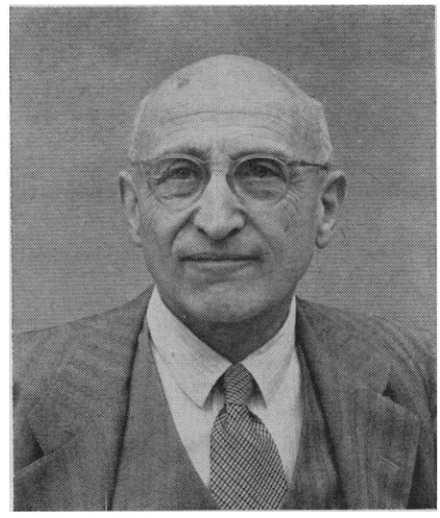
in the development of the magnitude scale was most fruitful. His computations of energy release by earthquakes were well summarized in his William-Smith lecture before the Geological Society (London) in 1955.

Gutenberg's particular discovery was the low-velocity layer in the earth just below the Mohorovičič discontinuity. His conclusion that this layer exists shows his remarkable feeling for seismograms. The effect of the layer on the amplitudes of *P* waves in earthquakes was apparent to him but not to others. He would reduce the records of various seismographs from various earthquakes to a common denominator. For 30 years, almost alone, he maintained the existence of this layer. Fortunately, in the last two years before his death he found his view generally accepted on the grounds of records of explosions recorded on similar instruments and of the effect of the layer on the dispersion of surface waves. We now have the Gutenberg low-velocity layer as well as the Gutenberg discontinuity at the core boundary.



Beno Gutenberg

Gutenberg's work was recognized as widely abroad as at home. He received the Prix de Physique du Globe (1952) from the Académie royale de Belgique. He was a member not only of our National Academy of Sciences but also of the academies of New Zealand, Finland, Sweden, and Rome. He had been president of the International Association of Seismology and the Physics of the Earth's Interior as well as of the Seismological Society of America.

It is fortunate for us that Gutenberg had just published his last book, *Physics of the Earth's Interior*, before he died. It leaves to young geophysicists an account of earth physics, with particular emphasis on problems needing further study.

The affection which Gutenberg's family felt for him was very strong. He reciprocated fully. He is survived by his widow Hertha, by his son Arthur, and by his daughter Stefanie.

PERRY BYERLY
University of California, Berkeley

The World into Which Darwin Led Us

The Darwinian revolution changed the most crucial element in man's world—his concept of himself.

George Gaylord Simpson

Almost everyone is aware that the year 1959 was the centennial of the publication of *The Origin of Species* by Charles Darwin. It was also the sesquicentennial of Darwin's birth and, coincidentally, of the publication of *Philosophie Zoologique* by Lamarck, the first really important work on organic evolution. That sesquicentennial has been little noted, but the centennial has been most elaborately celebrated by conferences, symposia, all manner of meetings and oratory, and a veritable spate of publications. Every aspect of Darwin, his contemporaries, and his predecessors has been presented. The gamut runs from lavish eulogy of Darwin to peevish accusation of plagiarism and dishonesty. More responsibly, almost everything Darwin ever said or did has been carefully re-evaluated.

In the face of all these studies, it is now practically impossible to say anything fresh about Darwin. (I must confess to a growing surfeit on that topic, approaching boredom.) Yet there are aspects of the subject of such transcendent importance that they bear frequent repetition. At this point there is reason for a summing up not so much about Darwin himself as about the continuing impact of the revolution of which he was the chief initiator.

It has often been said that Darwin changed the world. It has less often been made clear just what the change has been. Darwin did not—to his credit he did not—make any of the discoveries that have led to our present overwhelming physical peril. Most, although not quite all, of our technology would be the same if Darwin's work had not been done, by him or anyone else. Doubtless we would in that case still have our same traffic jams, horror movies, bubble gum, and other evidences of high civilization. The paraphernalia of civilization are, however, superficial. The influence of Darwin, or more broadly of the concept of evolution, has had effects more truly profound. It has literally led us into a different world.

How can that be? If evolution is true, it was as true before Darwin as it is today. The physical universe has not changed. But our human universes, the ones in which we really have our beings, depend at least as much on our inner perceptions as on the external, physical facts. That can be made evident by an elementary example. Suppose a stone is seen by a small boy, an artist, and a petrologist. The small boy may per-

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ceive it as something to throw, the artist as something to carve into sculpture, the petrologist as a mixture of minerals formed under certain conditions. The stone is three quite different things to the three people, and yet they are seeing exactly the same thing. The stone has identical properties whatever anyone thinks about it.

In that trivial example all three conceptions of the stone, although profoundly different, are equally true. The stone can indeed be thrown, be sculptured, or be analyzed petrologically by procedures suitable to each of the three perceptions. But there are differing perceptions of objects and of our whole world that are not equally true in the same sense, which is the scientific sense of material testability. Perceptions that are not materially testable or that have been contradicted by adequate tests are not rationally valid. As they petrify into tradition and dogma they become superstitions. Perception of the truth of evolution was an enormous stride from superstition to a rational universe.

The Changing Universe

Years ago I lived for a time with a group of uncivilized Indians in South America. Their world is very different from ours: in space, a saucer a few miles across; in time, from a few years to a few generations back into a misty past; in essence, lawless, unpredictable, and haunted. Anything might happen. The Kamarakoto Indians quite believe that animals become men and men become stones; for them there is neither limitation nor reason in the flux of nature. There is also a brooding evil in their world, a sense of wrongness and fatality that they call *kanaima* and see manifested in every unusual event and object.

That level of invalid perceptions might be called the lower superstition. It is nevertheless superior in some respects to the higher superstitions celebrated weekly in every hamlet of the United States. The legendary metamorphoses of my Indian friends are grossly naive, but they do postulate a kinship through all of nature. Above all, they are not guilty of teleology. It would never occur to them that the universe, so largely hostile, might have been created for their benefit.

It is quite wrong to think that uncivilized Indians are, by that token, primitive. Nevertheless, I suppose that the conceptual world of the Kamarakotos is more or less similar to that of ancient, truly primitive men. Indeed, even at the dawn of written history in the cradles of civilization, the accepted world pictures do not seem very different from that of those Indians.

The world in which modern, civilized men live has changed profoundly with increasingly rational, which is to say eventually scientific, consideration of the universe. The essential changes came first of all from the physical sciences and their forerunners. In space, the small saucer of the savage became a large disc, a globe, a planet in a solar system, which became one of many in our galaxy, which in turn became only one nebula in a cosmos containing uncounted billions of them. The astronomers have finally located us on an insignificant mote in an incomprehensible vastness—surely a world awesomely different from that in which our ancestors lived not many generations ago.

As astronomy made the universe immense, physics itself and related physical sciences made it lawful. Physical effects have physical causes, and the relationship is such that when causes are adequately known effects can be reliably predicted. We no longer live in a capricious world. We may expect the universe to deal consistently, even if not fairly, with us. If the unusual happens, we need no longer blame *kanaima* (or a whimsical god or devil) but may look confidently for an unusual or hitherto unknown physical cause. That is, perhaps, an act of faith, but it is not superstition. Unlike recourse to the supernatural, it is validated by thousands of successful searches for verifiable causes. This view depersonalizes the universe and makes it more austere, but it also makes it dependable.

(It would here be going too far afield to discuss the principle of indeterminacy or the statistical nature of some other modern physical principles, nor is this necessary for my thesis. Indeterminacy need not deny causality, and statistical prediction is still rationally lawful prediction.)

To those discoveries and principles, which so greatly modified concepts of the cosmos, geology added two more of fundamental, world-changing importance: vast extension of the universe in time, and the idea of constantly lawful progression in time. Estimates of geological time have varied greatly, but even in the 18th century it became clear to a few that the age of the earth must be in millions of years rather than the thousands then popularly accepted from Biblical exegesis. Now some geological dates are firmly established, within narrowing limits, and no competent geologist considers the earth less than 3 billion years old. (Upper estimates for the solar system range from 5 to 10 billion.) That is still only a moment in eternity, but it characterizes a world very different from one conceived as less than 6000 years old.

With dawning realization that the earth is really extremely old, in human terms of age, came the knowledge that it has changed progressively and radically but usually gradually and always in an orderly, a natural, way. The fact of change had not earlier been denied in Western science or theology—after all, the Noachian Deluge was considered a radical change. But the Deluge was believed to have supernatural causes or concomitants that were not operative throughout earth's history. The doctrine of geological uniformitarianism, finally established early in the 19th century, widened the recognized reign of natural law. The earth has changed throughout its history under the action of material forces, only, and of the *same* forces as those now visible to us and still acting on it.

The Higher Superstition and the Discovery of Evolution

The steps that I have so briefly traced reduced the sway of superstition in the conceptual world of human lives. The change was slow, it was unsteady, and it was not accepted by everyone. Even now there are nominally civilized people whose world was created in 4004 B.C. Nevertheless, by early Victorian times the physical world of a literate consensus was geologically ancient and materially lawful in its history and its current operations. Not so, however, the world of life; here the higher (or at least later) superstition was still almost unshaken. Pendulums might swing with mathematical regularity and mountains might rise and fall through millennia, but living things belonged outside the realm of material principles and secular history. If life obeyed any laws, they were supernal and not bound to the physics of inert substance. Beyond its original, divine creation, life's history was trivial. Its kinds were each as created in the beginning, changeless

except for minor and obvious variations.

Perhaps the most crucial element in man's world is his conception of himself. It is here that the higher superstition offers little real advance over the the lower. According to the higher superstition, man is something quite distinct from nature. He stands apart from all other creatures; his kinship is supernatural, not natural. It may, at first sight, seem anomalous that those scientists who held this view did classify man as an animal. Linnaeus, an orthodox upholder of the higher superstition, even classified *Homo* with the apes and monkeys. No blood relationship was implied. The system of nature was the pattern of creation, and it included all created things, without any mutual affinities beyond the separate placing of each in one divine plan.

Another subtler and even more deeply warping concept of the higher superstition was that the world was created for man. Other organisms had no separate purpose in the scheme of creation. Whether noxious or useful, they were to be seriously considered only in their relationship to the supreme creation, the image of God. It required considerable ingenuity to determine why a louse, for example, was created to be a companion for man, but the ingenuity was not lacking. A world made for man is no longer the inherently hostile and evil world of *kanaima,* but that again is offset in some versions of the higher superstition by the belief that man himself is inherently evil or, at least, sinful.

Those elements of the higher superstition dominated European thought before publication of *The Origin of Species,* but various studies of the centennial year have exhaustively demonstrated that evolutionary ideas existed and were slowly spreading among a minority of *cognoscenti* long before Darwin. Some believed that a species, although divinely and separately created, might change, and in particular might degenerate from its form in the original plan of creation. That is not a truly evolutionary view, since it does not really involve the origin of one species from another, but it does deserve to be called proevolutionary in that it recognized the fact that each separate species may change. In the 18th century Buffon went that far, but hardly further, in spite of some apologists who now hail him as an evolutionist.

Some 18th-century worthies—among them Linnaeus in his later years—did go one step further. They conceived that each of the separately created "kinds" of Genesis might later have become considerably diversified, so that the unit of separate creation might be what we now call a genus or even a family or higher group, and the species or subgroups might have arisen, or indeed evolved, since the creation. Just as the many breeds of domesticated dogs are all dogs and of common origin, so the wolves, coyotes, foxes, jackals, and other wild species might all descend from a single creation of the dog-kind. That would still admit no relationship between the dog-kind and the now likewise diversified but singly and separately created cat-kind, for example. (It is an intellectual curiosity that precisely that variation of creationist superstition has recently been seriously revived by an American who had been exposed, at least, to excellent training in zoology.)

By the end of the 18th century there were a few true and thorough-going evolutionists—Charles Darwin's grandfather Erasmus was one, as has so often been pointed out. Their number increased during the first half of the 19th century. Some of them even had glimmerings of Darwin's great discovery, natural selection, although (contrary to some recent historians whose aim seems to be to denigrate Darwin) none of them elucidated that principle clearly and fully.

Darwin

Practically all of the ideas in *The Origin of Species* had been dimly glimpsed, at least, by someone or other before 1859. The only surprising thing about that is that so many centennial authors have thought it worthy of special emphasis. Organization, understanding, and conviction are the main contributions of theorists like Darwin, and obviously none ever succeeded until there already existed something to organize and to understand. It is, however, less obvious why Darwin was the first evolutionist ever to carry conviction to a majority of his fellow scientists. The whole answer is more complex, but its essentials are evident in a statement later made by Thomas Henry Huxley to explain why he was an antievolutionist until he read *The Origin of Species:*

"I took my stand upon two grounds: firstly that up to that time, the evidence in favor of transmutation [evolution] was wholly insufficient; and, secondly, that no suggestion respecting the causes of the transmutation assumed, which had been made, was in any way adequate to explain the phenomena. Looking back at the state of knowledge at that time, I really do not see that any other conclusion was justifiable."

The reason why *The Origin of Species* carried conviction was that it did supply sufficient evidence of evolution and also provided an explanation of the phenomena of evolution. That twofold nature of Darwin's accomplishment has certainly been pointed out often enough, but the statement has also been criticized, and perhaps some small notice should here be given to some of the criticisms. It has, for one thing, been maintained that previous evidence *was* sufficient. It had persuaded Eramus Darwin, Lamarck, Chambers (author of the anonymous *Vestiges of Creation*), and others, so (some critics say) it should have persuaded anyone without Charles Darwin's needing to recompile it. That conclusion is simply ridiculous. What anyone thinks *should* have happened has nothing to do with the question of historical fact. Previous evidence *did not* convince a majority of interested scientists; therefore it was insufficient for that purpose. Darwin's evidence *did* in fact convince them; therefore it was sufficient. (It may of course be recognized, as Darwin himself implied, that the way had been prepared by a changing climate of opinion and that even his evidence might have been insufficient if adduced at an earlier date.)

It has further been suggested that evolution could have been, perhaps should have been, established as a fact without requiring an explanation, and also that Darwin's explanation was not really adequate. The first proposition is debatable, certainly, and examples can be produced to support both sides. The inheritance of acquired characters was accepted by practically everyone, down to and including Darwin, even though no one had adequately explained it. Darwin himself did not like to deal with unexplained facts, and he did belatedly attempt to explain the inheritance of acquired characters. Since in this case the "facts" were not true, that particular Darwinian theory is now charitably forgotten. (Fortunately it was not really essential to his broader theory explanatory of evolution as a whole.) In any case, belief in the inheritance of acquired characters did not

depend on any explanation of the supposed phenomena. (Is there perhaps a warning in the fact that the unexplained phenomena did not in truth occur?) On the other side of the argument is the modern example of extrasensory perception. A great mass of facts is claimed to demonstrate the reality of that unexplained phenomenon, and yet it is not generally accepted. It seems quite clear that it will not carry conviction unless some credible explanation is produced.

It does seem to me highly improbable that the fact of evolution would have been accepted so widely and quickly if it had been unaccompanied by an explanatory theory. Again, to question whether it *should* have been would be childish arguing with history.

The adequacy of Darwin's original explanation of evolution is also decidedly subject to debate. It was certainly an incomplete explanation, as Darwin was keenly aware. We now have much more extensive explanations, built in large part on Darwin's. Parts of Darwin's complex theory are also now known beyond serious doubt to have been wrong, although the more essential parts, those most stressed by Darwin, have been largely substantiated. That is important, and I shall have more to say about it later on. Darwin's theory was adequate at the time in the sense of being convincing. The conviction did not depend entirely on the truth or falsity of different parts of his explanation, which was not wholly accepted by students who nevertheless were immediately persuaded of the truth of evolution. The essential point was demonstration that material causes of evolution are possible and can be investigated scientifically.

The Fact of Evolution

The fact—not theory—that evolution has occurred and the Darwinian theory as to how it has occurred have become so confused in popular opinion that the distinction must be stressed. The distinction is also particularly important for the present subject, because the effects on the world in which we live have been distinct. The greatest impact no doubt has come from the fact of evolution. It must color the whole of our attitude toward life and toward ourselves, and hence our whole perceptual world. That is, however, a single step, essentially taken a hundred years ago and now a matter of simple rational acceptance or superstitious rejection. How evolution occurs is much more intricate, still incompletely known, debated in detail, and the subject of most active investigation at present. Decision here has decidedly practical aspects and also affects our worlds even more intimately, and in even more ways, than the fact of evolution. The two will be separately considered.

The import of the fact of evolution depends on how far evolution extends, and here there are two crucial points: does it extend from the inorganic into the organic, and does it extend from the lower animals to man? In *The Origin of Species* Darwin implies that life did not arise naturally from nonliving matter, for in the very last sentence he wrote, ". . . life . . . having been originally breathed by the Creator into a few forms or into one . . . ." (The words *by the Creator* were inserted in the second edition and are one of many gradual concessions made to critics of that book.) Later, however, Darwin conjectured (he did not consider this scientific) that life will be found to be a "consequence of some general law"—that is, to be a result of natural processes rather than divine intervention. He referred to this at least three times in letters unpublished until after his death, the one from which I have quoted being the last letter he ever wrote (28 March 1882 to G. C. Wallich; Darwin died three weeks later).

Until comparatively recently, many and probably most biologists agreed with Darwin that the problem of the origin of life was not yet amenable to scientific study. Now, however, almost all biologists agree that the problem can be attacked scientifically. The consensus is that life did arise naturally from the nonliving and that even the first living things were not specially created. The conclusion has, indeed, really become inescapable, for the first steps in that process have already been repeated in several laboratories. There is concerted study from geochemical, biochemical, and microbiological approaches. At a recent meeting in Chicago, a highly distinguished international panel of experts was polled. All considered the experimental production of life in the laboratory imminent, and one maintained that this has already been done—his opinion was not based on a disagreement about the facts but on a definition as to just where, in a continuous sequence, life can be said to begin.

At the other end of the story, it was evident to evolutionists from the start that man cannot be an exception. In *The Origin of Species* Darwin deliberately avoided the issue, saying only in closing, "Light will be thrown on the origin of man and his history." Yet his adherents made no secret of the matter and at once embroiled Darwin, with themselves, in arguments about man's origin from monkeys. Twelve years later (in 1871) Darwin published *The Descent of Man,* which makes it clear that he was indeed of that opinion. No evolutionist has since seriously questioned that man did originate by evolution. Some, notably the Wallace who shared with Darwin the discovery of natural selection, have maintained that special principles, not elsewhere operative, were involved in human origins, but that is decidedly a minority opinion about the causes or explanations, not the fact, of evolution.

It is of course also true that the precise ancestry of man is not identified in full detail and so is subject to some disagreement. That is a minor matter of no real importance for man's image of himself. No one doubts that man is a member of the order Primates along with the lemurs, tarsiers, monkeys, and apes. Few doubt that his closest living relatives are the apes. On this subject, by the way, there has been too much pussyfooting. Apologists emphasize that man cannot be a descendant of any living ape—a statement that is obvious to the verge of imbecility—and go on to state or imply that man is not really descended from an ape or monkey at all, but from an earlier common ancestor. In fact, that common ancestor would certainly be called an ape or monkey in popular speech by anyone who saw it. Since the terms *ape* and *monkey* are defined by popular usage, man's ancestors *were* apes or monkeys (or successively both). It is pusillanimous if not dishonest for an informed investigator to say otherwise.

Evolution is, then, a completely general principle of life. (I refer here, and throughout, to organic evolution. Inorganic evolution, as of the stars or the elements, is quite different in process and principle, a part of the same grand history of the universe but not an extension of evolution as here understood.) Evolution is a fully natural process, inherent in the physical properties of the universe, by which life arose in the first place and by which all living things, past or present, have since developed, divergently and progressively.

This world into which Darwin led us is certainly very different from the world of the higher superstition. In the world of Darwin man has no special status other than his definition as a distinct species of animal. He is in the fullest sense a part of nature and not apart from it. He is akin, not figuratively but literally, to every living thing, be it an ameba, a tapeworm, a flea, a seaweed, an oak tree, or a monkey—even though the degrees of relationship are different and we may feel less empathy for forty-second cousins like the tapeworms than for, comparatively speaking, brothers like the monkeys. This is togetherness and brotherhood with a vengeance, beyond the wildest dreams of copy writers or of theologians.

Moreover, since man is one of many millions of species all produced by the same grand process, it is in the highest degree improbable that anything in the world exists specifically for his benefit or ill. It is no more true that fruits, for instance, evolved for the delectation of men than that men evolved for the delectation of tigers. Every species, including our own, evolved for its own sake, so to speak. Different species are intricately interdependent, and also some are more successful than others, but there is no divine favoritism. The rational world is not teleological in the old sense. It certainly has purpose, but the purposes are not imposed from without or anticipatory of the future. They are internal to each species separately, relevant only to its functions and usually only to its present condition. Every species is unique, and it is true that man is unique in new and very special ways. Among these pecularities, parts of the definition of *Homo sapiens*, is the fact that man does have his own purposes that relate to the future—but of man's peculiarities I have more to say below.

Early Naturalistic Theories

The heart of Darwin's explanation of how evolution occurs was natural selection. He always considered this his most important contribution, and posterity agrees with that judgment. It is true that Wallace independently but later reached almost identical views on natural selection and that several others had anticipated both Darwin and Wallace on some points. It is further true that the concept of natural selection has changed through the years since 1859 and that its major importance has occasionally been questioned. Nevertheless, natural selection was primarily Darwin's discovery, later understanding of it has developed from his, and by overwhelming consensus it is now considered the main controlling factor in most evolutionary events.

From the first edition of *The Origin of Species* Darwin expressed the opinion "that natural selection has been the main but not the exclusive means of modification." Yet in the first edition he stressed it almost to the exclusion of other factors. Summing up in the last chapter, he wrote: "Species have changed, and are still slowly changing by the preservation and accumulation of successive slight favorable variations."

That is ambiguous as to what preserves and accumulates the variations, although in context it was obvious that natural selection was supposed to do so. The ambiguity was removed by rewording in the second edition: "Species have been modified, during a long course of descent, by the preservation or the natural selection of many successive slight favorable variations."

There was considerable criticism that Darwin imputed everything, or at any rate too much, to natural selection, and he tended to retreat from so strong a stand. In the fifth edition he changed his previously flat statement by saying that modification of species occurred only "chiefly" through natural selection. In the sixth edition, 1872, the last to be fully revised, Darwin complained that he had been misrepresented, and that he had never thought modification of species due exclusively to natural selection. He made this clear, and unfortunately retreated from a stronger position, by expanding the summary of factors believed to modify species: "This has been effected chiefly through the natural selection of numerous successive, slight, favourable variations; aided in an important manner by the inherited effects of the use and disuse of parts; and in an unimportant manner, that is in relation to adaptive structures, whether past or present, by the direct action of external conditions, and by variations which seem to us in our ignorance to arise spontaneously."

That summarizes the full and final Darwinian theory, which thus recognizes four factors or causes of evolution, in sequence of importance in Darwin's opinion: (i) natural selection; (ii) inheritance of acquired characters due to use or disuse of organs; (iii) inheritance of acquired characters due to direct effects of the environment; (iv) what we now call mutations in the broadest sense.

Darwin rejected, without even mentioning them, various dualistic, vitalistic, or otherwise nonmaterialistic theories of evolution already proposed by 1872. He accepted only factors that were believed to be strictly materialistic or naturalistic, but among those he played safe. He accepted them all, although he considered the last two unimportant as explanations of adaptation. Later in the 19th century there was an interesting parceling out of Darwin's four factors into three distinct theories, each emphasizing one or two of those factors at the expense of the others.

One school took the attitude of which Darwin had, as he felt, been falsely accused. They emphasized Darwin's first factor, natural selection, and flatly rejected almost any others, explicitly the inheritance of acquired characters, whether acquired from habit or from environmental influence. Their theory, more Darwinian than Darwin's, came to be called flatly Darwinism or, more specifically, Neo-Darwinism.

A second school of theory accepted and emphasized the inheritance of acquired characters, Darwin's second and third factors, and minimized without necessarily wholly rejecting the influence of natural selection and of mutation. That theory is now usually called Lamarckian or Neo-Lamarckian, but the designations are misleading. I shall not here take the time to discuss Lamarck's own theory, which never gained any important adherents in its original form. Neo-Lamarckism, which has more strongly influenced evolutionary studies, rejects the very heart and basis of Lamarck's personal theory, which was an idealistic and vitalistic view of continuous and continual climbing of a "ladder of nature," from simple to complex beings. Neo-Lamarckism also stresses a factor that Lamarck rejected: inheritance of direct effects of the environment. Neo-Lamarckism is more Darwinian than Lamarckian and is, indeed, about as Darwinian as Neo-Darwinism. It emphasizes Darwin's second and third factors rather than his first one, but it does not wholly reject any Darwinian factor, and it includes nothing that was not explicitly accepted by Darwin.

The third theory here in question emphasized Darwin's fourth factor, his

"variations which seem to us in our ignorance to arise spontaneously," now called mutations. This was not, however, a development of parts of Darwinian and to some extent pre-Darwinian theory, as both Neo-Darwinism and Neo-Lamarckism were. To Darwin, mutation (not yet under that name) was only one way, and the least important way, in which materials for evolution arose. The mutationists were striking out along quite new lines, developing modern genetics and rediscovering Mendelism. The extreme mutationists, notably De Vries, held that mutations were the *only* way in which significant evolutionary change occurs. They reduced natural selection to the minor and negative role of eliminating mutants so grossly malformed as to be inviable. They agreed with the Neo-Darwinians in denying the reality of the inheritance of acquired characters.

Those three theories, tagged as Neo-Darwinism, Neo-Lamarckism, and mutationism, seemed in the early 20th century to be the principal if not the only alternatives as naturalistic explanations of evolution. They have in common the fact that they are naturalistic. That is, they hold that evolution is a consequence of the material, physical properties of the universe and that it is explicable without postulating any immediate nonphysical, non-natural influences. Beyond that quite basic philosophical point, the three theories do lead to three different views of the world and of man's nature and potentialities.

In the Neo-Darwinian view, the crucial point in evolutionary change is the comparative success of genetical variants in producing offspring. Given a store of varying genetical materials within a population, natural selection usually tends to produce and to increase genetical combinations that are likely to ensure survival and continued reproductive success for the group as a whole. Genetical variation in itself is not considered adaptive in origin, and it is not *directly* influenced by any needs, desires, or activities of individuals in the population. Yet genetical change through the generations is decidedly nonrandom, as a rule, and tends to be adaptive for the population. To that extent, the Neo-Darwinian theory is still accepted by a majority of biologists today. It has not been rejected but only modified by being integrated into a synthesis that is both broader and deeper. The Neo-Darwinian world view originally stressed individual survival, especially competitive success. The later synthesis has involved considerable modification of that emphasis.

The Neo-Lamarckians give prime importance to exactly those factors that were minimized by the Neo-Darwinians: the needs, desires, and activities of individuals. Those factors, together with the modifying influences of soil, climate, food, and other environmental features, are supposed to lead directly to evolutionary change. Thus, genetical modification is supposed to be adaptive in its very essence. The entire process is oriented by the direct, unmediated reactions of individual organisms to their environments. The simplicity of this view is appealing, and it also has a special emotional attraction. It suggests that personal accomplishment counts not only in one's own lifetime but also in posterity and in the eventual evolution of the human species. Improvement in physique by exercise, diet, and so on, may lead to stronger descendants, and education may lead to more intelligent ones. A world in which that was true would on the whole be a pleasant one, and also one in which human progress would be comparatively easy to control. Undoubtedly it is that appeal and its political implications that have made a form of Neo-Lamarckism popular among the rulers of the Soviet Union. As I have already pointed out, there is justification for not labeling this theory with the name of Lamarck. The Russians variously call it "Soviet creative Darwinism" (as opposed to capitalistic and unacceptable Neo-Darwinism), "Michurinism," or "Lysenkoism." Although it is improbable that any of the really able Russian biologists fully accept that theory in private, it is publicly approved Communist dogma.

The only trouble with Neo-Lamarckism in any of its various seductive guises is that it is not true. Now that we understand the mechanism of inheritance, which Darwin could not know, it is certain that acquired characters cannot possibly be inherited in the way demanded by this theory, and that is that.

The extreme mutationist world view is very different from either the Neo-Darwinian or the Neo-Lamarckian. In it evolution is dominated by chance. Change within species or from one species to another is believed to be not only initiated but also carried through by a mutation or, eventually, a sequence of mutations. Mutations certainly have definite physical causes, even though these are unknown in most specific instances, and they have determinate effects. They arise, however, by chance, and their effects are random in the sense that the cause of a mutation has no evident relationship to the nature of the result and that the effects are unoriented with respect to usefulness or adaptation in the organism. The same cause, such as radiation, may result in any and all kinds of mutations, none producing changes adaptively related to the original radiation. Furthermore, if, for instance, animals are in a situation where increase in size would be adaptive, mutations for larger size do not thereby become either more or less frequent. Mutants are in these senses random or accidental. If there just happens to be some niche into which they can fit, they survive, and a step in evolution has occurred. A recent form of the theory calls such lucky mutants "hopeful monsters." If the mutant does not happen to fit anywhere, it dies, and that is all. Evolution in the mutationist world is not merely aimless but also directionless.

That mutations occur and are random in the stated sense of that word are facts established by innumerable observations. Mutationism, unlike Neo-Lamarckism, rests on a basis of real phenomena. Nevertheless, the further deductions drawn by the original and the extreme mutationists are flatly contradicted by other phenomena, notably those of adaptation. The origin of such an organ as an eye, for example, entirely at random seems almost infinitely improbable. Added to such considerations are many paleontological examples showing evolution occurring through millions of years not fitfully and haphazardly but in a perfectly definite and manifestly adaptive way. The theory that the direction of evolution is fully controlled by mutation simply cannot be true.

Synthesis

Adaptation and the apparent purposefulness of evolution are basic problems that a successful theory *must* solve. The rising science of genetics early in this century not only failed to solve the problem but also made it appear insuperably difficult. That explains why almost no students of other disciples were inclined to accept mutationism,

and why Neo-Lamarckism, an elegant but as we now know incorrect solution, hung on for so long. It also was one of several reasons for continued popularity of non-naturalistic theories, to which I allude below.

The way out of the dilemma seems simple now that it has been found. Mutationism is not an alternative to Neo-Darwinism but a supplement to it. If mutation is the source of new variation and yet is substantially nonadaptive, and if the actual course of evolution is to a large extent adaptive, then some additional factor or process must frequently intervene between the occurrence of mutations and the incorporation of some of them into evolving populations. The intervening process must be literally selective, because it must tend (not necessarily with full efficiency) to weed out disadvantageous mutations and genetic combinations and to multiply those that are advantageous in existing circumstances. Natural selection is just such a process, and the principal modern theory of evolution, although it contains much besides, is in large part a synthesis of selection theory and mutation theory.

Evolution is an extremely complex process, and we are here interested mainly in the effects of the concept on our world rather than in the process for its own sake. For that purpose I must, however, briefly note the main elements of the process now known. Genetic systems, governing heredity in each individual case, are composed of genes and chromosomes, discrete but complexly interacting units at different levels of size and complexity. The genes themselves, their organized associations in chromosomes, and whole sets of chromosomes have a large degree of stability as units, but all the kinds of units are shuffled and combined in various ways by the sexual processes of reproduction in most organisms. Thus, a considerable amount of variation is maintained, and, so to speak, genetic experimentation occurs in all natural populations. Mutations, in the broadest sense, affecting individual genes, chromosomes, or sets of chromosomes, introduce wholly new variation, which is fed into the processes of recombination.

Populations of similar animals, usually interbreeding among themselves and definable as species, have genetic pools, characterized by the total of genetic units in the included individuals and the distribution of combinations of those units through the population. Evolutionary change involves changes in the genetic pool, in kinds of included units, in frequencies of them, and in kinds and frequencies of combinations of them. Recombination alone does not tend to change the genetic pool. Only three processes are known to do so: mutation, fluctuation in genetic frequencies (what are known statistically as "sampling errors"), and differential reproduction. The first two of those processes are not oriented toward adaptation. They are in that sense essentially random, and are usually inadaptive, although they may rarely and coincidentally be adaptive. By "differential reproduction" is meant the consistent production of more offspring, on an average, by individuals with certain genetic characteristics than by those without those particular characteristics. That is the modern understanding of natural selection, including but broader than the Darwinian or Neo-Darwinian concept, which emphasized mortality and survival more than reproduction. Natural selection in the Darwinian sense and still more in this expanded sense is nonrandom, and its trend is adaptive. It also tends, not always with complete success, to counteract the random effects of mutation and sampling error.

Evolutionary processes are tremendously more complicated in detail than this bald outline suggests. The point of the outline is that here is a mechanism, involving only materials and processes known beyond a doubt to occur in nature, capable (as one of its proponents has said) of generating just the degree of improbability evident in the phenomena of evolution.

Further information pertinent to our theme is provided by paleontology, the actual record of events in the history of life. Observation and experimentation with living organisms can extend over a few years, at most. There is always a possibility that processes there evident worked out differently over spans of millions of years, or that the actual history involved principles undetectable in shorter periods of time. There is admittedly some difference of opinion, but I think it fair to say that there is now a consensus for the view that the fossil record is fully consistent with the modern synthetic theory of evolution and that it neither requires nor suggests any alternative explanation.

There is one thing demonstrated by the fossil record that is decidedly pertinent here and that probably would never have been inferred from study of living organisms. Throughout the whole history of life most species have become extinct, without issue. The statistically usual outcome of evolution is not, then, the progressive appearance of higher forms but simply obliteration. There has, indeed, been progression and even (still more rarely) progress, but this has been in the comparatively few, exceptional lines of descent. The adaptive mechanism of natural selection has guaranteed that some lineages would win, that the world would indeed be filled and kept filled with adapted organisms, but just as inexorably it has insured that most lineages would lose. It has, moreover, had the result that even the winners, the lineages that have survived so far, have not necessarily been progressive, from a human point of view at least. The primitive ameba has remained adapted, hence has survived, while the lordly dinosaurs lost adaptation and therefore life. The degenerate tapeworm is to all appearances as well adapted as the—we like to think—progressive man.

Naturalism, Vitalism, Finalism

The theory just outlined obviously does not yet answer all questions or plumb all mysteries, even when the details here omitted are taken into consideration. It casts no light on the ultimate mystery—the origin of the universe and the source of the laws or physical properties of matter, energy, space, and time. Nevertheless, once those properties are given, the theory demonstrates that the whole evolution of life could well have ensued, and probably did ensue, automatically, as a natural consequence of the immanent laws and successive configurations of the material cosmos. There is no need, at least, to postulate any non-natural or metaphysical intervention in the course of evolution.

That conclusion has been questioned or opposed not only by many philosophers and theologians but also by a comparatively small number of scientists. The alternatives occasionally supported by scientists or scientific philosophers, and therefore pertinent here, comprise many shadings and variations of opinion, but most of them can be placed in the rubrics of vitalism and finalism.

The vitalists maintain that life is an

essence or principle in itself, absent in nonliving matter and not reducible to the interaction of fully material factors. They usually point to a directedness or apparent purposefulness in the development and activities of living things and conclude that the vital, nonmaterial essence within them is a controlling influence in evolution. The finalists maintain that the evolutionary history of life has a preordained over-all pattern which, at least until the appearance of man, was purposefully directed toward a future goal or end. There is no absolute logical necessity that vitalism and finalism should go together, but the ideas are related if only because both are to some degree non-naturalistic and, in that sense, nonmaterialistic. More often than not, vitalists are finalists and finalists are vitalists.

Darwin's legacy in this respect was somewhat but not altogether negative. He did not discuss these issues explicitly and in plain terms. From the whole body of his work, and perhaps more particularly from notes and letters not written for publication, it is clear enough that he felt an antipathy for these philosophical approaches. The very fact that he did not specifically go into these problems amounts to a tacit but positive stand that metaphysical postulates are not necessary for a scientific explanation of evolution.

To that extent it is quite true, as has been so often said, especially by his enemies, that Darwin was a materialist. *Materialist* has become a highly ambiguous word and in some circles a dirty one. It is better here to use the word *naturalist*, in the proper philosophical sense of a scientific inquirer who eschews recourse to the supernatural. Such an inquirer does not deny the possible existence of the supernatural but only excludes it from attempts at scientific explanation. Almost all scientists agree that such exclusion is pragmatically justified and indeed necessary. Appeal to the unknown or to the scientifically untestable always stultifies the progress of science, because it stops the search for material explanations that *are* scientifically testable—and that, as a matter of experience, have generally been forthcoming when the search has been continued.

Most scientific evolutionists since Darwin have followed his lead in this matter and have continued to seek material, natural explanations of evolution without necessarily taking any overt stand on vitalism or finalism. To the extent that vitalism and finalism are nontestable, that attitude is justified, and the scientist, as scientist, has no right to go further than to repeat the classic remark that he has no need of that hypothesis. However, I do not see how the matter can in all candor be dropped at that point even by the least philosophical of evolutionists, for there are repeated claims by vitalists and finalists that their views *are* testable and that there *is* need for that hypothesis.

In the space available I cannot discuss concrete items of evidence but can only rather flatly state conclusions. These conclusions are not accepted by all evolutionists, but I think it safe to say that they are by most. The sort of testable evidence that would suggest vitalism or finalism would be the steady progression of life, and of each of its evolving lineages, toward a final and transcendentally worthy goal. That is not, in fact, what the known record of life's history shows. There is no clear over-all progression. Organisms diversify into literally millions of species, then the vast majority of those species perish and other millions take their places for an eon until they, too, are replaced. If that is a foreordained plan, it is an oddly ineffective one. Single lineages, when they can be followed for long, often do show rather steady change, but not indefinitely. They become extinct, or if they survive, the directions and rates of their evolution change. They evolve exactly as if they were adapting as best they could to a changing world, and not at all as if they were moving toward a set goal. As for the directedness that does indeed characterize vital process, it is amply explicable by natural selection without requiring any less mundane cause.

That sort of evidence, with much else in detail, convinces me, at least, that the hypotheses of vitalism and finalism are not necessary. Everything proceeds as if they were nonexistent. That does not prove that they are untrue, but it makes their positive adoption unjustified.

Vitalism and finalism have one other aspect that has no particular scientific bearing but that does require mention. They are sometimes advanced with the avowed hope of retaining something from the world of superstitution. Vitalism then pretends to find a place in nature for the supernatural. Finalism tries to bring in by the back door the teleology that Darwin swept out the front door.

The World of Man

Let me summarize and conclude as to this world into which Darwin led us. In it man and all other living things have evolved, ultimately from the nonliving, in accordance with entirely natural, material processes. In part that evolution has been random in the sense of lacking adaptive orientation. As a rule, however, it has been oriented or directed toward achieving and maintaining adaptive relationships between populations of organisms and their whole environments. Nevertheless, this blind, amoral process has not guaranteed indefinite maintenance of adaptation for any given lineage of populations. On the contrary, it usually leads to eventual extinction and a repeopling of the world by the newly divergent offspring of a minority of earlier successful lineages. The mechanism of orientation, the nonrandom element in this extraordinarily complex history, has been natural selection, which is now understood as differential reproduction.

Man is one of the millions of results of this material process. He is another species of animal, but not just another animal. He is unique in peculiar and extraordinarily significant ways. He is probably the most self-conscious of organisms, and quite surely the only one that is aware of his own origins, of his own biological nature. He has developed symbolization to a unique degree and is the only organism with true language. This makes him also the only animal who can store knowledge beyond individual capacity and pass it on beyond individual memory. He is by far the most adaptable of all organisms because he has developed culture as a biological adaptation. Now his culture evolves not distinct from and not in replacement of but in addition to biological evolution, which also continues.

Concomitant with these developments is the fact that man has unique moral qualities. The evolutionary process is not moral—the word is simply irrelevant in that connection—but it has finally produced a moral animal. Conspicuous among his moral attributes is a sense of responsibility, which is probably felt in some way and to some degree by every normal human being. There has been disagreement and indeed confusion through the ages regarding to whom and for what man is responsible. The lower and the higher superstitions have produced their several an-

swers. In the post-Darwinian world another answer seems fairly clear: man is responsible to himself and for himself. "Himself" here means the whole human species, not only the individual and certainly not just those of a certain color of hair or cast of features.

The fact that man knows that he evolves entails the possibility that he can do something to influence his own biological destiny. The fact that uncontrolled evolution often leads to degeneration and usually to extinction makes it highly advisable that man take a hand in determining his own future evolution. If man proceeds on the wrong evolutionary assumptions—for instance, on those of Neo-Lamarckism or Michurinism—whatever he does is sure to be wrong. If he proceeds on the right assumptions, what he does may still be wrong, but at least it has a chance of being right.

A world in which man must rely on himself, in which he is not the darling of the gods but only another, albeit extraordinary, aspect of nature, is by no means congenial to the immature or the wishful thinkers. That is plainly a major reason why even now, a hundred years after *The Origin of Species,* most people have not really entered the world into which Darwin led—alas!—only a minority of us. Life may conceivably be happier for some people in the older worlds of superstition. It is possible that some children are made happy by a belief in Santa Claus, but adults should prefer to live in a world of reality and reason.

Perhaps I should end on that note of mere preference, but it is impossible to do so. It is a characteristic of this world to which Darwin opened the door that unless *most* of us do enter it and live maturely and rationally in it, the future of mankind is dim, indeed—if there is any future.

Science in the News

Environmental Radiation Studies Begun by Public Health Service in New Mexico and Missouri

Two long-range studies of the effects of environmental radiation on the health of large populations were begun in March by the U.S. Public Health Service in cooperation with state and local health agencies. One study is in San Juan County, New Mexico, site of one of the largest uranium-producing areas of the country. Earlier studies showed the radioactivity from radium in the surface water of the Animas River in San Juan County to be higher than the level in most areas in the United States. The other study is in the St. Louis, Missouri, region. Earlier studies showed levels of strontium-90 to be somewhat higher in the St. Louis milkshed than in other areas.

The San Juan project, on which preliminary work has already begun, involves detailed medical and laboratory examinations of approximately 100 families totaling about 400 individuals. Teams of federal and state physicians, nurses, and technicians will obtain complete medical histories of each individual in the cooperating families and will determine a typical week's diet. The typical diets will be analyzed to determine the amount of radioactivity taken in. Body wastes and breath samples will be collected and analyzed to determine the amount of radioactivity excreted.

Exhaustive study will also be made of vital statistics for the area. Some aspects of the research project will require follow-up interviews, medical examinations, laboratory studies, and statistical analyses over a period of several years.

Arrangements have been completed to develop laboratory facilities and offices for the staff of the project in the San Juan District Health Department Building in Farmington, N.M. Laboratory analyses will be performed there and at the new Public Health Service Laboratory in Las Vegas, Nev.

Howard McMartin of the Public Health Service will be the medical officer in charge of the field activities. He will be assisted by six full-time resident staff members and four part-time staff members. The San Juan County Health Department and the County Medical Society will cooperate in the project.

Describing the new study, Surgeon General Leroy E. Burney of the Public Health Service said that selection of San Juan County for the first of these radiation studies does not mean that the health of people in this area is known to have been adversely affected by environmental radiation. On the contrary, official health records and observations of local physicians indicate no unusual health problems.

Effective steps have already been taken to reduce the amounts of radioactive waste discharged into the rivers in this area from milling operations, Burney said. However, the extensive data recently obtained on environmental radioactivity in the area presents a good opportunity to determine through further study the amounts of radioactivity that are currently being taken in by people, the amounts retained, the total body burden, and the effects upon their health.

Plans for the St. Louis Project

The St. Louis project will begin with a preliminary survey of dairy farms in the St. Louis milkshed. The survey will consist of investigations of water supplies, sources of animal food, climate, farming practices, animal feeding practices, and other variables that may be associated with different types and levels of radioactivity in milk. The final phase of the milkshed study will consist of field experiments to determine whether, if necessary, the level of radioactivity in milk can be reduced by modifications in dairy-farm practices.

The St. Louis study is an outgrowth of negotiations over the past several months that culminated in agreements among the federal, county, and city health agencies. Under these agreements the federal government will reimburse the St. Louis County Health Department for the cost of personnel, mate-