients or raw materials which may be utilised in the fashioning of evolutionary modifications.

It is particularly worth noticing, in this connection, that it is only in a completely deterministic scheme of causation that the earlier links in the chain of events are causally equivalent to those that follow them. So that a Laplace could, by pressing logic to an extreme, regard the motions of particles of a primitive nebula as, in a real sense, the determining causes of consequences taking place to-day. On an indeterministic theory intermediate events cannot be neglected or eliminated. In consequence scientific research is interested not merely in the manner in which precedent events determine or influence their consequences, but in locating in time and place the creative causation to which effects of especial importance are to be ascribed. In the present condition of evolutionary theory there can be little doubt that it is in the interaction of organism and environment—in the myriad biographies of living things—that the effective causes of evolutionary change must be located.

In speaking of the location in time and space of the creative causation which is responsible for effects of special interest, it should be remembered that all that we mean by the designation creative is that certain happenings entail consequences, or entail systems of probability for various consequences, other than those that could have been foreseen from antecedent happenings. It is not the writer's intention that this term should imply any foresight or will directed towards these consequences; as would be the case if the creative element were due to the intervention of a personal Creator. The discussion of such intervention appears to be outside the province of natural science. The writer is discussing only the creative element inherent in any system of natural law which is specified in terms, not of certainty, but of probability.

Dealing with the matter after the fashion of mathematical statistics, we may distinguish in any event a creative, or casual, component defined as the deviation of the event in question, in its quantitative aspects, from the average to be expected, according to the laws of nature, from previous occurrences. Natural law is supposed to determine the probabilities of future events with exactitude, and therefore the average value, though not the direction, of the casual component. It is appropriate to speak of this component as casual in relation to preceding causes, and as creative only in relation to the consequences which it entails, The entire system of ideas might indeed be regarded as a simple extension to causation in general of concepts long familiar in the Darwinian theory of evolution by natural selection.

An examination of this parallelism, in relation to the foregoing critique of evolutionary theories, suggests yet another limitation, which may be borne in mind when we speak of the components of happenings which are not predetermined as 'creative'. Somewhat analogous to these in evolutionary theory are the mutations of genetics. (This of course is not to suggest that these mutations are undetermined, but only that the concepts are analogous.) The reader will remember that we have insisted with some emphasis that the process of mutation should not properly be regarded as a cause governing the direction of evolutionary change, but only as a condition which renders evolution possible. In the same way it is probable that in relation to any effect of special interest we should never think of the casual component of any one particular event as by itself creative, but should recognise the creative quality as belonging only to aggregates of such casual components.

This opinion, if well founded, is not probably to be taken as reflecting any objective property of the external world, but merely a common limitation of the kind of effects, as to the causes of which the human mind is prone to enquire. Such effects must, it seems, always present some element of simplicity which our minds can grasp. Thus we may ask intelligibly why a pebble is round, or what has made it round, whereas to specify in detail the geometrical configuration of pieces of matter of the more complicated shapes that occur, and to ask the same question of them, would be a far less natural enquiry. The explanation that it has been rounded by the abrasive action of surf on a beach is a satisfactory one because we recognise that such action will be less destructive and more uniform on a round pebble than on one with edges or corners and not at all on account of our ascribing any special rounding tendency to the chipping or scratching caused by each particular impact. The whole process is thus a cause of roundness, though we should feel it unnatural to speak of any particular event of the process as such a cause. The simplicity of one aspect of an aggregate of results has stimulated enquiry in the manner in which I believe research is usually stimulated, and the enquiry has led us to recognise a multitude of causal happenings, the statistical aggregate of the effects of which affords us the explanation we require. It is in such cases proper to speak of the aggregate of causes, rather than of any particular element of it, as creative.

Rothamsted Experimental Station
Harpenden, Herts.