Life*

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TO many an unsophisticated human being, the universe of stars seems only a fancy backdrop, provided for embellishing his own and his fellow-creatures' performances. On the other hand, from the converse position, that of the universe of stars, not only all human beings but the totality of life is merely a fancy kind of rust, afflicting the surfaces of certain lukewarm minor planets. However, even when we admit our own littleness and the egotistical complexion of our interest in this rust, we remain confronted with the question: What is it that causes the rust to be so very fancy?

In the childhood of our species, the answer to this question seemed obvious: Life is a spirit. This spirit, inhabiting the matter we call *living,* works its will upon it, enduing it with wondrous forms and with purposeful activities. Sometimes the idea of spirit was clothed in more pretentious terms, such as perfecting principle, entelechy, vital force, or mneme, yet all these still implied some sort of conscious or semiconscious entity, striving to dominate matter. The verbal subtlety of the terms veiled a naive animism.

Life as Result of the Mode of Organization of Matter

The animistic view has been increasingly called into question. For instance, with the invention of machinery it was found that entirely lifeless matter can be fashioned into complex forms, capable of engaging in remarkable activities, some of them reminiscent of those of living things. Further, it was found that even in a state of nature some lifeless matter attains considerable complexity, and that in some cases it can give extraordinary reactions, which, although based on the regular principles of operation of lifeless material, simulate one or another supposedly "vital" phenomenon.

These doubts concerning the animistic interpretation were strengthened by the studies on living matter itself. All of its activities were found to conform strictly to the law of conservation of energy. That is, no energy was involved in any of its operations except what had been supplied to it from measurable physicochemical sources, nor was any of this energy done away with by it. Its atoms were found to be the same as atoms elsewhere. They were bound by the same rules into molecules. These molecules could in many cases be constructed artificially, and even the reactions that they underwent within living things could often be repeated in a test tube. Moreover, for some important operations, such as chromosome movements, for which physicochemical formulas were still lacking, regular rules of procedure were nevertheless discovered which elucidated age-old mysteries in terms of orderly material processes.

At the same time, however, such studies have revealed in living things greater and greater complications, which in this respect remove them ever further both from natural nonliving things and from artificial devices. For, as we examine the interior of a living thing and then magnify it more and more, we find at each successive level of magnification a new and different set of complications: first, on naked-eye inspection, that of organs then that of tissues, then of cells, then of cell parts and of parts within these, until immense molecules are reached, some containing hundreds of thousands of atoms, precisely and intricately arranged into groupings composed of subgroupings of several grades. Such molecules are present in even the simplest microbes known.

Yet this prodigious complication, even in its many still unexplained features, encourages not vitalism but the common-sense interpretation that it is this organization itself on which life's remarkable properties depend. If, on the contrary, an imponderable spirit were the source of life's capabilities, these complications would be superfluous. Daily this inference becomes reenforced as more and more of the operations of living things are traced to the orderly workings of given parts of the complex. Moveover, each living thing as a whole is ever more clearly seen to be one great integrated system, the operations of which are all coordinated in such a way that, collectively, they tend to result in one ultimate outcome: the maximal extension of the given type.

Genesis of the Organization

Granting all this, the question is thereby rendered especially acute: How did these marvelous organizations, constituted in such a way as to achieve so peculiar an effect, come into being? The process of their origination, surely, appears at first thought to require some sort of conscious designing. To begin with, it was believed that all species had been designed and created separately in their present forms; but in the 19th century the evidence for their gradual interconnected development out of one or a few primitive forms that were the common ancestors of all became convincing. It was then speculated by certain schools that the ancestral organisms had been endowed with built-in, long-range designs that forced them to evolve as they did. Another view, which has been revived by the so-called "Michurinists" of Iron Curtain countries, where it has (until recently at any rate) been obligatory, postulated a generalized adaptive ability in living things. By its means they altered themselves in advantageous ways when they were subjected to changed conditions and, along with this, they somehow implanted into their reproductive cells specifications for these same alterations. Such an ability to select and to install just the kind of alteration that is going to work out advantageously, *before it has been tried out,* clearly implies some sort of foresight, despite the disclaiming of this implication by some of the advocates of this view. In this case, then, the designing is merely done in bits, instead of in the grand manner.

Darwin's and Wallace's greatest contribution was to show that, even without planning, complex adaptations necessarily evolve. Since members of any population show manifold variations which their offspring tend to inherit, some of these variations—those that happen to be conducive to survival and multiplication —will find themselves more abundantly represented in the next generation. Thus the population will gradually accumulate more characteristics of an "adaptive" kind, that is, of a kind advantageous for the species' preservation and increase, even though there has been no tendency for helpful rather than harmful variations to arise in the first place.

In confirmation of this principle, modern studies in genetics, the science of heredity and variation, have shown that the great majority of newly arisen variations of an inheritable sort are indeed detrimental, as must be true of unplanned alterations that occur in a complex organization of any kind. Moreover, when outer conditions are changed, the few variations that happen to be useful in coping with these outer changes are found not to arise in greater relative abundance than they did before. Yet of course they do succeed better: that is, they are *naturally selected* afterward, in the actual tests of living.

From Gene to Protoplasm

The major actor in this great drama of evolution by natural selection has proved to be the *gene,* a particle too tiny to be seen under the microscope but immense by inorganic standards. There are thousands of different genes in a cell of a plant or animal, each gene with its distinctive pattern and, in consequence, its special type of chemical influence. For the most part, at any rate, the genes are strung together to make up the threadlike bodies called *chromosomes,* which are visible under the microscope in the inner compartment or nucleus of the cell. Although the genes form only a small part of the cell's bulk, they control through their diverse products, primary, secondary, and more remote, the composition and the arrangement of most or all of the other materials in the cell and, therefore, in the entire body. Their control is a conditional one, however, since the nature of the setting in which the genes' products find themselves has much to do with which of their potentialities are allowed to come to fruition.

Recent evidence indicates that the gene consists of the substance known as *nucleic acid,* in the form of a much coiled chain, or double chain, composed of a great number (thousands) of links. The links, called *nucleotides,* are of only four kinds. Yet there are so many links in each chain that, through their different arrangements in line, they would make possible a practically unlimited number of kinds of genes. How such differing arrangements would result in the very different functional effects that different genes are known to exert is a question now being widely asked, but the attack on it is only beginning.

The most remarkable thing about the gene is that each huge chain-molecule has the faculty of capturing, by some specialized sort of affinity peculiar to its links, chemical groups in its vicinity which in some way correspond to these links. The captured groups thereby become matched up alongside the gene's links in an arrangement similar to that in the gene itself, and they are enabled to become bound together, just as the gene's own links are. As a result, they finally constitute another gene essentially like the original one. Thus the gene reproduces itself.

The details of gene reproduction have long eluded investigation. The most direct interpretation was to suppose that each subunit of the gene tended to attract and fasten next to itself a free subunit of the same type that happened to come into its neighborhood (*1*). Although the seeming attraction between like groups of genes (chromosomes) has lent support to this view (*2*), it has met with difficulties on physical grounds. Recently, however, my suggestion that the attraction may derive from electric oscillations has been developed by Jehle (*3*). Calculations of his group along these lines are now giving promising results (*4*).

On the other hand, a number of investigators have proposed that gene reproduction, instead of involving the direct capturing or molding of like by like subunits, is a two-step process in which each subunit of the gene captures or molds one of an opposite or "complementary" kind, and that when the complementary structure in turn captures or molds its own complement a formation like the original one becomes reconstructed. An analogy would be the use of a positive print to make a negative one, from which in turn another positive is derived (*5*). On the most recent and best supported variant of this idea, Watson and Crick, in a series of brilliant papers (*6*), have proposed that each nucleotide has as its complement a nucleotide of a given one of the three other types. By capturing their complements from materials in the medium about the gene, the chained nucleotides in a gene are thought to construct alongside themselves a complementary chain of nucleotides. This at its own next act of reproduction, by constructing a chain complementary to itself, gives rise to a formation identical in type with the original gene. Moreover, since on the view of these investigators the original chain is really a double one, with one member of the doublet the complement of the other to begin with, the construction by each of these two parallel chains of another chain complementary to itself would even at the first step result in a new pair of chains which, considered as a whole, would be identical with the original pair. Further complications have been proposed, involving interchanges of subunits between the original chains and those in process of formation (*7*), but as yet these serve to point up difficulties of the hypothesis rather than to answer them.

With the present activity in this field, it may well be that a relatively few years will suffice to establish definitely the solution of the problem of gene reproduction and, thus, to elucidate the most essential phenomenon in the operation of living matter. At this point, however, the important thing to note is the fact that, whatever the means by which it does so, each gene succeeds in constructing a physicochemical duplicate of itself. Later, when the cell containing the genes divides to form two daughter cells, the two identical genes that are present as a result of the duplication of every gene originally existing in the cell become drawn apart into different daughter cells. The fact that the genes are strung together in line to form the chromosomes provides a means for the orderly carrying out of this separation. Thereby the descendant cells come to contain identical genes.

Despite this identity of gene content, however, the groups of cells in different parts of a many-celled body are differentiated from one another. This is because the structure of the cells in each group results from a limited set of reactions, representing only a part of the numerous potentialities of the contained constellation of genes. These limits have been fixed by the special conditions prevailing within the given groups of cells. On the other hand, in a reproductive cell the same outfit of genes is sufficient, when multiplied, to organize the development of the entire body. In this way the genes serve as the basis of heredity.

On rare occasions a gene meets with an ultramicroscopic collision or other accident, which jolts its parts (or those of the duplicate that it has under construction) into a new arrangement, having a different chemical influence from before. We call this event a *mutation*. The mutant gene, in reproducing itself thereafter, tends to copy its new pattern as faithfully as the original gene had copied its old pattern. Thus, if the mutation has occurred in a reproductive cell, it may become evident as a variation inherited by a line of descendants. In this way, the mutations of the genes provide the inherited variations on which the process of evolution by natural selection is based. The reason why this role is reserved for the genes alone is that only they have the strange property of making copies of themselves in just such a way as to incorporate within the daughter particles even those features that have been newly introduced into their own structure. In other words, their most important peculiarity is their ability to reproduce, not merely themselves as they originally were, but also their variations (*2*).

The material that forms the bulk of most cells, although often designated by the single word *protoplasm,* is really a most elaborate composite of numerous constituents. The production of many of these constituents, including fundamentally important ones, has been shown to depend upon groups of special genes. Remove one of these genes and a given protoplasmic substance disappears or is replaced by something different; restore the gene and that protoplasmic substance reappears. In contrast to this, the production of any distinctive type of gene is not ordinarily a process initiated by the presence of certain distinctive protoplasmic substances. For, when a new type of gene arises by the mutation of some preexisting gene, this mutant gene proceeds to reproduce itself, along with the growth and division of the cell, even though the protoplasmic substances present were, to start with, no different from those in other cells not containing the given mutant gene. On the basis of this, as well as other considerations (including that of economy of assumptions), it is reasonable to infer that in the origination of life the gene arose first, and that protoplasm came into existence later, very gradually, in the form of a series of products of the chemical action of aggregates of genes that had mutated in such ways as to be able to give rise to these products. Protoplasm would thus consist of substances accessory to and produced by the genes. Its existence would be due to the fact that those mutant genes had been naturally selected whose products happened to afford chemical tools, such as enzymes, that are useful for the survival and multiplication of these genes themselves.

It may be concluded that the essence of life is not protoplasm or its operations, collectively termed *metabolism,* as has often been asserted, but that these are themselves results of biological evolution. Life's essence lies in the capability of undergoing such evolution, and this capability is inherent in the gene, by virtue of its property of duplicating its variations. At the present time, protoplasm is so highly evolved and complex, even in the most primitive cells known, that we should probably be justified in estimating the amount of advance in complexity between the stage of the simplest gene and that of a single cell, such as a bacterium, to be at least as great as that from the bacterium to the highest many-celled organism.

It is not surprising that, in the remote past, the gene itself should have come into existence. For conditions were such, in the envelopes of the primitive earth, that the accidental encounters of substances, together with the absorption of energetic radiation, continued during many millions of years, must have provided a tremendous accumulation of ever more complicated organic compounds, including many of those occurring today within cells (*8*). And if, among the myriad types of molecules thereby produced, genes were included (only one successful gene being required!), then the component parts also would already have been formed, out of which these genes could manufacture duplicates of themselves. Moreover, there would also be numerous other ready-made constituents present, which were capable of being utilized as accessory substances after mutations implementing such utilization had occurred in the descendant genes.

Advances in Protoplasmic Organization

The chemical nature of the pathways whereby the genes control the composition and workings of the protoplasm have not yet been made clear. In any case, these pathways today involve so many steps and are so intricately branched and conjoined that much of the control is very indirect. With regard to the primary step in gene functioning, the long-neglected view is now gaining ground that this consists in the construction by the genes in the chromosomes of modified likenesses of themselves which enter the general protoplasm and there act as the genes' working delegates. Now that there is reason to regard the genes as being composed of nucleic acid, it is natural to suppose that the modified kind of nucleic acid, ribonucleic acid, found in high concentration in special protoplasmic granules, represents these gene delegates. Rich and Watson (*9*), who advocate this view, present evidence that this kind of nucleic acid, like that of the genes themselves, consists of coiled chains, possibly double, of nucleotides—in this case, however, of the four corresponding "ribonucleotide" types. Since the synthesis of protein and possibly of other substances occurs in association with these granules, it seems likely that it is the ribonucleotide chains in them that conduct this synthesis. Perhaps they also, to a limited extent, carry out some duplication of their own substance. The proteins and other materials, in their turn, engage in the multitudinous other reactions that occur in the cell.

In addition to those ribonucleotide links that are united in long chains, to form the ribonucleic acids, there are more or less separated units of them, and these have been found to be indispensable in many protoplasmic reactions. In these reactions they act as conveyors of large amounts of energy (carried on detachable phosphate groups) from one type of molecule to another, under the guidance of proteins and other companion substances. It may be that this special ability to transfer energy is also possessed by chained nucleotides and comes into play when they carry out their synthetic activities, both in gene duplication and in the building of other materials.

Aside from the nucleic acids themselves, the proteins are the most highly organized and diversified of the protoplasmic substances. In connection with most of the chemical steps taken by organic materials in protoplasm, there is some distinctive protein that acts as an enzyme for just that reaction—that is, a substance that induces the given change in other molecules without itself being used up. One or a few molecules of enzyme, because they can continue to do the same job repeatedly, are able to change a relatively large amount of other material. In consequence, an outfit of numerous different enzymes, sufficient for a multitude of different operations, can be contained within a minute bulk of protoplasm.

The molecules of proteins, like those of nucleic acids, are made up of chains, often coiled, composed of a great number of links. Important in determining the physical and chemical potentialities of any given protein molecule is (for one thing) the exact arrangement in line of its diverse types of links, called *amino-acid groups.* Nucleic-acid molecules, both those of the genes and those elsewhere (ribonucleic acids), commonly exist in close association with protein molecules. These and other considerations have lent plausibility to the idea that the building of protein molecules involves an activity of the nucleic acids of the genes somewhat resembling that by which they duplicate themselves. Even more likely is the possibility that the ribonucleic acids work in this way.

If, however, the construction of a protein molecule is pictured as a capturing, by the links of a nucleotide chain-molecule, of amino acids corresponding to these nucleotides, with the resultant formation of a parallel amino-acid chain-molecule, the difficulty arises that, whereas there are only four types of nucleotides, there are some two dozen types of amino acids. How then can a given nucleotide specify which amino acid is to be selected at a given point? Gamow (*10*) has suggested what appears to be a likely solution: namely, it takes a group of four neighboring nucleotides to capture one amino acid, and the type of amino acid selected depends upon how these four nucleotides (of their four possible types) are arranged with respect to one another, somewhat as the arrangement of letters determines the meaning of a word. He points out that, at any point in a coiled double chain of nucleotides, the number of effectively different arrangements of four neighboring nucleotides would just about correspond with the number of different types of amino acids in proteins. Whether or not the details of his hypothesis are correct, it would seem that some such relationship must exist if, as seems likely, the nucleic acids synthesize the proteins directly.

Even if the protein molecules are produced in this way in the first place, however, they would still be subject to considerable and diverse alterations afterward, since proteins are among the most modifiable substances known. It would therefore be unwarranted to suppose that any given enzyme or other protein of functional importance is the product of some one special gene alone and that other genes have played no part in the determination of its nature. In fact, there is, in particular cases, direct genetic evidence against this oversimplified view.

Whatever the means by which proteins and other organic substances were synthesized, there must, soon after the earliest stages of their association with genes, have been great advantage in the ability to utilize, as raw materials for them, other materials than those constituent groups out of which they were immediately put together in the process of capture and arrangement by nucleotide chains. These hitherto alien materials would become available for use if they could be subjected to reactions that converted them into such constituents, and these reactions could be brought about by appropriate enzymes and other accessory substances, resulting from given mutations of genes. Moreover, in the construction of some substances methods of their manufacture would be worked out which did not require any direct reshaping of their constituents by the nucleotides themselves. In consequence, as the operations of gene aggregates, gradually aided by more numerous accessory substances, became more complicated through the natural selection of advantageous mutations in the genes, means must have been evolved for transforming into the materials of living things substances that required an ever more extended series of steps for the conversion process. At the same time, increasingly elaborate and effective methods were also developed for obtaining energy, storing it, and transferring it. Thus ultimately some organisms, the typical plants, became able to live entirely on certain inorganic substances and to derive their energy directly from the prime source, sunlight.

Other organisms meanwhile evolved mechanisms for utilizing other substances, some inorganic, some organic, for material, or for energy, or for both, until at last there was one vast interconnected system of living things on earth, diversely specialized chemically. This system kept in circulation the materials for life and also, until it had become dissipated, the captured energy, instead of letting them accumulate in the form of unusable wastes, as many of them must have done before. Life was thereby able to attain far greater abundance, faster turnover, increased diversity, and speedier, richer evolution.

Another circumstance that accelerated evolution, probably even at a prebacterial stage, was the establishment of sexual reproduction, in its more general sense of the coming together of two sets of genes from different sources. Before this process could be biologically effective, the series of maneuvers known as *meiosis* had to be developed. In meiosis some of the genes of each of the two sets that meet become recombined so as to form a single complete set. By the repetition of this process in successive generations, an entire population comes to constitute one great pool of genes, out of the innumerable shifting combinations of which the choicest (from the standpoint of self-perpetuation) tend to prevail. The accumulation of advantageous mutant genes is thereby caused to take place much more rapidly than in organisms that reproduce only asexually, which have their genes confined within mutually isolated lines of descent. Undoubtedly sexual reproduction owes its survival to the other advantages that, secondarily, accrued in its possessors by virtue of their faster evolution. Its function, therefore, is to make more effective the gene's ability to evolve.

Still another innovation the main significance of which lies in its hastening of evolution, or, to be more accurate, in its hindering of the retardation of evolution, is the natural death of the body. Of course this phenomenon arises, in its more typical manifestations, only in the later stages of evolution, in which organisms have become many-celled and have had their reproductive cells differentiated from the cells of their body proper. Natural death is not the expression of an inherent principle of protoplasm, but in each species natural selection has tended to develop a length of life that is optimal, in relation to the other characteristics of that species and to its conditions of living. In other words, death is an advantage to life. Its advantage lies chiefly in its giving ampler opportunities for the genes of the newer generation to have their merits tested out. That is, by clearing the way for fresh starts, it prevents the clogging of genetic progress by the older individuals. Secondarily, in higher organisms which as a result of the existence of natural death have allowed defects to develop during senescence, death has become doubly advantageous, in that it now serves also to sweep away these defects for which it is indirectly responsible.

Even before the attainment of the many-celled stage, with its complicated embryonic development, passing into adulthood, senescence, and death, many organisms had evolved regular sequences of transformations, constituting developmental cycles. They had also evolved numerous regulatory mechanisms that adapted them to environmental changes of those types that had been repeatedly encountered. Some of these mechanisms stabilized the organism internally, in reaction to outside disturbances; others set on foot operations that counteracted harmful circumstances or that took advantage of potentially helpful circumstances. Among the mechanisms were those that endowed the organism with the properties known loosely as *irritability, conductivity*, and *contractility*, all of which were so interadjusted as to result in adaptive (that is, advantageous) movements.

These diverse adaptive reactions all have their bases in specific structures, caused by genes, accidentally arisen by mutation, which had won out in the struggle for survival when the given conditions were met with many times in the past. They are not, however, expressions of any generalized adaptive ability, and they do not control the course of variation in the genes themselves. Thus the pre-Darwinian evolutionists and their Michurinist descendants have put the cart before the horse in assuming that living matter, by virtue of its inherent nature, makes an effort to adapt itself directly to new circumstances, and that evolution has consisted in the accumulation, by inheritance, of the adaptations thereby evoked.

Plant and Animal Ways

In some lines of one-celled organisms, which had probably been typical plants, adjustments of the structures subserving movement enabled the organism to add to its income by capturing and assimilating bits of already formed organic material and finally even other organisms. It then proved profitable for them to concentrate entirely on the predatory mode of life, with resultant loss of most synthetic abilities and ever-increasing development of the motor ones. Thus animals arose.

Although animals and plants thereafter diverged, there were some parallelisms in their evolution. In both groups increased size proved advantageous for some ways of living and was accomplished by the integration of many cells into a larger organism. This in turn allowed the development of far greater specialization of parts. However, in plants the fact that the supplies needed could usually be had best by simply "staying put" and reaching steadily out for them caused this specialization to take the form of relatively motionless branched structures, with (for land plants) roots in the ground for securing minerals and water, leaves above for sunlight and carbon dioxide, and a strong conducting structure between. Movements were still necessary to bring the male reproductive cells to the eggs and to disseminate the products of fertilization, but these were in the main accomplished passively, by mechanisms that utilized motions of water, air, or animals.

On the animal side, the nature of the food put a premium on the development of means of capturing it and of avoiding being captured. It is true that many small bits of food which floated or swam through water could be caught even by sedentary animals, provided that these sifted the food out from the water that was swept by them or sucked into them. Hence such animals are often plantlike in appearance. But more of a challenge was presented by food that was large, well protected, difficult of access, elusive, or possessed of counteractivity. The more the food used had such characteristics, the more advantageous was it for the animal to develop adroitness and strength of movement, including locomotion. The same capabilities also became valuable in protecting it against predators equipped with them. In varied lines of animals, therefore, natural selection favored the accumulation of those mutations that resulted in more effective sensory, coordinating, motor, and supporting systems. At the same time, since the exercise of strength requires a comparatively massive body, in the interior of which materials are not introduced or removed at a fast enough rate by diffusion alone to service a high level of activity, it became important to elaborate systems for ingesting and processing food materials and oxygen, for supplying them effectively to the cells, and for extracting and eliminating the wastes.

The strikingly divergent forms taken by many of these advances in different groups were, of course, evolved in adaptation to their great differences in circumstances and ways of living. Often these differences were in considerable measure dependent upon one or a few major peculiarities of their construction, such as a gliding membrane or tube-feet, which furnished a key to the mode of construction of many other parts. It is evident that some of the features, including even some of those in the key positions, were originally adopted, at least in the particular form taken by them, as a result of some unusual combination of minor, temporary circumstances, which would be unlikely to recur. Having once arisen, however, they proved their usefulness, which sometimes extended to some very different function, and they thereby became a solid, important part of the pattern of the organism. In this position, they might help to determine the natural selection of a long series of further steps, proceeding in a given direction. Because the method of evolution was thus opportunistic instead of farsighted, it is found that organisms, despite the marvelous interworking of their parts, conceal many imperfections and indirections of structure and functioning. In fact, evolution presents such a curious combination of arbitrariness and consequentialness as to lead us to infer that on another world physically like ours only remotely analogous forms of life would have evolved.

Learning and Consciousness

Among the more regularly occurring of the higher developments in active animals is the elaboration of the coordinating system and the inclusion within it of mechanisms for modifying its operations in adjustment with the individual's experiences. The basic feature in this process, which from the objective standpoint is called *conditioning* and from the subjective standpoint *learning* or *association,* is the formation of connections among different groups of neuronic (nerve cell) reactions that have been aroused at or nearly at the same time, so that subsequently the arousal of either tends to invoke the other as well. These connections form an ever more intricate web, since if reaction-group A becomes connected with B at one time and B becomes connected with C at another time, it follows that A thereby becomes connected with C, in the arrangement ABC.

Also essential in learning is the procedure called *analysis,* whereby particular components or relationships existing within a neuronic reaction-complex become dissected out, as it were, so that when they occur in different settings they can serve to cross-connect these other features with one another, somewhat as B connected A and C in the foregoing illustration. Doubtless there are as yet unguessed but far-reaching inherited neural mechanisms that effect the isolation of certain characteristic relationships, such as (on a sensory-motor level) possession of the same color or motion of a given kind across the field of view. However, much of the analysis at deeper levels depends also upon associational procedures in which the neuronic reaction-complex is subjected to various learned operations. These, in modifying it, bring out features implicit in it which it shares with some other complex.

All these processes become useful to the organism only by virtue of their modification of its behavior. This modification is made possible by the fact that the neuronic activities for movements become strengthened or inhibited according to whether these movements have been followed by experiences (neuronic reactions and reaction-complexes) of the types subjectively designated as desirable or undesirable. Which experiences are originally felt to be desirable or undesirable, and which emotional and behavioral ("instinctive") responses are concomitantly aroused by them, are matters determined by inherited neuronic structures. These have been shaped by evolution in such wise that the creature, in working for its own goals, unwittingly furthers the multiplication of its kind. However, through association it learns to achieve its primary desires by more effective means, better adjusted to the circumstances surrounding it, and learns to coordinate and subordinate its different desires to one another so as to attain greater total gratification.

Despite our present ignorance of the nature of the physicochemical bases of all these phenomena, their physicochemical *existence* is attested by numerous facts of observation and experiment.

As, through association and analysis, an increasingly coherent and serviceable formulation or representation of the world outside becomes built up out of the neuronic reaction-complexes, we become justified in speaking of intelligence. Only here, at last, does foresight make its debut in the operations of living things. Moreover, within this same neuronic reaction-system, a representation of the individual himself, including his own associations, gradually takes its place. A speaking individual, in referring to this phenomenon, then uses the expression *consciousness* or some equivalent.

Although this term denotes what may be called the inner or subjective view of oneself, it is only by a confusion of ideas that it is thought of as implying the existence of two "parallel sides," conscious and material, to neuronic or other processes: that is, two systems of phenomena that coexist and completely correspond but do not interact. If this view were correct the existence of consciousness, being only "parallel," could in no way affect our behavior. Hence we could not speak of it. Nor could we, for that matter, even think of it (for the conscious could no more than parallel the material side, and the latter could not be affected by the former). It follows that the conscious phenomena *are* the physicochemical phenomena or, at least, are some integrated portion of them. In other words, matter and mind present no real antithesis. Moreover, in the case of mind, as in the case of life, its difference from matter and energy in their more ordinary forms lies in the peculiarities of its mode of organization and resultant operation.

Pooling of Learning

Turning to a consideration of the native intelligence of our own species, we find that it is not so very much greater than that of some other existing animals. However, this relatively moderate difference, taken in conjunction with man's social disposition and with his queer proclivities for vocalizing and symbolizing, enables him far more effectively than other animals to communicate with others of his kind. This has resulted in his social evolution, by the accumulation of tradition, a process wherein each individual becomes provided with the distilled experience of a vast, ever-increasing body of his ancestors and associates. Through this knowledge and the cooperative activities and resultant material equipment based upon it, man has become incomparably more potent than any other form of life on earth, even without any perceptible improvement having taken place in his genes since before civilization began.

It is true that ancient tradition is often faulty and tends to overelaborate itself by an inner inertia in arbitrary and injurious ways. Moreover, the strange human propensity for symbolization, although invaluable not only for communication but for thought itself, has often led men astray, running away with them, causing them to misinterpret and glorify their own symbols, and to confuse them with the things denoted. But with the increase of useful knowledge men have come to realize that tradition, even when ancient, is manmade, and that only the systematic testing, unhampered criticism, and rational judgment denoted as *science* can give them a more correct understanding of things. By the conscious, organized use of this method life today, in the form of man, is ever more rapidly reaching out to new spheres and to new modes of existence. At the same time, transcending its role of animal, it is making its position firmer by learning to promote, and in part even to supersede, the synthetic functions of the plant kingdom.

It must be recognized that at this point man's social development has lagged far behind his "material" development, and that the resultant insufficiency of cooperation among his own members may bring about the annihilation of his hard-won achievements, if not of man himself. Alternatively, he may begin to advance to hitherto unimagined outer and inner conquests. Such advance, however, will require a wisdom that can be gained only by genuinely free inquiry, based solidly upon our advancing knowledge of the nature of things and backed by the broadest, most unbiased good will.

If our dangerous drifting from one short-range goal to another is to be replaced by really long-range foresight, we shall have to overhaul courageously all our ancient standards of value, for value judgments, far from being immune to scientific investigation as is sometimes asserted, should be a main object of such study. In accordance with the conclusions thereby reached, we shall then have the task of modifying our systems of inner motivation and the relationships of individual with individual and group with group. Recognizing that our conscious objectives, which we subsume under the expression *the pursuit of happiness,* are the complex and modifiable resultants of more primitive urges chosen by natural selection in compliance with the pressure of the gene to preserve itself and to extend its domain, we must seek more *functional* ways of pursuing happiness. These should more successfully harmonize the gene's trend to increase and evolve with the deepest fulfillment of our conscious natures, so that the serving of either of these ends will by that very act promote the other. In fact, any other policy is ultimately self-defeating, in this world of interpenetrating competition and cooperation.

Crisis in Gene Increase

It is, however, a mistake to assume that the gene's tendency to increase gives biological victory to the organisms with the highest gross fertility. In general, the "higher" the organism, the greater the security of individual life that it achieves and the lower its production of offspring. Natural selection has decreased the fertility because, with too high a pressure toward population increase, the well-being and efficiency of the organisms are so reduced as actually to lower the potential of the species to undergo biological expansion. In fact, civilized man, through his advanced techniques, has attained such security of life (except for war!) that an even lower fertility now becomes appropriate for him, both biologically and for his individual happiness, than that which was established for him by natural selection in adjustment to primitive conditions.

Civilized man is now going part of the way toward meeting this requirement artificially, by means of birth control, but it will be necessary for him to make much more widespread and adequate use of such technique, in order that he may attain and maintain a world-wide optimum per-capita supply of energy and of food and other materials. Otherwise he would be forced back into a misery and disorganization that would not only rob him of most of the benefits of his previous progress but would find him deprived, perhaps permanently, of the resources needed to raise himself again and at last to expand into new and more commodious realms of living. Thus it is preeminently true of civilized man that his success in pursuing happiness is a necessary basis for the success of his genes in their job of multiplication. Conversely, however, the pursuit of happiness must also be so directed as ultimately to lead to biological expansion, if man is to utilize his opportunities for bringing "the greatest good to the greatest number," and if he is to minimize the risks of disaster and of being left behind in the universal struggle for existence.

But even if we grant that man will achieve adequate control over his numbers and will advance to untold reaches in his social evolution, all this progress must still rest on a crumbling biological basis, unless not merely the quantity but also the quality of that basis is vigilantly taken care of. For the artificial saving of lives under modern civilization will allow the increasing accumulation of detrimental mutant genes, unless this accumulation is deliberately compensated by an enlightened control over the types of genes to be reproduced. This course of action, to be both sound in its direction and effective in its execution, must be entered upon not under complusion but in the spirit of freely given cooperation, founded not upon illusions but upon the idealism that is natural to men who engage in a great mutual endeavor.

Man a Transitional Phase

The spirit thus aroused would inevitably tend to proceed further, to the realization that the mere prevention of deterioration is an inadequate, uninspiring biological ideal and that instead, by extension and supplementation of the methods followed for maintaining our genetic foundation as it is, it can actually be raised to ever higher levels. Acceptance of this course will be facilitated by the rapid growth of human understanding and technical proficiency that we see under way about us now. This present progress is, as we have seen, not based on any changes in the hereditary endowment but only on the extreme responsiveness of the human organism, even with its present endowment, to educational and other environmental influences. But great as are the advances possible in this way, men cannot remain satisfied with them alone when they become aware of the vastly greater enhancement of life that could result from the combination of this kind of progress with that in their underlying genetic constitution. This would include the genetic remodeling of our primitive urges, the improvement of our intellectual ability, and even of our body construction.

There is no limit in sight to the possible extent of such advances, provided that we *will* them to take place. However, the possibility of their coming about automatically, by the type of unconscious natural selection that has operated in past ages, has been done away with, as is explained earlier, by the conditions resulting from social evolution. For these conditions rightly lead to the increasing protection, by society at large, of those who are weak and ailing by heredity, as well as of those handicapped by misfortunes caused by outer circumstances. Yet at the same time this very social evolution has provided and will provide increasingly effective knowledge and techniques for the voluntary, artificial guidance of biological evolution. These make available, in compensation for the deficiency of natural selection under civilization, novel means of directing many of the processes involved in reproduction and heredity.

Among the methods of this kind that are being, and will be further, developed are those for managing the generation and the storage of the reproductive cells, both within the body and outside of it, those for artificially controlling insemination and fertilization, for instigating parthenogenesis and twinning or polyembryony, and for instituting foster pregnancy. It should be possible eventually to find ways of influencing the behavior and distribution of the chromosomes themselves. Means of substituting, for the original nuclei of eggs, other cell nuclei, of chosen types, are even now being worked out, and such operations may in time be made fine enough to deal with individual chromosomes or their parts. Far more remote and unlikely than these possibilities, however, is that of regulating the direction taken by the mutations of genes.

However that may be, the rate at which biological progress could be made even by the means available today is already incomparably greater than that to which it was limited by the slow unconscious processes of nature. Only fear of the dead hand of ancient superstition today holds most men back from a recognition of these opportunities for greater life. But, with the progress of enlightenment, this fear must wither away. Thus, man as we know him is to be regarded as only a transitional operative in the progression of life, but one that commands a critical turning of the road. For at this point the method of evolution may change from the unconscious to the conscious, from that of trial and error to that of long-range foresight.

Man in the shackles of authoritarianism is incapable of such advances. Should he attempt them, his efforts would be misdirected and corrupting. But, with the amplified opportunity to create that is his when he is free to see things as they are, he will find his greatest inspiration in the realization that he is by no means the final acme and end of existence, but that, through his own efforts, he may become the favored vehicle of life today. That is, he can be the means whereby life is conducted onward and outward, to forms in ever better harmony within themselves, with one another, and with outer nature, endowed with ever keener sentience, deeper wisdom, and further reaching powers.

Who can say how far this seed of self-awareness and self-transfiguration that is within us may in ages to come extend itself down the corridors of the cosmos, challenging in its progression those insensate forces and masses in relation to which it has seemed to be but a trivial infestation or rust? For the law of the gene is ever to increase and to evolve to such forms as will more effectively manipulate and control materials outside itself so as to safeguard and promote its own increase. And if the mindless gene has thereby generated mind and foresight and then advanced this product from the individual to the social mind, to what reaches may not we and our heirs, the incarnations of that social mind, be able, if we will, to carry consciously the conquests of life?

References and Notes

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Herbert Osborn: Scientist, Teacher, Leader of Men

ONE of this country's greatest entomologists, Dr. Herbert Osborn, died 20 September 1954, in Columbus, Ohio, at the age of 98. His accomplishments as a scientist and teacher insure him a permanent place among America's men of science.

Today, the American people are among the healthiest and best fed of any on earth. This is due, in part, to the profound effect of research in the control of insect pests and to successful efforts on the part of our public to control its insect enemies.

Without the control of insect pests, our national annual agricultural production—crops and livestock—would be half or less than they are today. In addition, insect-borne diseases would cause thousands of deaths and hundreds of thousands of illnesses each year.

Economic and health benefits such as these stemmed from the pioneer efforts of far-seeing entomologists like Dr. Osborn. He, together with a tiny number of other dedicated persons, brought about the successes of economic entomology that are well known to everyone today.

Dr. Osborn was born in Wisconsin on 19 March 1856. Thus, his life span almost duplicated the first century of professional entomology—1854–1954. His first paying job concerned knocking Colorado potato beetles into a can for later destruction. By the time he was 15, he had lived through the greatest agricultural catastrophe this country has ever seen—the horrible grasshopper plagues of the 1870's. For three straight years grasshoppers destroyed almost all the agricultural production of the soils from Texas into Canada and from the Rocky Mountains into Illinois. In these boyhood days, he saw the Hessian fly destroy 50 to 90 percent of the wheat crops of early settlers almost every year. No one knew then how such pests could be controlled or how losses they caused could be prevented.

Young Osborn decided to take on that job. He dedicated himself not to the study of generalized entomology but to a search for ways to protect people and their crops, livestock, and possessions from insect depredation.

Osborn received his B.S. degree in 1879 and M.S. degree in 1880—both from Iowa State College. He taught at Iowa State College for the next 19 years.