27 January 1967, Volume 155, Number 3761 SCIENCE

Changing Man

Modern evolutionary biology justifies an optimistic view of man's biological future.

Theodosius Dobzhansky

Optimists believe that ours is the best of all possible worlds. And pessimists are those who fear that the optimists are right. This is a flippant, but valid, statement of a truth. Optimism is often a result of ignorance of cold and unwelcome realities. There is, however, another kind of optimism, which is pessimism surmounted. The world is far from perfect, but it is not unalterable. I am tempted to call this evolutionary optimism.

The clash of optimistic and pessimistic world views is nowhere more poignant than in the evaluation of the prospects of mankind. Human nature has flaws too evident to be shrugged off. What is the outlook for the future? Prophets of doom are not in short supply, and they receive strong support from some eminent biologists. It is alleged that the genetic endowment of the human species is deteriorating. The evolutionary future is consequently bleak. A catastrophe may be avoided only by drastic measures, applied without delay. Regardless of whether they may be effective biologically, these measures are not likely to gain rapid acceptance psychologically and sociologically.

Mankind is exposed to some biological dangers. Ways to avoid them, or to minimize their effects, must be found. Yet cogent arguments may be adduced in favor of the view that man's evolution is still ascending, rather than going downhill. Rapid advances of the biological sciences, though not in themselves sufficient to solve all problems, may make evolutionary progress easier to achieve.

The author is professor of biology and genetics at Rockefeller University, New York, N.Y. 10021. This article is the basis of a lecture presented 26 December 1966 at the Washington meeting of the AAAS.

Darwin versus Copernicus

Two crucial discoveries were decisive in shaping modern man's image of himself. The names of Copernicus and Darwin stand as symbols of these discoveries, although others anticipated them or contributed to their validation. It is often held that the Copernican and Darwinian ideas make a pessimistic world view compelling. I wish to argue that this is a mistaken judgment. The post-Copernican and post-Darwinian man would not like to find himself back in the childhood of the pre-Darwinian and pre-Copernican world. Childhood memories may be pleasing indeed, but we have simply outgrown them.

Man is not the center of a snug little world created expressly to serve as his abode. Our earth is a second-rate planet, and our sun is only one among myriads of suns in the universe. This universe runs according to precise and inexorable laws; the more comprehensible of these were discovered by Newton, while Einstein and other modern physicists and cosmologists added some less comprehensible ones. And finally, man himself is very much a newcomer; he inhabits a vanishingly small bit of the cosmic scene, for at most 2 million years, while the scene itself is somewhere between 5 and 10 billion years old.

Man's smallness and recency are undeniable. Are these valid grounds for regarding him as no more than a bit of slime with a capacity for self-deception? This seems to be the opinion of some avant-garde writers, painters, and musicians. Even a theologian has recently published a book entitled *The Lord of the Absurd*. What these sages overlook can be summed up in a single word: evolution.

An evolutionist need not be a Pangloss or a Pollyanna; he may recognize that the absurd is widespread. Evolution is not predestined to promote always the good and the beautiful. Nevertheless, evolution is a process which has produced life from non-life, which has brought forth man from an animal, and which may conceivably continue doing remarkable things in the future. In giving rise to man, the evolutionary process has, apparently for the first and only time in the history of the Cosmos, become conscious of itself. This opens at least a possibility that evolution may some day be directed by man, and that the prevalence of the absurd may be cut down.

Evolution comprises all the stages of the development of the universe: the cosmic, biological, and human or cultural developments. Attempts to restrict the concept of evolution to biology are gratuitous. Life is a product of the evolution of inorganic nature, and man is a product of the evolution of life. In a sense, the discovery of evolution reinstates man in the station from which he was demoted by Copernicus: man is again the center of the stage—at least of the planetary, and quite possibly of the cosmic, one. Most important of all, the stage and the actor not only have evolved but are evolving.

Man Continues to Evolve

Mankind evolves. For perhaps as long as 100,000 years the most rapid and radical changes have been cultural ones. Man is a product of his cultural development as well as of his biological nature. The preponderance of cultural over biological evolution will continue or increase in the foreseeable future. We would not wish this to be otherwise; adaptation to the environment by culture is more rapid and efficient than biological adaptation. Moreover, control of the cultural evolution is achievable probably more easily than control of the biological evolution.

And yet mankind has not ceased to evolve biologically. Cultural evolution is superimposed on, it has not supplanted, biological evolution. The claim that something called "man's intrinsic intelligence" has remained constant at least since Paleolithic times is most likely erroneous, although a proof one way or the other is difficult to come by. The cranial capacity of the Neanderthal race of *Homo sapiens* was, on the average, equal to or even greater than that in modern man. Cranial capacity and brain size are, however, not reliable criteria of "intelligence" or intellectual abilities of any kind. The painters of the Altamira and Lascaux caves may have been no less talented than Picasso, and the intellectual powers of Aristotle were at least equal to those of the Nobel prize winners. But it does not follow that all the contemporaries of Aristotle were his intellectual equals, or that all inhabitants of Altamira could paint equally well.

The argument in favor of the view that mankind continues to evolve biologically is deductive and inferential, but it seems strong enough nevertheless. There are but two necessary and sufficient conditions for the occurrence of evolutionary change. First, there must be available genetic variance affecting different traits, and, second, this variance must be relevant to Darwinian fitness in different available environments which change in time and in space. Both conditions are fulfilled: many human traits, including intellectual and behavioral ones, are genetically variable; at least some of these variations affect the chances of survival and of reproductive success; and human environments, most of all cultural environments, are changing constantly and rapidly. Cultural and biological evolution are linked by feedback relationships (*1*).

If, then, mankind changes biologically, are the changes beneficial or detrimental? Cassandras prophesying doom attract public attention more easily than do those who hold the unspectacular view that a disaster is not around the corner, and not even inevitable. The alarmist argument is by now so well known that a brief summary will suffice here. Mankind's distinctive attributes and capacities arose in evolution under the control of natural selection. Natural selection makes the evolutionary changes usually adaptive in the environments in which the species lives. It fosters the gene patterns which enable their carriers to survive and to reproduce, and it fails to perpetuate the patterns less well attuned to the demands of the environments. Genetic variants of low fitness constantly arise in all living species, owing to the pressure of mutation. Some generations may elapse between the origin of a harmful mutant by mutation and its elimination by selection; therefore, the populations of every living species carry genetic loads of relatively unfit or downright inviable or sterile variants.

Mankind, like any other biological species, has carried a genetic load since the dawn of time. It is claimed, however, that man's genetic load grows rapidly heavier. Civilized living, technology, medicine, help to the handicapped, protection of the weak—all these factors are blamed for the relaxation of natural selection. Pessimists go even further and declare that natural selection and civilization are incompatible. On the other hand, the mutation rates have, if anything, increased, owing to radiation exposure and to chemical mutagens. A vision is thus conjured of mankind's degenerating rather than improving biologically, of his sliding downhill rather than rising upward.

Negative Eugenics

If, in developing culture and civilization, mankind has somehow managed to imperil its genetic endowment, the situation can be corrected only by more and better civilization. Even if one does not accept the pessimist rendering of the situation as accurate, one may well ponder the ways and means for possible control of the evolution of the human species. Any deliberate measures to improve genetic endowment belong to the province of eugenics. Euthenics and "euphenics" (*2, 3*) are concerned with amelioration of the manifestation of existing genetic endowments. Eugenics, euthenics, and euphenics are complementary rather than alternative. It is in the highest degree unlikely that an "optimal" genotype will be found that could produce excellent physical and mental health and vigor in all environments, and equally unlikely that environments could be devised to elicit satisfactory products from any and all genotypes. Environmental engineering, education, and social betterment are not made any less necessary by eugenics; the converse is also true, at least in the long run.

There is no agreement as to which eugenical measures may be effective and, at the same time, in good taste and ethically acceptable. The measures proposed are roughly classifiable into negative and positive, and range from persuasion to coercion. Nobody (outside Hitler's Germany) advocates killing the weak and the defective. Sterilization, optional or mandatory, is legal in some states. There is nothing cruel about eugenic sterilization, and, hedged with proper medical and legal guarantees, it may be acceptable in some circumstances. Its overall effectiveness in reducing the load of major genetic defects in the human species is, however, inadequate. Recessive defects are carried mainly in heterozygotes and escape detection, while the dominant ones are due mostly to new mutations.

I am inclined to favor a more tender-minded form of negative eugenics, which is the spread of elementary knowledge of genetics and of genetic counseling. The carriers of genetic defects must be assured that their condition is not their fault, or sin, or shame. They may also be informed of the probable consequences of their begetting children. It is perhaps not silly optimism to hope that some of such prospective parents would draw the proper conclusions from the information made available to them. Nobody is more competent than the carrier of a genetic defect to decide whether he wants to pass it on to descendants.

Positive Eugenics

Some eugenists are skeptical about the good judgment of their fellow men. Indeed, the carriers of certain genetic defects are patently incapable of exercising such judgment. One may also feel that negative eugenics is not enough. In addition to keeping down the incidence of major genetic defects, one may aspire to attain a vastly more ambitious goal—no less a goal than to reform the genetic endowment of the human species and to engineer the genetic foundation of a New Man. This is positive eugenics. The difficulty of this enterprise should be obvious. There is, unfortunately, more than a grain of truth in Lederberg's remark (*3*) that "positive eugenic programs can be defended roughly in proportion to their ineffectiveness."

Perhaps the boldest of all such programs, one which certainly would be effective if it were put into operation, has been outlined in numerous popular and technical writings of H. J. Muller and Sir Julian Huxley (see, for example, *4* and *5*). We shall restrict our consideration here to the first stage of the Muller-Huxley program, which is relatively "modest" and would seem to be technically feasible at present.

This first stage relies on a "germinal choice" of the male parents. Semen of selected donors (or of all healthy males) is to be collected and stored at low temperatures in "sperm banks." After a time sufficient for reaching a dispassionate judgment concerning the biological and other virtues of the donors, the sperm will be withdrawn from the banks, unfrozen, and utilized for artificial insemination of as many women as the supply permits, or of as many as may wish to have it. The application of germinal choice may, however, start on a relatively less ambitious scale immediately. Artificial insemination of women whose husbands produce no functional sperm is practiced at present, the donors not being selected with genetic considerations in view and remaining unknown to the prospective mothers. Muller gives 10,000 per year as an estimate of the number of artificial inseminations in the United States. Make the selection eugenically motivated and you have an entering wedge for the more ambitious schemes.

Many objections can be made to Muller-Huxley eugenical schemes. Not all the objections are, of course, equally serious. The recommended techniques will be branded by some as "unnatural," with as much or as little justification as in the case of family planning. In my opinion there is nothing wrong in this "unnaturalness," or in letting women who must or who wish to produce children by artificial insemination have a choice of sperm donors, and thus of the biological father of their offspring. Keeping human semen for long periods in deep-frozen state is not to be accepted so lightly, since there is no evidence to rule out the possibility that such treatment may cause mutational changes, and thus increase rather than decrease man's genetic load.

What Should the Selection Select?

Even if we had safe and dependable *means* of selection, very difficult questions would arise regarding the *ends*. As with other ambitious schemes of positive eugenics, that of Muller and Huxley is likely to be shipwrecked on attempts to decide what sort of man is the ideal to be striven for. Does anyone know what will be best for mankind centuries or millennia hence? Muller wants man to be intelligent, compassionate, altruistic. This is unexceptionable, but shall we endeavor to breed a race of brawny athletes, or brainy intellectuals, or sensitive esthetes, or some combination of these qualities, or a population containing certain proportions of each kind? Negative eugenics meets fewer difficulties in this regard. It is easier to reach a consensus on which defects man would be better off without than on which traits and abilities he should possess.

In general, dominant defects give rise to the fewest doubts. One can hardly imagine circumstances in which such disorders as dominant muscular dystrophy, aniridia, epiloia, multiple polyposis of the colon, fragile bones, and neurofibromatosis may be useful. However, these conditions lower the fitness of their carriers so greatly that almost the only measure to be considered for their control is minimization of the rates of their origin by mutation. With recessive defects the thorny question has to be faced of whether they are maintained in populations only by the mutation pressure or also by increased fitness of the heterozygous carriers—that is, by hybrid vigor, or heterosis.

The classic example of this sort is, of course, the sickle-cell condition, which is almost completely lethal when homozygous but which confers some protection against falciparum malaria when heterozygous. Increased Darwinian fitness of heterozygotes appears, however, in most unexpected places; Myrianthopoulos and Aronson (*6*) have published fairly convincing evidence that the heterozygous carriers of the Tay-Sachs disease (infantile amaurotic idiocy) may show a reproductive advantage of about 6 percent in Ashkenazic Jewish populations. How widespread such situations are in human, or for that matter in *Drosophila*, populations is one of the outstanding still-unsolved problems of population genetics. Some authorities have declared them to be negligibly rare, but this only shows a cavalier disregard of increasingly substantial evidence to the contrary.

The average and above-average fitness and vigor in populations of sexually reproducing organisms, including man, are quite possibly the result of multiple heterozygosis for many genetic variants which decrease the fitness in homozygous condition. This does not quite mean that we should perpetuate recessive hereditary diseases in human populations, even if they do have heterozygous heterotic effects. It means that the problem is too complex for a simple-minded approach. The ideal of mankind free of all forms of genetic loads may be not only unattainable but also unacceptable, owing to the adaptively ambivalent effects of some of these load forms. Such a load-free mankind may turn out to be a dull stereotype, with no particular physical or mental vigor. At present we simply do not know enough to be sure either way, and more research, both in man and with animals, is needed.

Possible Antagonisms of Old and New Adaptations

Civilization has often been blamed for diverting human biological evolution from its "natural" and beneficial to its present and allegedly pernicious course. Pampered by civilization, medicine, technology, and growing security, the human species, or at least the pampered part of it, is losing its physical and mental stamina and its resistance to environmental shocks of various kinds. It is becoming flabby and vulnerable. It is indeed possible, though not proved, that even if we were brought up to lead the life of our Paleolithic ancestors we would be less efficient in their environments than they were.

Is this, however, a terrible loss? Except for "roughing it" during summer vacations, most of mankind, or at least the inhabitants of technologically advanced countries, rarely face these ancient environments; nor, barring a breakdown of civilization, are our descendants likely to face them. What is needed is, rather, the strength and energy to face the ever more complex, and chiefly psychological, problems with which our industrial civilization is confronting us. If this strength and the primitive ruggedness were genetically one and the same, or if they were compatible, we would of course like to have them both. The process of adaptation by natural selection frequently works out, however, in such ways that a high adaptedness in some respects has to be paid for by a lesser development of other adaptive traits, or even by toleration of some downright harmful features. This is a part of what is sometimes referred to as the opportunism of natural selection. The Darwinian fitness is a property of a genotype as a whole, in relation to its environment, and not of this or that genetic factor in isolation. Now, if forced to make a choice, we must certainly prefer an adaptedness to the present environments, not to those long defunct.

The choice may be clearest in the case of resistance to certain diseases. As pointed out first, apparently, by Haldane (*7*), until very recent times, selection for resistances to multifarious infectious diseases was probably one of the major factors in the biological evolution of man. With the infections more and more under control, this selection is relaxed and possibly reversed. Genetic resistance to a disease may have to be paid for by disadvantages in other respects. The sickle-cell condition mentioned above is a paradigm: a resistance of the population to falciparum malaria is bought by the death of the anemic homozygotes, and possibly by a slight anemia in the heterozygotes as well. When a population learns to combat malaria by mosquito control or by chemotherapy, must it strive at all costs to retain the genetic resistance as well? The answer evidently depends on one's confidence that our civilization is here to stay. Although Dubos (*8*) has, with good reason, warned against overconfidence in this matter, it is a fact that an increasingly large part of mankind now lives in environments in which infectious diseases and old environmental hazards are being gradually brought under control. For this part of mankind, a source of genetic improvement may be, paradoxical as this may sound, a weakening or elimination of resistances to environmental hazards, resistances which were indispensable to our not-so-remote ancestors.

Euthenics, Euphenics, and Algeny

There is considerable distrust of eugenics, especially among some social scientists. The reason is that the name, though of course not the substance, of eugenics has often been exploited by those who want to obstruct social change. They claim that social ills stem from bad heredity and cannot be corrected by anything in the environment (*9*). The fallacy is evident. No heredity is "good" regardless of the environment. Genetic improvements are worthless if the improved genotypes have no access to environments which elicit their strong and inhibit their weak qualities. Man adapts his environments to his genes more often than he adapts his genes to his environments. Euthenics—environmental engineering, ranging all the way from control of infectious diseases to education and to social and political reforms—is not an alternative but is an indispensable partner of eugenics. Osborn (*10*) has pointed out not only the need of this partnership but also the possibility that positive eugenics—selection of superior genetic endowments—may result from properly directed social change. I return to this idea below.

Lederberg (*2*) has suggested "euphenics" as a designation for that part of euthenics concerned particularly with "the engineering of human development." Euphenics can compensate for, or redeem, certain genetic defects. The simplest example is the provision of eyeglasses to those with weak eyesight. Some forms of weak eyesight are genetically conditioned. There exist treatments to relieve the symptoms of, and in this sense to "cure," certain genetic defects. Among these defects are some otherwise fatal, or at any rate crippling, hereditary diseases. Galactosemia is an example. Children homozygous for a certain recessive gene lack an enzyme that converts the milk sugar galactose into glucose; if the condition is discovered sufficiently early, galactose-free diets permit fairly normal development; otherwise the homozygotes suffer severe liver damage and mental retardation. There is every reason to hope that treatments will be discovered for many other genetic defects.

Spectacular achievements of molecular biology have raised the hopes for euphenics very high. According to Lederberg (*2*), we are witnessing a "medical revolution" which may lead to the invention of such new techniques as construction of artificial organs; synthesis of hormones, enzymes, antigens, and structural proteins; and breeding of suitable laboratory animals to serve as donors of organs or tissues that could be transplanted to human bodies. Finally, he thinks, we may come to "more confidently design genotypically programmed reactions, in place of evolutionary pressures, and search for further innovations."

Distant vistas equally alluring seem to be opened by the discovery that the functioning of genes or gene groups in the development of the individual is subject to repression or to stimulation at the intracellular level. If one learns the art of "switching" on or off at will the action of desirable and undesirable genes at specified periods of development, the possibilities of controlling realization of the heredity in the treated individuals would be impressive indeed (*11*).

Still another array of conceivable techniques are called genetic engineering by Tatum (*12*), genetic surgery by Muller (*4*), and "algeny" by Lederberg (*3*). This concept is the altering of genes in the body cells or in germinal tissues, or the introduction of desired genes from outside. In Luria's words (*13*), "If the code sequence of a given gene can be deciphered, it might then be feasible to synthesize in vitro a segment of DNA with a desired 'improved' sequence, but with enough similarity to the recognized sequence of the gene in question to be able to replace it in the genetic apparatus." These techniques would, then, straddle the dividing line between euphenics and eugenics and would represent an instrument of scarcely imaginable power for guidance of the evolution of the human species.

Is this "Brave New World" of algeny more than a daydream? Some biologists talk and write about it as though all the wonderful techniques are as good as ready to be applied tomorrow. It would be very unwise for a scientist to maintain that some inventions (short of *perpetuum mobile*) will never be made. Such claims have too often been belied by subsequent discoveries. It is permissible, however, to doubt that genetic surgery would easily solve all problems. I am forced to agree with Muller (*4*) that, even if the needed techniques were available, "it would be a task of transcendent magnitude, intricacy, and reconditeness to do all this by genetic surgery for any one individual. Moreover, every individual to be operated on would present his own unique complex of labyrinthine problems. . . ."

Translation of the existing genetic knowledge into social practice may give man considerable powers to make Man. New discoveries will doubtless enhance these powers incalculably. This obviously raises many thorny questions which cannot be dealt with here. A biologist should have the humility to recognize that these questions are more sociological than biological. Are we to have, in place of Plato's philosopher-king, a geneticist-king? And who will be the president of the National Sperm Bank and of the National DNA Bank? What checks and balances are to be imposed on the genetic legislative and the genetic executive powers? Who will guard the guardians?

Genetic Consequences of Equality of Opportunity

While eugenic and euphenic projects are being framed, evolutionary changes, cultural and biological, are going on. On the biological side, insufficient attention has been given to these changes. They are discussed mostly from the point of view of the alleged relaxation or stoppage of natural selection, which is at most a half truth. Natural selection is operating, although in modern man it does not always select the same gene patterns which it selected in the past. Its operation is conditioned by the tremendous social changes which are taking place throughout the world. We may consider here briefly the genetic effects of social mobility and of equality, versus inequality, of opportunity, a topic which I discussed in *Science* earlier from a different point of view (*14*).

None other than President Dwight D. Eisenhower proclaimed that "humanity shall one day achieve the unity of freedom to which all men have aspired from the dawn of time." Herbert J. Muller, the historian, comments (*15*) that this idea "truly reflects the history of Western civilization, especially in recent centuries. It points to a significant change in the basic mentality of ordinary men, or to some extent their 'nature'. Today it reflects the extraordinary stir all over the world, as 'backward' peoples are beginning to realize possibilities and demand opportunities that through ages they scarcely dreamed of. With this stir the revolutionary doctrine of the Rights of Men . . . has swept the world as has no other idea, or no religion. If it is still widely violated in practice, it is now universally accepted in theory as the bill of 'human rights' affirmed by the United Nations."

In caste and rigid class societies the ascription of status and the assignment of occupation is made according to the social position of the parents. In-group marriage maintains the genetic as well as the social stratification. The explicit, or more often implied, justification is the belief that the different estates concentrate genes for different aptitudes. The truth of this is questionable. What is, however, undeniable is the fact that individual differences within each class have remained greater than any possible average differences between the classes. This is true even of the most rigorous and most enduring caste system, that of India.

The transition, taking place at different rates in different countries, from closed to open class systems increases the social mobility and the consequent gene exchange. As equality of opportunity is approached, will the significance of the genetic differences among men be reduced to naught? The truth is the exact opposite. Equality of opportunity should not be confused with genetic identity. More than one eminent biologist has been hailed in the popular press for having discovered that "men are not equal," when all he wanted to say was that men are not genetically alike. Equality and inequality are social, identity and diversity biological, phenomena. Equality may be bestowed upon diverse people, and identical twins may have unequal opportunities.

Social mobility does not lead to genetic uniformity. Neither does interracial marriage. The genetic differences between populations are transmuted into genetic variability of individuals. The variety of genetic constitutions increases. The greater the diversity of environments—of social, economic, and educational opportunities—the fewer the genetic differences manifested in the observable variety of personalities and abilities. In exactly uniform environments all differences would be genetically determined. Environmental uniformity is a theoretically thinkable condition, not realized anywhere. The existing societal arrangements form a spectrum, ranging from very restricted to relatively free social mobility and from inequality to equality of opportunity. The trend is, however, toward the equality side; this is acknowledged by those who welcome this trend and by those who oppose it.

If all humans had the same genetic endowment, if man were born a *tabula rasa*, if every individual had the same potentialities for intelligence, for special abilities, and for all other socially significant traits, then the differences between most rigid caste societies and societies providing equality for their members would be inconsequential. With "equality," different occupations could be distributed by lot, or according to the day of the week on which one was born. Equality is invaluable because it enables people to be different and to follow their diverse inclinations.

The genetic variety of capacities and aptitudes is partly concealed and smothered under rigid caste and class systems. A son of a peasant, of an artisan, or of a musician is encouraged, and sometimes even pressured or forced, to become a peasant, an artisan, or a musician, as the case may be. If his tastes or abilities, no matter whether genetically conditioned or otherwise, make him attracted to or suited for a social role or a profession different from that of his parents, he may encounter a resistance severe enough to frustrate his plans. The situation would be equally unpropitious for individual self-actualization in a society so compulsively egalitarian that it would insist on reducing the diversity of abilities to a uniform level by differential treatment and education. It is in open class societies that genetic diversity can be most fully utilized for social good.

According to Gardner (*16*), "our devotion to equality does not ignore the fact that individuals differ greatly in their talents and motivations. It simply asserts that each should be enabled to develop to the full, in his own style and to his own limit. Each is worthy of respect as a human being. This means that there must be diverse programs within the educational system to take care of the diversity of individuals; and that each of these programs should be accorded respect and stature." I believe that Gardner gives here what amounts to a concise statement of a program of both positive eugenics and euthenics.

Assortative Mating

Equality of opportunity and social mobility are not unidimensional but are pluridimensional. They should not be envisaged solely in terms of individuals becoming members of wealthier classes or of less-privileged groups. The diversity of human abilities cannot be accommodated in so simple a model. What is significant to a biologist is the fact that people not only rise upward or fall downward on a scale of social status and emoluments but also choose among a great variety of occupations. Man's outstanding evolutionary adaptation is his trainability and behavioral plasticity; most people can become competent in any one of many vocations and employments. This does not preclude the existence of genetically conditioned aptitudes, preferences, and special abilities. And it is a reasonable generalization to say that people do best in what they find congenial and where they feel they are most likely to pass muster. A practical recognition of the diversity of abilities can be seen in the fact that between 150 and 250 million standardized aptitude tests of various types are now administered per year in the United States (*17*). Although the usefulness of these tests has been questioned, they are apparently here to stay. The Russian poet Voznesensky has been quoted as follows: "Talent cannot be grown like potatoes. It is a national resource, like radium deposits, healing springs, or autumn in Sigulda [a resort]."

Given something close to freedom of social mobility, the most significant genetic consequence of the occupational diversity is the fact that it almost necessarily leads to assortative mating. An old saying has it that "birds of a feather flock together." A mathematician may marry a ballerina, and a boxer a philosopher. Yet mathematicians meet mathematicians and members of their families on the average more often than they meet ballerinas, and boxers do not as a rule spend their leisure time in the company of philosophers. Positive assortative mating, marriage of persons with similar genetic abilities and preferences, has greater freedom to operate in open class societies than in societies with rigid class boundaries. This is a matter of probability, not an inflexible rule. Assortative mating operates more freely among people of higher than of lower educational levels, and more freely in urban than in rural communities.

The genetic consequences of assortative mating in man have not been adequately studied [Spuhler (*18*) is one of the pioneers in this field]. It does not of itself change the gene frequencies in the populations in which it occurs. It may nevertheless be a genetic and evolutionary agent of appreciable importance. Spassky and I (*19*) made experiments, with *Drosophila* flies, which may simulate the processes of assortative mating in human societies. The experimental results show that genetically different moieties may differentiate out of a formerly random breeding, but, of course, genetically variable, population. In these experiments the gene exchange between the moieties in a measure simulates the social mobility in human populations. Without going into technical details, one may state that the assortative mating, although it created no new genes, permitted the formation of gene combinations which would have been unlikely to arise in a randomly breeding population.

Equality of opportunity and assortative mating are not alternatives to other eugenics programs. As pointed out particularly by Osborn (*10*), they are, rather, necessary conditions for the success of such programs. Equality of opportunity promotes formation of professional and occupational aggregations of people; the genes which predispose for, or enhance the chances of, success in certain lines of endeavor may be concentrated in such aggregations. And yet such aggregations have, in at least their biological aspects, no resemblance to traditional class societies. They promote, rather than impede, social mobility, and make it genetically meaningful. They further positive assortative mating, and thus increase the likelihood that gene combinations propitious for particular kinds of achievement will appear.

Conclusions

The human condition is changing both culturally and biologically. Although the cultural evolution overshadows the biological, the two are connected by feedback relationships; culture has a biological foundation. Natural selection continues to operate in modern mankind, but its action ought to be supplemented by artificial selection. The problems of the management of human evolution are, however, as much sociological as they are biological. The success of any eugenical program depends on the creation of favorable conditions for human development and self-actualization. In particular, the urgency of the problem of uncontrolled overpopulation exceeds at present that of genetic improvement. Contrary to the alarmist views of some biologists, the evolutionary perspectives for the human species may be regarded as favorable, although, of course, subject to improvement. Man should be the maker of his history, including his evolutionary history. The trend toward increasing social mobility and equality of opportunity may have desirable genetic effects because of the positive assortative mating which it encourages. It makes possible the realization of many hitherto concealed genetically conditioned talents and aptitudes. Rapid progress of both molecular and organismic, Cartesian and Darwinian, biology gives hope of development of new and powerful methods of genetic engineering, control of gene action, betterment of the environment, and improved understanding of the evolutionary processes in the living world, including man.

References and Notes

1. T. Dobzhansky, *Mankind Evolving* (Yale Univ. Press, New Haven, Conn., 1962).
2. J. Lederberg, in *Man and His Future*, G. Wolstenholme, Ed. (Little, Brown, Boston, 1963).
3. ———, *Amer. Naturalist* **100**, 519 (1966).
4. H. J. Muller, *Amer. J. Human Genet.* **2**, 111 (1950); *Perspectives Biol. Med.* **3**, 1 (1959); in *Man and His Future*, G. Wolstenholme, Ed. (Little, Brown, Boston, 1963); in *The Control of Human Heredity and Evolution*, T. M. Sonneborn, Ed. (Macmillan, New York, 1965).
5. ———, an address given at the 3rd International Congress on Human Genetics; J. Huxley, *The Humanist Frame* (Allen & Unwin, London, 1961); *Eugenics in Evolutionary Perspective* (Eugenics Society, London, 1962); *Essays of a Humanist* (Harper & Row, New York, 1964).
6. N. C. Myrianthopoulos and S. M. Aronson, *Amer. J. Human Genet.* **18**, 313 (1966).
7. J. B. S. Haldane, *Ric. Sci. Suppl.* **19**, 68 (1949).
8. R. Dubos, *Man Adapting* (Yale Univ. Press, New Haven, Conn., 1965).
9. M. H. Haller, *Eugenics, Hereditarian Attitudes*

in *American Thought* (Rutgers Univ. Press, New Brunswick, N.J., 1963).
10. F. Osborn, *Preface to Eugenics* (Harper, New York, 1951).
11. I am obligated to Professor A. E. Mirsky for pointing out to me some of these possibilities.
12. E. L. Tatum, in *The Control of Human Heredity and Evolution*, T. M. Sonneborn, Ed. (Macmillan, New York, 1965).
13. S. E. Luria, *ibid.*
14. T. Dobzhansky, *Science* **126**, 191 (19[illegible]) *ibid.* **137**, 112 (1962).
15. H. J. Muller, *Freedom in the Modern World* (Harper & Row, New York, 1966).
16. J. W. Gardner, in *Goals for Americans* (Prentice-Hall, Englewood Cliffs, N.J., 1960), p. 81.
17. D. A. Goslin, *The Search for Ability* (Russell Sage Foundation, New York, 1963).
18. J. N. Spuhler, in *The Use of Vital and Health Statistics for Genetic and Radiation Studies* (United Nations, New York, 1962), p. 241.
19. T. Dobzhansky and B. Spassky, *Proc. Roy. Soc. London Ser. B*, in press.
20. M. Lerner, *America as a Civilization* (Simon & Schuster, New York, 1957).
21. Variants of parts of this article have been included in lectures given at the University of Maryland, at Wittenberg University, at the New York Academy of Medicine, and at a conference on Biology and Behavior Genetics held under the auspices of the Russell Sage Foundation, the Rockefeller University, and the Social Science Research Council. I am greatly obliged to the colleagues who made suggestions, comments, and criticisms of the ideas and arguments presented.

Mechanisms of Organic Oxidation and Reduction by Metal Complexes

Electron and ligand transfer processes form the basis for redox reactions of radicals and metal species.

Jay K. Kochi

The mechanisms of most organic reactions can be classified into two categories, according to the mode in which the covalent bond undergoes fission: heterolytic (ionic) and homolytic (free-radical). For reactions proceeding by way of an ionic path, the transition state of the reaction takes on polar character, and in some cases carbonium ions and carbanions are actually intermediates. The general concept of acids and bases based on the electron pair, proposed by G. N. Lewis (*1*), in large part forms the framework for discussions of the mechanisms of ionic reactions.

Homolytic reactions, on the other hand, result from symmetric cleavage of chemical bonds and involve free radicals as intermediates. Combination and disproportionation of radicals as well as addition and atom transfer are characteristic reactions of radicals. In contrast to ionic reactions, both solvent and polar effects are usually small in homolytic reactions.

This mechanistic dichotomy into ionic and radical mechanisms is preserved intact in a large number of organic reactions (*1*). Yet such a categorization into mechanistic types has not prevailed in the study of inorganic mechanisms. This is, in part, due to the prevalence of charged inorganic species, which would make such a classification meaningless. There has been, however, an attempt to systematize inorganic oxidation and reduction reactions into one-equivalent and two-equivalent changes which have formal analogies to the radical and ionic categories.

Organic chemistry has relied heavily on inorganic chemistry to provide numerous reagents to effect oxidation and reduction and to promote catalysis. Cross-fertilization of ideas between these two disciplines, moreover, has markedly increased in recent years. The study of the mechanism of oxidation and reduction of organic compounds by inorganic reagents provides an important example of this interrelationship, and it seems to focus attention on the growing inadequacy of the gross categorization of reaction mechanisms. For example, if the concept of one-equivalent changes between inorganic species is applied to organic intermediates, the strict heterolytic-homolytic dichotomy is vitiated. The interconversion of the series of species carbonium ion (R^+), free radical ($R\cdot$), and carbanion ($R:^-$)

$$R^+ \overset{\pm e}{\rightleftharpoons} R\cdot \overset{\pm e}{\rightleftharpoons} R:^-$$

results from one-equivalent changes. In this manner free radicals can be considered intermediates in ionic reactions, and vice versa.

Such a broadening of the base of organic reaction mechanisms is most likely to result from studies of oxidation and reduction reactions. Inorganic oxidants and reductants are particularly useful in these investigations because of the variety of elemental species available with a multiplicity of oxidation states. Chromium (VI) and manganese (VII), as chromate and permanganate, are usually included in the repertory of readily available and useful oxidants (*2*). Oxidation of organic compounds with these reagents has been well examined and found generally to involve overall three-equivalent reduction of the oxidants to Cr^{III} and Mn^{IV} species, respectively. Mechanistic studies have shown that a number of intermediate metastable oxidation states such as Cr^{V} and Cr^{IV} and Mn^{VI} and Mn^{V} must be included in the reaction sequence. The manner in which each of these species in turn reacts with the organic intermediates is still incompletely understood.

An alternative initial approach to delineating the mechanisms of these complex reactions is to deal directly with the usual organic intermediate—the free radical. In such a case, the oxidation and reduction process is constrained to a one-equivalent change, and a more manageable number of species (organic and inorganic) is involved. In the following discussion, oxidation and reduction mechanisms involving organic free radicals and metal complexes are presented, with Cu^{II}, Cr^{II}, and Pb^{IV} used as illustrative examples.

The products, when metal salts and complexes are used as oxidants of free radicals, are highly dependent on the nature of the anion or ligand associated with the metal moiety. For example, cupric chloride and bromide oxidize alkyl radicals to the corresponding alkyl halides, but cupric sulfate or acetate under the same conditions pro-

The author is professor of chemistry at Case Institute of Technology, Cleveland, Ohio.