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# EVOLUTION - ORGANIC AND SUPERORGANIC

BY THEODOSIUS DOBZHANSKY

*The biological and cultural evolution of mankind proceed in parallel, but not independently of each other. So man is more than just a bag of DNA*

SCIENCE SHOULD BE anthropocentric or relevant to man, but in the broadest sense. Thus knowledge and understanding of subatomic particles, of atoms and molecules, of organisms high and low, of mountains and oceans, of planets and suns and galaxies, assist man in his quest to understand himself and his place in the Universe. What is man, whence came he, and whither is he going? It is debatable whether science alone can hope to answer these questions. However, even the best intellects are plainly powerless to face up to them in the absence of scientific knowledge. Omar Khayyám expressed this powerlessness most poignantly some eight and a half centuries ago.

> Into this Universe, and Why not knowing,
> Nor Whence, like Water willy-nilly flowing,
> And out of it, as Wind along the Waste,
> I know not Whither, willy-nilly blowing.

Darwin complained that, as he grew older, he lost the capacity to enjoy poetry. He may or may not have been familiar with the great poet of Persia, but he sketched a rough draft of possible answers to some of Omar Khayyám's queries. Biologists have been working on this draft for a century since Darwin. There has been notable progress, but a vast amount of work remains to be done. Man is the outcome of a long process of evolutionary development. He is kin to all that lives. Not only has he evolved; he is evolving. The direction of his evolution is unknown.

Another poet, Nietzsche, has dared to suggest a solution — "Man is a rope stretched between the animal and the Superman — a rope over an abyss. Thus spake Zarathustra." This is a fine statement of the direction which the evolution of man *ought* to take. Strange to say, Nietzsche had only contempt for that "English shopkeeper," Darwin, even though in Nietzsche's own great work there is, as Brinton justly notes, more Darwinism than Zoroastrianism. But is mankind really evolving towards some sort of Supermankind? Let us not forget, the Nietzschean "rope" leading from animal to Superman hangs over an abyss. There is no assurance that the passage over the rope will be accomplished safely; to many of our contemporaries, the abyss seems mankind's likeliest destination. Probably not the gravest danger is that atomic energy, which used wisely could benefit mankind enormously, may become the instrument of suicide of the human species. There is no biological law, nor any other law of nature, that guarantees either evolutionary progress and betterment or deterioration and downfall to the human or to any other species.

## *Evolution*

Man is, however, an extraordinary creature. The human species has already moved some distance along the Nietzschean "rope," away from simple animality. Man, and he alone, has it within his potentialities to refuse to accept the evolutionary direction of blind forces of nature. He may be able to understand, to control, and to guide his evolution. The

ness also in other people whom I have not met personally. But where is the extension of the analogy to stop? Are consciousness and self-awareness attributes only of the human species? If so, have they appeared suddenly and fully fledged at some particular spot in man's phylogeny?

Evolutionists as different in their general philosophies as Teilhard de Chardin and Bernhard Rensch saw themselves compelled to assume that rudiments of consciousness are omnipresent in nature, not only in living beings down to the simplest but in inorganic systems as well. The considerations that drove Teilhard and Rensch to these uncomfortable expedients are of the same kind that made as eminent a philosopher as Whitehead assume that there could be no life or consciousness in men unless there were rudiments of life and consciousness everywhere, down to the atoms and presumably to subatomic particles.

Not being a philosopher, I expose myself to criticism by saying that I fail to see why life and consciousness, or rather their first rudiments, could not have originated at some stages of the evolution of the Universe, and then developed to their present conditions. I fear that Whitehead, Teilhard, Rensch, and others have in this matter chosen the same path of reasoning that led in biology to theories of preformation or the assumption that a miniature image of the adult body exists in the sex cells from which the body develops. Evolution is, however, not simply an unfolding of preformed shapes and structures any more than embryonic development is mere expansion of a pre-existent body frame. The process of evolution is capable of producing real novelties.

## *"Transcendence"*

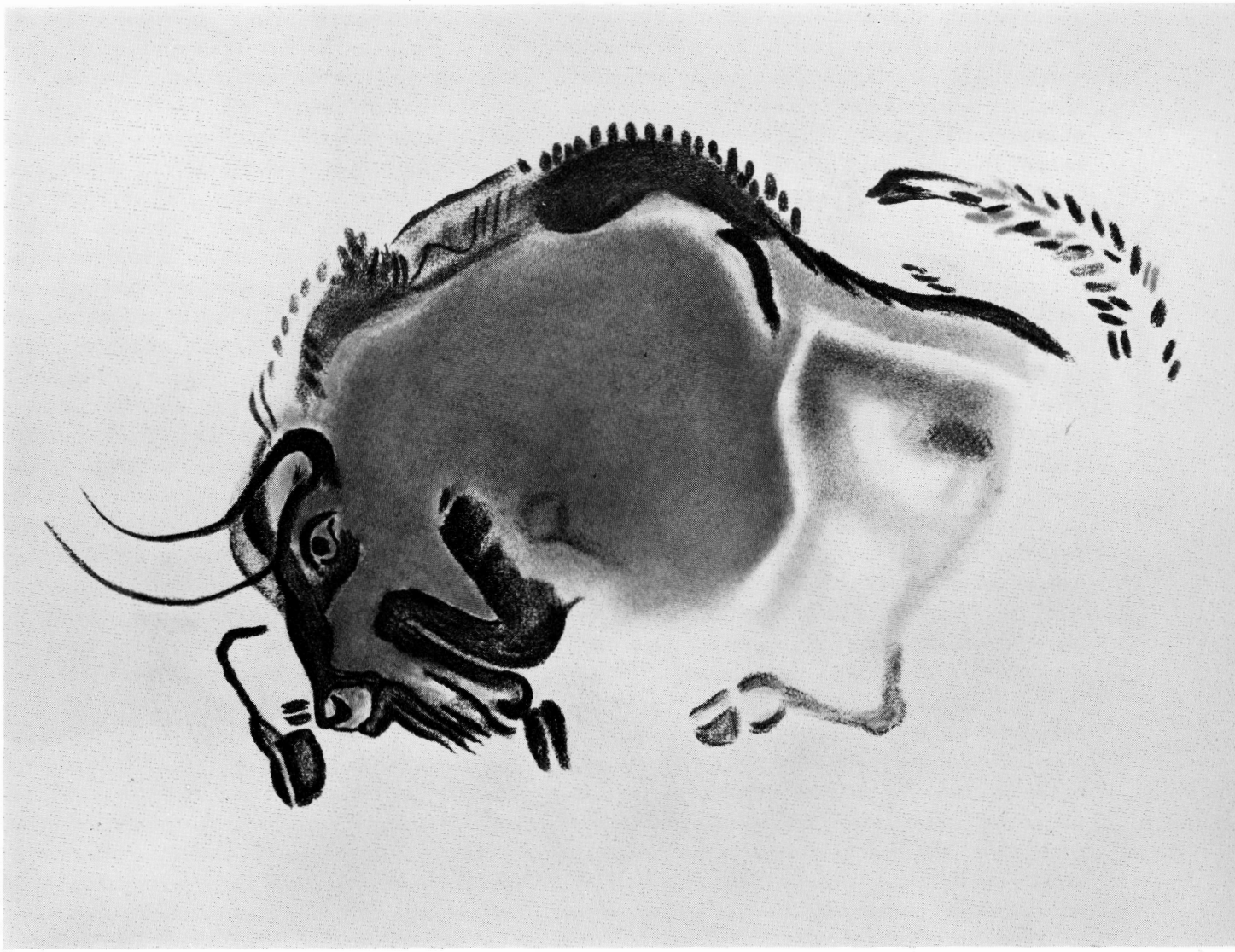
Cosmic evolution has transcended itself in producing life; the origin of man transcends biological evolution. The highest achievements of the human spirit involve self-transcendence. Now "transcendence" is a dangerous word which is liable to be misunderstood but I can find no other word to express an idea which must, I think, somehow be brought to the attention of biologists as well as of philosophers. To me, transcendence does not mean injection of a novel species of energy. The statement that life transcends the limits of inert matter does not imply that biological phenomena are manifestations of some special vital force; human consciousness and culture transcend the limitations of animal life without any addition of a non-biological energy. Transcendence does mean the emergence of systems or phenomena subject to regularities which are meaningless without these systems or phenomena. Mendel's law does not apply to chemical reactions, and poetry makes no sense to a mouse; this does not prevent the units, the behavior of which is described by Mendel's law, from being chemical compounds, and poetry uses words and concepts used also in ordinary language.

## *Feedback*

Although analogies between evolution and individual development are slippery, the gradual emergence of self-awareness in a child may be a good model of human evolution transcending biology. Rensch admits that the human self "is nothing but the result of the connection of psychic processes by one central nervous system." My self came into being gradually; not even my genetic potentialities existed before the meiosis in the germ cells of my parents or before the union of two of these cells in fertilization. This neither leads me to doubt that I exist at present (remember Descartes' *cogito ergo sum*) nor forces me to assume that I was somehow present in the primordial virus in which biological evolution presumably took its rise.

Unreconstructed nineteenth-century-style reductionists see nothing but agitation of molecules in life and in man. Theological fundamentalists are, however, not alone in contending that the cosmic (inorganic), biological, and cultural evolutions are separated by unbridgeable gaps, instead of being integral parts of the grand process of evolution of the Universe. Strangely enough, they are bedfellows with Marxist theoreticians, who proclaim that the biological evolution of mankind ended when it produced a being capable of "working." Henceforth, social or cultural evolution has taken over. Ways of thinking only a little less extreme than these are accepted by many social scientists, including anthropologists.

Man is not a molecule, and though he is an animal he is a very special kind of animal. But the idea that there is a feedback relationship between the biological and the cultural evolutions of mankind must, I



*Mankind has evolved culturally as well as biologically, as demonstrated by the painting in the cave at Altamira, Spain. The figure represents a curled bison.*

think, be maintained. The big problem is evidently how this relationship operates and where it is taking the human species. Let no one mistake it—there are *no easy answers here.* The matter needs careful rethinking in the light of the present knowledge, and even more, it needs further research.

The main premise that cannot be stressed too often is that what heredity determines are not fixed characters or traits but developmental processes. The path which any developmental process takes is, in principle, modifiable both by genetic and by environmental variables. The degree of the modifiability or plasticity is, however, quite different for different developmental processes. As a general rule the processes whose consequences are essential for survival and reproduction are buffered against environmental and genetic disturbances. Two eyes, a four-chambered heart, ability to maintain an approximately constant body temperature, suckling instinct in the infant and sexual drive in the adult, capacity to think symbolically and to learn a symbolic language—all these "normal," or species, or group char-

acters develop in almost every human. Conversely, plastic characters are generally those in which a variability is advantageous. Suntanning and shade bleaching are examples. Fixity or plasticity of a developmental process is itself genetically determined. They are set by natural selection usually at levels advantageous to the species.

## *Culture*

For a human being membership in a culture is vital. Lack of a capacity to acquire a culture makes an individual a low-grade mental defective. A fixed capacity to acquire only a certain culture, or only a certain role within a culture, would however be perilous; cultures and roles change too rapidly. To be able to learn a language is imperative, but a restriction of this ability to only a certain language would be a drawback. Insect behavior is largely, though not wholly, stereotyped and genetically fixed; human genotype brings about a comprehensive plasticity of behavior. This plasticity is adaptively essential, because culture is wholly acquired in every generation, not transmitted through genes. The connection between genetics and culture is often imagined to consist of the possession by some human populations of genes for this or that cultural trait, or the possession by the human species of genes for this or that "cultural universal," but that is sheer misconception. The biological success of the human species has been due precisely to the genetically secured capacity of every individual free from overt pathology to acquire any or all cultural traits or universals.

But does it follow that "for virtually all propositions in the analysis of culture or culture history, genetic constitution of individuals or of populations can be taken as constants"? This "proposition" seems to be fairly representative of the views of many social scientists. Now, if it asserts that the capacity to acquire a culture is not a property of only some races and populations, but is vouchsafed to all nonpathological human genotypes, this is warranted. But it must be qualified in at least two ways. First, the cultural capacity of the human species did not appear suddenly, but arose gradually in evolution, and its origin is a biological as well as psychological and social problem. Secondly, and even more important, this capacity is not a constant, not some sort of a single quantum, but varies quantitatively and probably also qualitatively in time, in space, and from individual to individual.

Here some biological considerations are in order. Modern biology is breaking away from the typological modes of thought. The concept of a species representing a "type," of which individuals are more or less imperfect manifestations, is being replaced by the concept of a Mendelian population composed of genetically different and usually unique and unrepeatable individuals. The genetic variations among individuals of a population, or among populations of a species, is not an accident or a sad imperfection of nature. Quite the contrary, much of this variation is adaptive in the environments in which the species lives, and it is kept up by natural selection. Perhaps the most interesting kind of variation is polymorphism, the presence of two or several more or less distinct genetically conditioned forms, polymorphs, in the same breeding population. The polymorphs are usually adapted to exploit most efficiently different facets of the environment, different ecological niches, or different ways of life.

Man is genetically a highly variable and polymorphic species. The variability affects behavioral traits no less than physiological and structural ones, and it is false to imagine that these three categories are clearly separable. The chief reasons why so many people are loath to admit the genetic variability of socially and culturally significant traits are two. First, human equality is stubbornly confused with identity, and inequality with diversity, as though to be entitled to an equality of opportunity people would have to be identical twins. Secondly, it is futile to look for one-to-one correspondence between cultural forms and genetic traits. Cultural forms are not determined by genes, but their emergence and maintenance are made possible by the genetically conditioned human diversity. The division of labor in many societies is, indeed, largely a cultural phenomenon and is only to a limited extent genetic. But could it be sustained in a population consisting of persons as similar as identical twins? This is not entirely an empty question, since at least one great geneticist has recently envisaged the possibility of bringing about such genetic uniformity.

The fact that the radical changes in the ways of life of our generation and those of our parents and grandparents must have been cultural rather than genetic only proves again the absence of one-to-one correspondence between genetic and cultural changes. It does not, however, prove that the biological evolution of mankind has stopped or that it is irrelevant to the cultural evolution. On the other hand, it is difficult to demonstrate that mankind has changed biologically even since, let us say, the days of the ancient Greeks and Romans, if by "proof" is meant the ascertainment of sizable gene differences. We cannot test the genes of Pericles, Caesar, Augustus, and their contemporaries. But neither was Darwin able to "prove" organic evolution in this sense. The evidence is indirect, inferential, but nevertheless, I think, conclusive.

## *Variants*

Paradoxically, it is precisely because we know that mankind changes so greatly in cultural aspects that we can be reasonably confident that it also changes to some extent genetically. When the environment changes, the only other necessary condition for the occurrence of genetic evolutionary change can be defined. This is the presence in human populations of genetic variants, some of which confer upon their carriers a higher fitness. Despite all the inadequacies of our present knowledge of human genetics, this can scarcely be doubted. What is more, since the environment in which man lives is in the first place his sociocultural environment, the genetic changes induced by culture must affect man's fitness for culture. The process thus becomes self-sustaining. Biological changes increase the fitness for, and the dependence of, their carriers on culture, and stimulate cultural developments. Cultural developments in turn instigate further genetic changes. This amounts to a positive feedback relationship between the cultural and the biological evolutions.

Positive feedback explains the great evolutionary change, so great that it creates the illusion of an unbridgeable gap, that transformed our animal ancestors into man. Human evolution is the outstanding example of what Simpson has termed quantum evolution, a rapid passage to an entirely new way of life. The rates of evolutionary changes tend however to be variable rather than constant. The evidence of paleontology shows that bursts of evolutionary activity are often, and even usually, followed by periods of an at least relative quiescence. Those who believe that man no longer evolves biologically might contend that our species has entered upon such a period. Here we must, however, proceed with the greatest caution. The potentialities for rapid evolution of the human species have not been depleted, since the environment continues to change and the genetic variance remains apparently as plentiful as ever. What may be happening is, however, that the direction in which the evolution has been proceeding may be altered, and altered on a pernicious course.

Mankind is faced with a cruel paradox – it is the outstanding success of both the biological and the cultural evolutions of our species that gives rise to dangers, and may even sow the seeds of its destruction. Consider that one of the criteria of biological success, maybe even the chief criterion, is increase of the population size, especially when combined with an expansion in space and capture of new opportunities for living. *Homo sapiens* is unquestionably successful in the light of this criterion. Unfortunately, the "success" of the human species has culminated in a population explosion. This tale is too well known, and has been told too many times, to need another recital. I wish only to stress that the uncontrolled population growth entails both genetic and cultural hazards, and here again it is wrong to imagine that these hazards are neatly separable.

Neither do I need to retell here the story of the alleged relaxation or suspension of natural selection in civilized mankind. The dangers from this source, although not necessarily exaggerated, have often been presented in a wrong perspective. True enough, the advances of obstetrics have reduced the selective pressures against difficult childbirth; dentistry has made the genes for weak teeth lose a part of their selective disadvantage; oculists can alleviate the drawbacks of some forms of weak eyesight. On the other side of the ledger selection for some traits has probably increased in intensity. The genotypes that enhance the ability of their carriers to withstand the stresses of crowding, of the enervating "tempos," of the anxieties and insecurities, have become selectively more advantageous than they were. Surely,

then, natural selection does not work in modern mankind as it did in the primitive or the pre-civilized man. But this is both inevitable and desirable. Natural selection is the agency which translates the environmental challenges into genetic alterations, and civilized environments present challenges utterly different from those of the past. We wish to be fit to live in today's environments, not in those of the Middle Ages, or preliterate societies, or the Stone Age.

The most mischievous error, however, is the notion that the progress of mankind would be safe and irresistible if only natural selection were permitted to operate unobstructed by civilization. Natural selection does not guarantee even the survival of the species, let alone its improvement. Dinosaurs became extinct even though their evolution had been piloted by natural selection quite unhampered by culture. Natural selection is automatic, mechanical, blind. It brings about genetic changes that often, though not always, appear to be purposeful, furthering the survival and opposing the extinction of the species. And yet, natural selection has no purpose. Purposes are human prerogatives.

## *Choice*

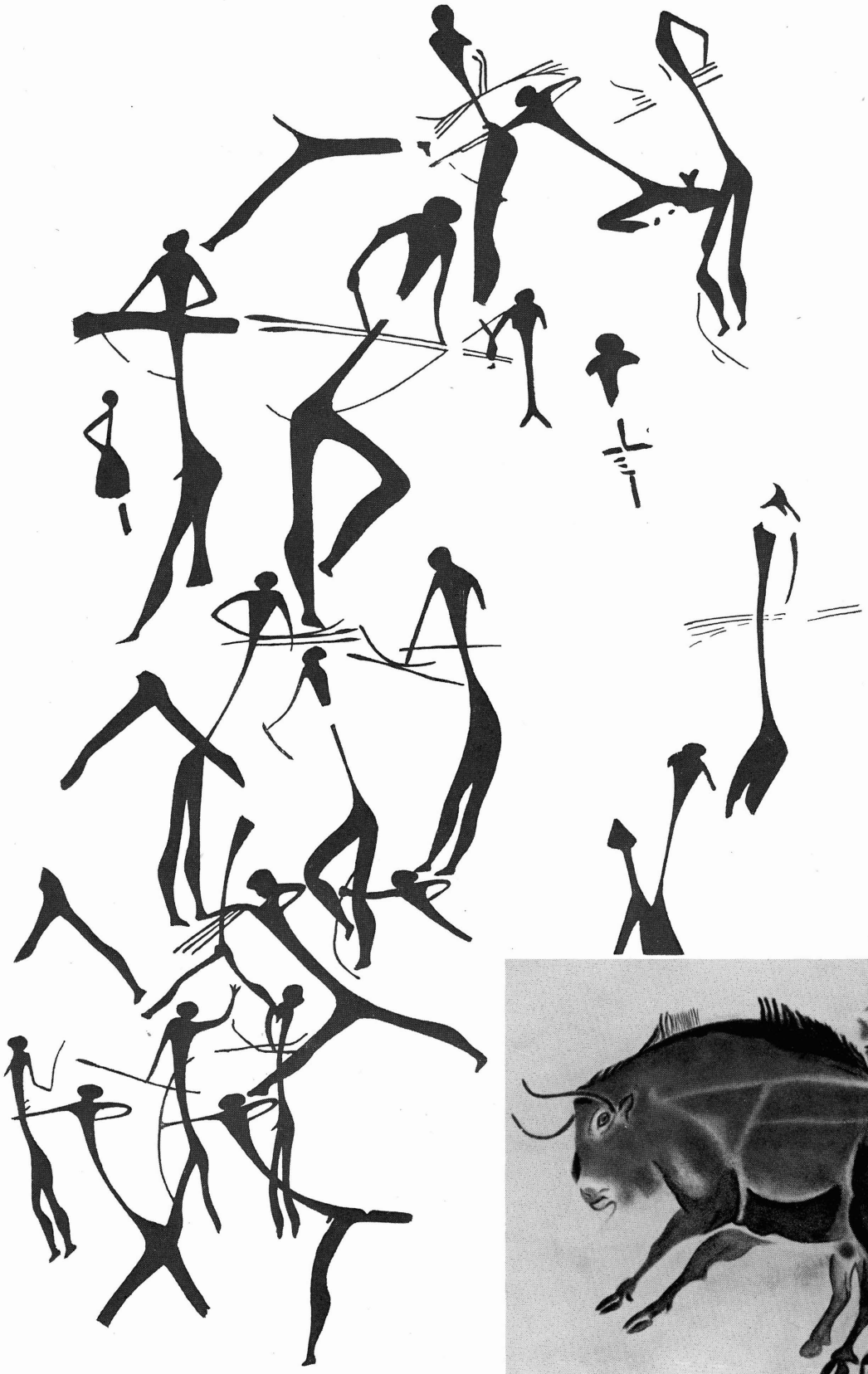
Man, if he so chooses, may introduce his purpose into his evolution. The biological predicament is not that natural selection has ceased to act; it is that the selection may not be doing what we wish it to do. Man is the only product of evolution to have achieved the knowledge that he came into this Universe out of animality by means of evolution. He may choose to direct his evolution towards the attainment of the purposes which he regards as good, or which he believes to represent the will of his Creator. "But who is to plan the planners?" John Greene, the philosopher who has asked this uncomfortable question, believes that man "contemplates his own handiwork with fear and trembling lest he reap the wages of sin, namely death."

Here again, let us not delude ourselves with easy answers. One such answer is that a superior knowledge of biology would make it unmistakable which plan is the best and thus best followed. Another is that biological evolution has itself implanted in man ethical ideas and inclinations favorable for the continued progress of evolution. Now, I would be among the last to doubt that biology sheds some light on human nature, but to plan even the biological evolution of mankind, let alone its cultural evolution, biology alone is palpably insufficient. Waddington has shown, I think clearly, that our biological evolution has instilled in us no ethics and no ability to discriminate between good and evil. What evolution has done is to make us "ethicizing beings," and "authority acceptors," particularly in childhood. But what ethical principles, purposes, and goals we accept and work out for ourselves come from our superorganic inheritance, from our culture.

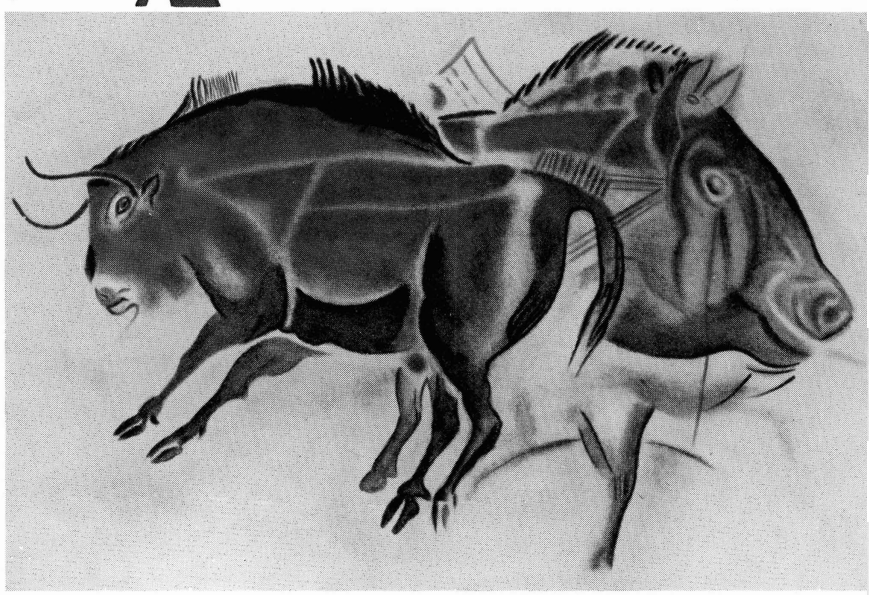
In man, organic evolution has transcended itself by producing the superorganic. It is in order to serve as the foundation for the further advancement of the superorganic that the biological nature of mankind must not only be maintained but improved and ennobled. In planning human evolution, including biological evolution, biology must be guided by man's spiritual and cultural heritage, by what Aristotle meant by "poetry" when he wrote that "It is not the function of the poet to relate what has happened, but what may happen — what is possible according to the law of probability or necessity."

Human evolution has forced mankind to a crossroad from which there is no turning back and no escape. Our animal past is irretrievably lost — we could not go back to it even had we wished. The choice is between a twilight, cultural as well as biological, or a progressive adaptation of man's genes to his culture, and of man's culture to his genes. I am optimistic enough to hope that the right choices will be achieved before it is too late. The grounds for this optimism cannot be put better than in the words of Albert Schweitzer: "Because I have confidence in the power of truth and of the spirit, I believe in the future of mankind. Ethical world- and life-affirmation contains within itself an optimistic willing and hoping which can never be lost. It is, therefore, never afraid to face the dismal reality, and to see it as it really is."

Different versions of this address were read before the Kaiser Foundation Symposium "The Flow of Life," on 20 October 1962, in San Francisco; before the American Anthropological Association Symposium "Anthropology among the Disciplines: Two Cultures or Three?" on 17 November 1962, in Chicago; and before the National Academy of Sciences Symposium "Human Biology," on 30 November 1962, in Austin, Texas.



*A group of armed men painted in a cave at Albocácer, Castellón, and a bison and wild boar from Altamira.*



# IS THERE AN ARROW OF TIME?

BY GEORGE E. UHLENBECK

*People have an innate sense that time flows on, but there is no trace of this in the laws of mechanics*

CLOCKS THAT RUN backwards in time are not to be found in the shops, and for the best of reasons. For people have an intuitive sense of the direction of the flow of time. To see the hands of a clock turn backwards would be, for an overwhelming majority of the potential customers of jewelers' shops, as upsetting as the sight of a man lifting himself off the ground by pulling at his shoelaces. So deeply ingrained is this intuitive sense that time moves on, and not back, that the clock-buying public might indeed be forgiven for expecting that this distinction between the future and the past should somehow be apparent in the most elementary properties of the physical universe. In other words, it seems reasonable that the basic laws of physics should be dominated by what may be called the "arrow of time."

From this point of view Newton's Laws of Motion are a cruel disappointment, and there is no comfort to be found in amendments of the classical laws of physics represented by the doctrines of Relativity and Quantum Mechanics. For, contrary to everybody's intuitive expectation, these assertions about the elementary nature of the physical universe are all indifferent to the direction of the flow of time. **The equation**s that describe the behavior of matter on an atomic or a subatomic scale make no distinction between past and future.

What, then, is the origin of the arrow of time? How does it come about that the common sense of the uniform onward progress of time is a reliable guide to the nature of the physical world in which we live? How are the symmetrical equations of physics on the atomic scale to be reconciled with the unsymmetric equations, such as the Second Law of Thermodynamics, that correctly describe the behavior of matter in bulk? These questions go deep. They will not be answered fully and convincingly until much more is known about the structure of the Universe as a whole.

## *Symmetry*

At the outset it is of interest that the symmetry of the elementary laws of physics with regard to the direction of the flow of time is but one of three principles of symmetry to have figured prominently in the discussion of physical phenomena. Briefly, the equations of motion show *no* preference for the direction of time or, more technically, they are invariant with regard to time reflection. In classical mechanics this is a familiar fact. With every motion of a set of particles can be associated another motion (obtained by reversing all velocities) in which all particles retrace their paths. If a film of the motion of the particles were played backwards, an observer would not know which was the forward direction, since both directions would show plausible mechanical motions. In the quantum theory this symmetry

cannot be expressed as simply, but the situation is in principle the same.

The second symmetry law is that of the equivalence of left and right. The basic laws are invariant with regard to space reflections. Since the distinction between right and left can best be expressed by the distinction between a right- and left-handed screw, this amounts to an assertion that physical phenomena have no preference for a definite screw sense or "do not contain a screw."

For the physicist this equivalence has so much *a priori* force that an apparent exception may be shocking. Ernst Mach has described his own sense of shock when he pondered, in his youth, on a familiar phenomenon. A straight wire carries an electric current, and parallel to the wire is a magnetic needle. The configuration of wire and needle is completely symmetric with regard to the plane through the wire and the needle, so that there is no preference for a deflection of the needle to the right or to the left. Yet, as every schoolboy knows, the magnet rotates in a definite sense. It seems as if the basic electromagnetic laws *do* have preference for a definite screw sense. How, Mach asked himself, does the physicist talk himself out of this? He makes the hypothesis (which is, of course, well confirmed) that on the molecular level magnetism consists of small circular currents or rotating charges in a plane perpendicular to the direction of the magnetic needle. Therefore, on the molecular level the configuration of magnet and electric current "contains a screw" which allows the magnet to distinguish between right and left, even though the basic laws are invariant.

In organic nature the equivalence between right and left seems, roughly speaking, to be confirmed. However, this is *not* true in detail. The heart and the aorta are arranged in a screw of a definite sense in almost all men. The prevalence of optically active substances in organic nature is also most striking, so that as far as the constitution of the organic world is concerned there seems to be an intrinsic difference between right and left. It is relevant that man is sometimes very sensitive with regard to the two different forms which the same organic molecule can assume.

The third and last symmetry law consists of the indifference of the elementary laws of physics to the reversal of the signs of electric charges. More technically but more precisely, this principle suggests an equivalence between fundamental particles and their so-called *anti-particles*. This is the most recent of the three symmetry laws. It was announced by Dirac in 1929, and again it is in apparent conflict with experimental evidence. Positive electricity is embodied in the heavy protons, while the negative charge is coupled to the electrons which are 1,800 times lighter. However, the discovery of the positive electron and recently of the negative proton has been a spectacular confirmation of charge symmetry, although there are, of course, still many points (for instance, the precise determination of the mass of the negative proton) which remain to be elucidated.

## *Validity*

Originally these symmetry laws were incorporated into the equations of physics without much concern for their validity, and certainly without the benefit of experiment. In the last few years, however, it has been possible to put them to experimental tests, and the results have been both surprising and disconcerting. Thus experiments concerned with the interactions between atomic particles, and especially those involved in radioactive beta-decay, have shown that left and right hand are not always equivalent to each other. The same experiments demonstrate that negative electric charges and positive electric charges are not equivalent to each other in all circumstances. These developments led physicists to question somewhat anxiously the validity of the symmetry of the laws of physics so far as time is concerned, but more recently it has been shown experimentally that there is no need to abandon this principle even in those circumstances in which the other two symmetry laws have been shown to be invalid. In other words, on the sub-microscopic scale the direction of the flow of time seems to be unimportant to the laws of physics.

It is therefore comforting that, where the symmetry of the laws of physics with regard to time is concerned, the apparent conflict with the laws of thermodynamics has been resolved by the classical work of Boltzmann, Gibbs, Smoluchowski, and Ehrenfest. The resolution of the apparent conflict between reversibility in time and the Second Law

of Thermodynamics can best be illustrated by a simple example due to Ehrenfest. Consider two boxes and distribute among them one thousand objects (which Ehrenfest calls fleas) numbered from 1 to 1,000. Take a sack containing a thousand numbered balls and play the following game of chance. Draw at random a ball from the sack, call its number, and then compel the flea with that number to jump from the box he is in to the other box. Return the ball to the sack, mix it well with the other balls, and make a second draw; call the number and let the corresponding flea jump. And so on. It is clear that the distribution of the fleas among the boxes will tend to equality, with five hundred in each box. It is also clear that if the original distribution was very unequal (999 to 1), it is a good bet that the next draw will make the distribution more equal.

## *Reversibility*

There is, therefore, a definite direction in time with regard to the change of the distribution. However, if in a very long series of draws the difference of the numbers of fleas in the two boxes is recorded at each step, all possible values will occur, and in a manner that does not indicate a unique direction in time. To be sure, it may be necessary to wait a long time for particular values of the difference to recur. The average time for a particular value of the difference to recur is called the recurrence time for that same value. It depends very sensitively on the magnitude of the difference between the populations of the two boxes. Large values entail very long recurrence times, while small deviations from equality or from the most likely distribution entail short recurrence times.

A similar argument can be applied to the diffusion of air. Consider two halves of a room. The molecules of air replace the fleas. Their presence in either half is, of course, not determined by a game of chance, but by their motion as governed by the laws of mechanics. However, it can again be shown that any distribution of the molecules between the two halves of the room will occur over and over again if only there is enough time. This was proved by Poincaré and is simply an expression of the fact that the laws of mechanics are reversible or symmetric in time. The apparent irreversibility of the gross macroscopic phenomena is a human illusion. Its origin is the fact that time spent on observation is necessarily very short compared with the recurrence time of unusual events. Therefore there need be no anxiety that in the next half-hour the air in the room will move spontaneously to one half of the room. In a very small volume of the room, however, it would be possible to detect a continuous mixing and unmixing of the oxygen and nitrogen, changes in density and temperature, which have short recurrence time and which therefore would seem quite reversible in time. The small deviations from equilibrium which occur spontaneously are the fluctuation phenomena. Their reality is strikingly shown by the so-called Brownian motion of small colloidal particles suspended in a fluid, which is visible through a microscope. I think everybody should see it at least once. It is one of the most impressive manifestations of the molecular constitution of matter. The perpetual zigzag motion, which often defies gravity, really seems to be governed by the laws of chance. In fact, the motion can be described by probabilistic models (so-called stochastic processes) in a very satisfactory way.

There is no doubt that this classical explanation of the apparent conflict between the laws of thermodynamics and the basic laws of mechanics (or quantum mechanics) is in principle correct. However, this does not mean that there are no problems left. For instance, even in simple models like that of Ehrenfest, where the rules of the game of chance are given, one can rarely determine the recurrence time. And the deeper problem of how and why the probability calculus can be used for the description of the completely determined motion of the molecules soon leads to the boundary of present-day statistical mechanics.

## *Fluctuations*

These questions are technical but they suggest one obvious problem. Can the Second Law of Thermodynamics be circumvented by using the fluctuation phenomena? Or, more specifically, since there continually occur fluctuations in conflict with the second law, could they not be stored somehow so as to provide a *perpetuum mobile* of the second kind which all the time would convert heat energy into mechanical energy—and which would be a boon to mankind?

For example, might it not be possible to rectify the current fluctuations in an electrical circuit in such a way as to drive an electric motor, however tiny? Unfortunately this dream is but a fantasy. Smoluchowski has analyzed a number of examples and he comes to the conclusion that if one means by a *perpetuum mobile* of the second kind an *automatically working machine,* working without human intervention, then the molecular constitution of the machine itself makes it impossible to use the fluctuations in the working substance. Of course, this is not a proof, since a general statement cannot be proved by considering examples. It is better to turn the question around, which was done by Szilard. Assuming that such an automatic machine is not possible, what can be said about the fluctuation phenomena?

If the basic laws of nature do not show the arrow of time, and if the Second Law of Thermodynamics is not in conflict with this, from what then does our sense of time in organic nature come? This is clearly a slippery question! In fact, speculation about it quickly leads to cosmological problems – to questions of the origin and the structure of the Universe. As a result it is almost inevitable that one is led to what Niels Bohr has called "deep statements,"* by which term he intended to indicate statements whose opposites are neither true nor false.

It is convenient to start from a speculation of Boltzmann. The world around us is certainly far from the most probable or equilibrium state. In fact, life depends on the sun and its high temperature, from which most of energy sources come. But if the Universe has lasted for an infinite time it must as a whole be in equilibrium, at least if we may consider it to be a closed system. It follows, says Boltzmann, that our part of the Universe may be a huge fluctuation of the kind which, like the mixing and unmixing of the air in different volume elements in a room, must occur spontaneously in different parts of the Universe. And perhaps with regard to the Universe, the world around us is just a small-volume element. For the whole Universe there is no future or past. But just as on the earth the direction against gravity is called upwards, so living organisms will define as the future the direction in time towards which the surroundings evolve from the less probable to the more probable, or the direction in which fluctuations regress towards the equilibrium state. And the reason that living organisms observe and feel the direction of time is that a large deviation from equilibrium is necessary if the process of living is to take place.

This was the device by means of which Boltzmann was able to resolve the *Wärmetod* dilemma, or the intellectual difficulty of understanding how it could be that the Second Law of Thermodynamics would require that the Universe should tend towards a condition of equilibrium differing radically from the conditions easily discernible in the locality of the Solar System. His explanation was that the Universe as a whole may be assumed to have reached equilibrium without denying the possibility that a comparatively local fluctuation might make it possible to account for such phenomena as radiation from hot stars into the surrounding space, and the existence of life itself.

### *Organization*

This view of Boltzmann's is seductive, and in one way or another it is echoed in many contemporary opinions. In the moving book *Tristes Tropiques,* for example, the anthropologist Lévi-Strauss declares that "le monde a commencé sans l'homme et il s'achèvera sans lui." He goes on to explain that it might be sensible to rechristen the study of human civilizations "entropology" on the grounds that anthropologists are, in their highest endeavors, chiefly concerned with the process of distintegration, or the destruction of natural "organizations," that is inescapable in civilized life and which can be considered as a spontaneous increase of entropy. For Lévi-Strauss, evidently, biological evolution is only a fluctuation that must eventually pass away. The view that life may have started independently in different regions of the Universe echoes the same point of view. In Boltzmann's language, a fluctuation that occurs at one place could (and probably will) happen elsewhere.

Plausible though this may be, and leaving aside the question whether or not Boltzmann's ideas could survive critical analysis, physicists cannot now avoid considering them to be a bit old-fashioned. Two rea-

*Bohr used the term in contrast to "clear statement." A clear statement is one whose opposite is either true or false. The opposite of a deep statement is again a deep statement.

sons for this are evident. In the first place, it is now customary to speculate and to theorize about the Universe as a whole. This may be presumptuous but it has also been fruitful. To rely for an explanation of observable phenomena on the assumption that the observable part of the Universe is in an exceptional condition would imply a return to an outmoded way of thought that has not really been respectable since Kepler's time.

There is also the issue of the origin of the Universe in time. A few years ago the "big-bang" theory of the development of the Universe was widely accepted, chiefly because of the surprising coincidence of a number of different ways of estimating the "age of the Universe." For example, the age estimated from the observed expansion of the Universe was only a little greater than the age of the Solar System deduced from the distribution of radioactive elements on the surface of the Earth. More recent measurements have upset this happy picture, however. The age of the Universe has been raised from something like five billion years to more like twenty billion years, and the comforting agreement of various estimates from different sources has disappeared. It no longer seems safe to relate the innate sense of the direction of time with which human beings are born to the asymmetry that comes from the supposedly sudden beginning of the development of the Universe some billions of years ago.

This may be somewhat unfortunate, for the view that the Universe may have developed from a certain origin in time has always had an air of grandeur, especially when it has been coupled with the concept of an expanding universe and the notion that there may have been a unique origin of life. Evidently this combination of assumptions is a means of escaping the *Wärmetod* dilemma and indeed, as Landau has pointed out, an expanding universe cannot be considered as a closed system. The over-all gravitational field is, on the contrary, to be thought of as an expanding vessel in which the material universe is contained. But just as a gas in an expanding vessel can never attain a state of equilibrium, an open expanding universe cannot do so either. This may also explain the preference for a definite screw sense in organic nature. If life occurred only once, then it may be that originally by accident, say, the right-hand form of the organic molecule was synthesized and then propagated itself, while the left-hand form either was not formed or was suppressed. Of course, with the hypothesis of a multiple origin of life, the right-left symmetry would demand that on the average the right-hand form would occur equally as often as the left-hand form, so that if there are men on distant planets, their hearts and aortas may have the screw sense opposite to ours.

The conflict of the charge symmetry of the basic laws of nature with the lack of symmetry of protons and electrons may also perhaps be explained by the origin of the Universe at some definite time. Perhaps, as Goldhaber has recently suggested, the first act of the explosion was like the splitting of a neutral particle into a particle and an anti-particle. Of course, the original particle must be a huge system, and the two halves into which it splits should better be named by the terms "cosmon" and "anti-cosmon" which Goldhaber has proposed. Our Universe would then have further developed, say, from the cosmon, while somewhere far away there is another universe where all heavy particles are negatively charged (negative protons) and the light particles are positively charged (positrons). Finally the second part of Boltzmann's speculation could then perhaps be maintained. The whole biological evolution and our own consciousness of the arrow of time is perhaps just the reflection in us of the evolution of the Universe.

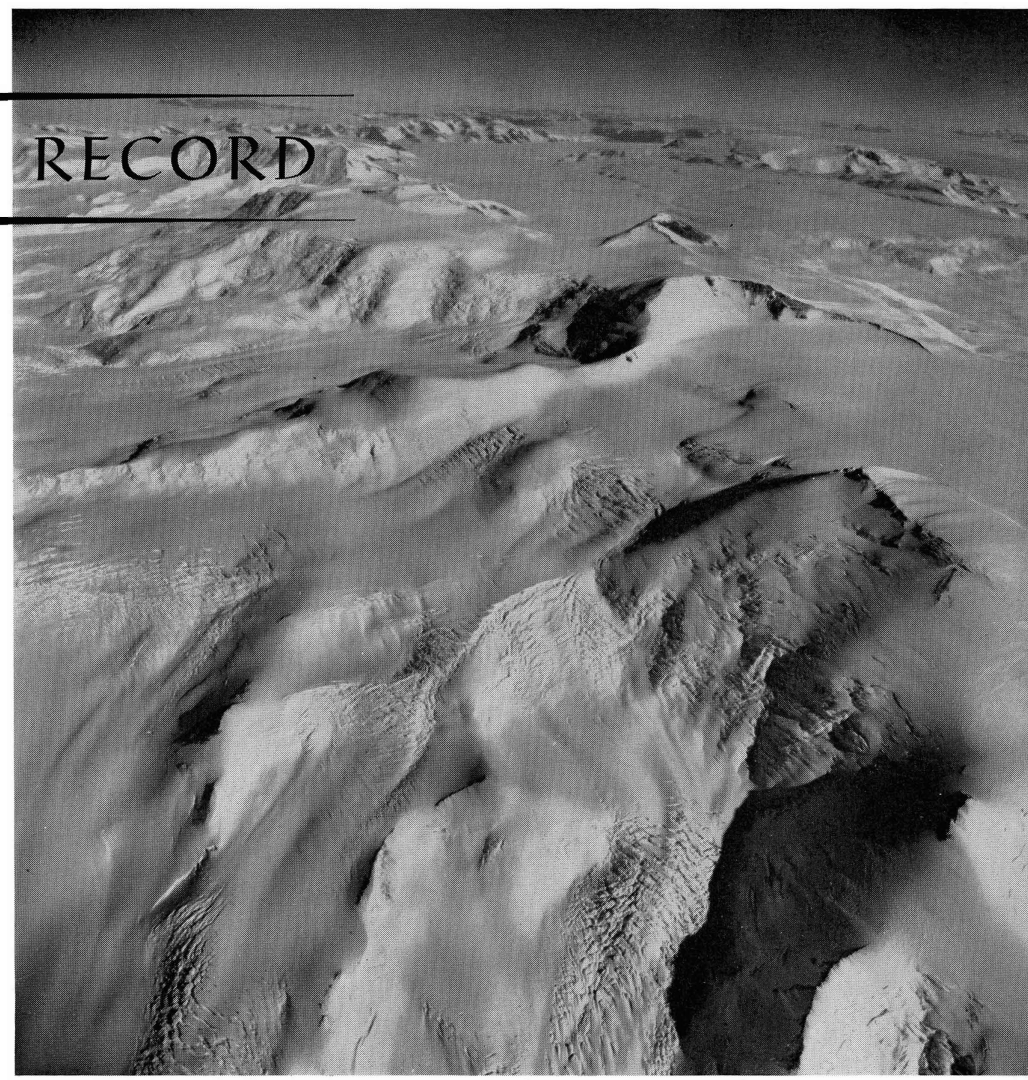
All this may sound grandiose and for many scientists it may also seem too similar to the religious view of the act of creation. Although this is of course not an *a priori* reason for its rejection, there is one aspect which makes it an uncomfortable solution. It is especially unsatisfactory that the awareness of the direction of time should stem from the imposition on laws of physics which do not carry the arrow of time of a special initial condition—the "big bang." This implies that the Universe in which we live is almost an accidental entity, produced by the coincidence of laws of nature (of which human beings are well aware) and fortuitous initial conditions.

Evidently it would be preferable if there were some means of accounting for the innate sense of the asymmetry in time by means of the laws of physics themselves, and this suggests that it may be

wise to keep in mind the possibility that the laws of physics as they are now enunciated may be valid only "in the small," or for intervals of time short compared with the time-scale of the universe. In other words, it may be that the laws of physics are not indifferent to the reversal of the sense of time when very long times are in question. This could be accomplished by a slow variation of the fundamental constants of physics with cosmic time, and it is relevant that a number of cosmological theories imply such a variation. To the extent that it entails a breakdown of the conservation laws, the continuous creation of matter in the Universe might also provide a sense of time in the evolution of the world.

It is too soon to say whether the problem of the arrow of time will ever be solved with the degree of certainty that would be convincing. Indeed, it may even be that the issue is so deeply embedded in human fate that it is presumptuous to ask for a strictly rational solution. Yet this is not a reason for throwing up the hands, and shirking the difficulty. To be sure, the issue prompts speculation, and even wild speculation, about the evolution of the Universe, but this is nothing to be ashamed of. For at their best speculations lead only to new concepts which, in turn, point constructively back to the laboratory.

# INSTITUTE RECORD



The National Science Foundation announced earlier this month that two mountains in Antarctica have been named as enduring peaks of recognition for Dr Detlev W. Bronk, President of the National Academy of Sciences and Chairman of the Board of the National Science Foundation, and Dr Alan T. Waterman, Director of the Foundation, for their outstanding services to Antarctic exploration during the International Geophysical Year. The statement was authorized by the Board of Geographic Names of the United States Department of the Interior. Visitors to Antarctica will wish to know that Mount Bronk and Mount Waterman are 350 miles north of the South Pole, and that they overlook one of the principal glacier systems feeding into the Ross Ice Shelf.

## PRIZE WINNER

Professor Theodosius Dobzhansky has been nominated for the Anisfield-Wolf Award for 1963. This was announced earlier this month by the *Saturday Review*, which said that Professor Dobzhansky had been chosen for his book

*Mankind Evolving: The Evolution of the Human Species.* In a statement of the award committee's reasons for its choice Mr Ashley Montagu said that by his writings and original work in several decades, Professor Dobzhansky has explained "how man, in all his vanity, got to be the way he is now" and also "has written one of the best accounts of the meaning of 'race' available to us."

### LECTURE

The first Ellery Sedgwick Lecture was delivered at the Institute on Thursday, 4 April 1963 by Professor Marjorie Nicolson. Her theme was the relationship between science and literature. She argued that though literature came within sight of "putting science to death" by ridicule in the years following the foundation of the Royal Society, the tables may now have been turned and literature may be threatened by science. The Ellery Sedgwick Lecture has been established as an annual occasion in memory of the late editor of the *Atlantic Monthly.*

### PROFESSOR

Dr William V. Houston, Honorary Chancellor of Rice University, has been made a Visiting Professor at the Institute and was in residence for a fortnight at the beginning of April. During that period he gave a short course of lectures on quantum mechanics. Professor Houston was Chancellor of Rice University until he resigned to carry on with his teaching career. He is President of the American Physical Society.

### INFORMATION

A two-day meeting at the Institute at the end of February led to the formation of a new national organization called the Scientists' Institute of Public Information. The purpose of the conference, which included a hundred participants from all over the United States, was to explore the problems of keeping the general public abreast of the implications of modern science. The function of the new organization will be to establish communications between groups already active in this field and, possibly, to raise money for this kind of work. Among the twenty-one members of the board of the Scientists' Institute are to be numbered five members of the Faculty of the Rockefeller Institute. These are Professors Theodosius Dobzhansky, René Dubos, Ludwig Edelstein, Edward Tatum and Dr Jules Hirsch.

### TRAVELERS

Professor Mark Kac is in residence at the University of Leiden during April and May as the 1963 Lorentz Visiting Professor in Theoretical Physics. Professor Fritz Lipmann has been visiting a number of universities in South America under a program of specialist technical assistance organized by the U. S. State Department. His stops have included Santiago, Buenos Aires, São Paulo, and Rio de Janeiro.

### MEDALIST

Dr William O. Baker, a Trustee of the Rockefeller Institute and Vice-President for Research at the Bell Telephone Laboratories, has been awarded the Perkin Medal by the American Section of the Society of Chemical Industry. His scientific reputation stems from pioneering work on the structure of solid materials consisting of polymeric molecules.

### PAINTER

The entrance lobby of the South Laboratory is now adorned with a number of paintings made by Mrs Patricia Berlin and based on microscope slides of sections prepared in Professor Palade's laboratories. Critics have remarked that Mrs Berlin has thus succeeded in producing paintings which have the stamp of modern art but which are firmly founded in experimental fact, and have been tempted to wonder whether this device might not disarm Mr N. S. Khrushchev's recent criticism of Russian artists.

### FACULTY APPOINTMENTS SINCE 1 FEBRUARY 1963

#### *Visiting Lecturer*

WILLIAM A. H. RUSHTON, Physiological Laboratories, Cambridge, England.

#### *Research Associates*

VICENTE HONRUBIA (Professor Lorente de Nó) Former Guest Investigator.

ANATOLE NICOLAIEFF (Associate Professor Stoeckenius) Attaché de Recherches, Centre National de la Recherche Scientifique (France), Strasbourg.

### GUEST INVESTIGATORS ARRIVING SINCE 1 FEBRUARY 1963

A. VASANTHI BHANDARY (Associate Professor Dan H. Moore) Damon Runyon Cancer Research Fellow.

PRISCILLA J. ORTIZ (Professor Hotchkiss) American Cancer Society Postdoctoral Fellow.

L. E. SCRIVEN (Professor Weiss) Associate Professor, University of Minnesota, Minneapolis.

MARIO WERNER (Professor Dole) Fellow of the Swiss Academy of Medical Sciences.

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### CONTRIBUTORS

Theodosius Dobzhansky is a professor at the Rockefeller Institute, the faculty of which he joined from Columbia University in 1962. George E. Uhlenbeck has been a professor at the Institute since the beginning of 1961.

Contributions to the *Review* are invited from members of the faculty and students at the Institute. Articles should be shorter – and preferably much shorter – than 4,000 words and should deal with matters likely to be of general interest to groups of readers similar to that at the Institute. Shorter contributions in the form of letters to the editor will also be welcomed.

### ILLUSTRATIONS

COVER PHOTOGRAPH: View of campus on south side of Abby Aldrich Rockefeller Hall by Stephan Pischinger. All photographs on PAGES 3, 4 and 5, and the cave painting of bison and wild boar on PAGE 9: courtesy of the American Museum of Natural History. PAGE 15: photograph taken on a U. S. Navy flight.