VI

RACIAL CHANGES AND THE GENE

IT WAS not known precisely how an animal or plant reproduces until the microscope was invented. It was then seen that all living substance consists of microscopic units known as cells, each containing a spherical body known as the "nucleus" (see Fig. 1). It was also seen that reproduction takes place through cells. A "sperm" cell from the male

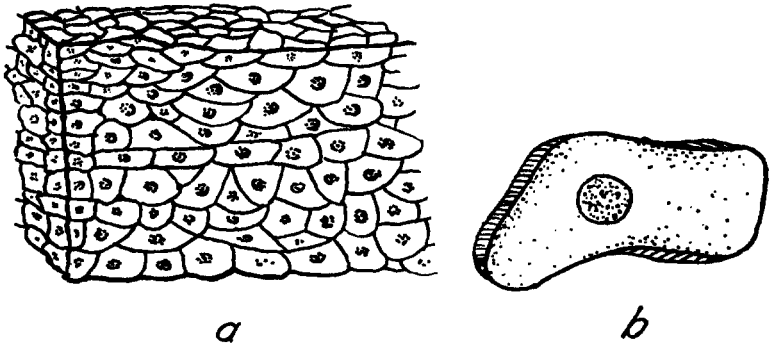

FIGURE 1. Cells (from the lining of the throat); *a*, mass of cells, magnified about 300 times; *b*, a single cell, more highly magnified.

combines with an egg cell from the female, at the time of mating (see Fig. 2). The product of the union is the "fertilized egg." From this the offspring develops. Further studies with the microscope showed how development takes place. The fertilized egg divides into two cells, and each of these again divides into two, making four cells. Next eight cells are formed, then sixteen, thirty-two, sixty-four, etc.; and the process of cell division is continued until the trillions

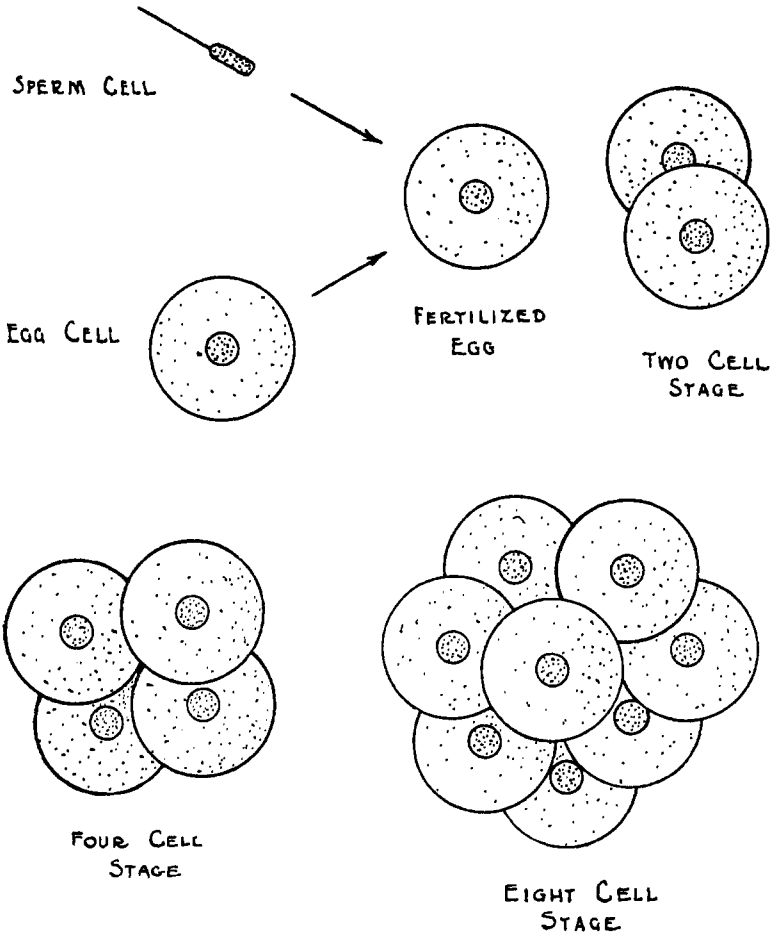

FIGURE 2. Fertilization and development.

of cells are formed that constitute the adult body. Thus reproduction and development take place.

But how and what do the offspring inherit from their parents? Here again the microscope was of assistance. As

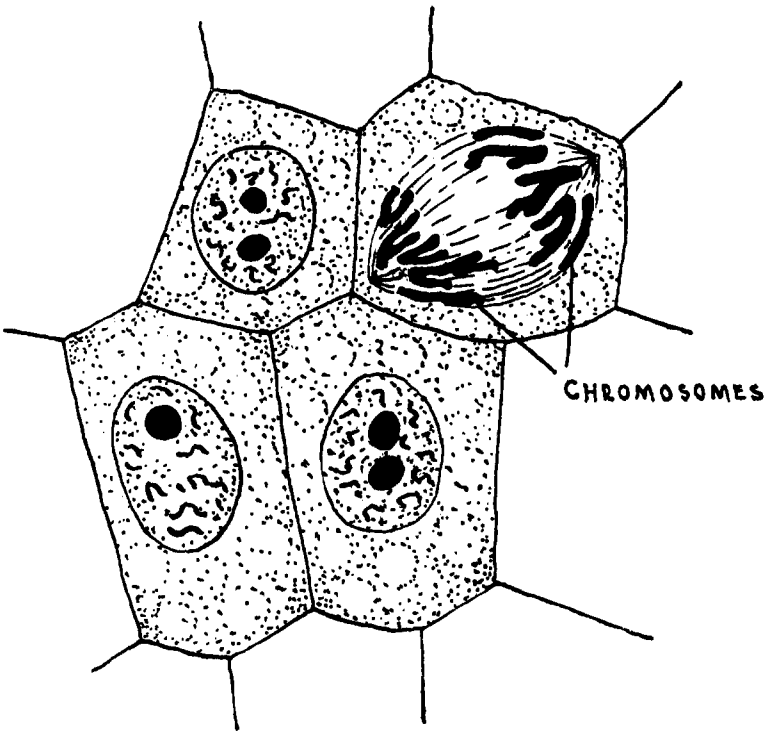

FIGURE 3. Cells, one showing chromosomes.

it became more perfect, it could penetrate further into the cell, and it showed that cells in general contain in their nucleus certain structures, usually rod-shaped, that are known as chromosomes (see Fig. 3). The reproductive cells, like other cells, contain chromosomes, and when sperm and egg combine at the time of fertilization, their chromosomes persist in the fertilized egg (see Fig. 4). In some way, not at

present understood, the chromosomes cause the fertilized egg to develop into a new individual that resembles its parents. Chromosomes therefore constitute the material basis of inheritance, in the sense that they are the bodies that

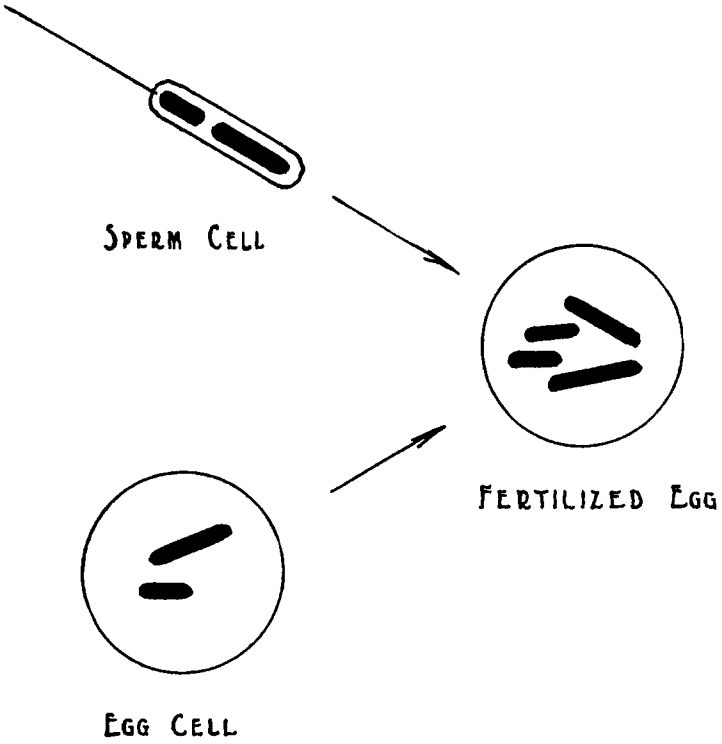

FIGURE 4. The inheritance of the chromosomes.

pass down from one generation to the next, and that cause the offspring to resemble their parents (under similar conditions).

Breeding work has shown that the chromosomes contain certain bodies, not visible under the microscope, that are known as genes (see Fig. 5). These are the ultimate units of heredity. They are arranged in linear order, like beads

on a string. Genes in different parts of a chromosome differ in their effects on development, and so presumably are not exactly alike in constitution. All genes, however, have the power of growth and division. The chromosome itself multi-

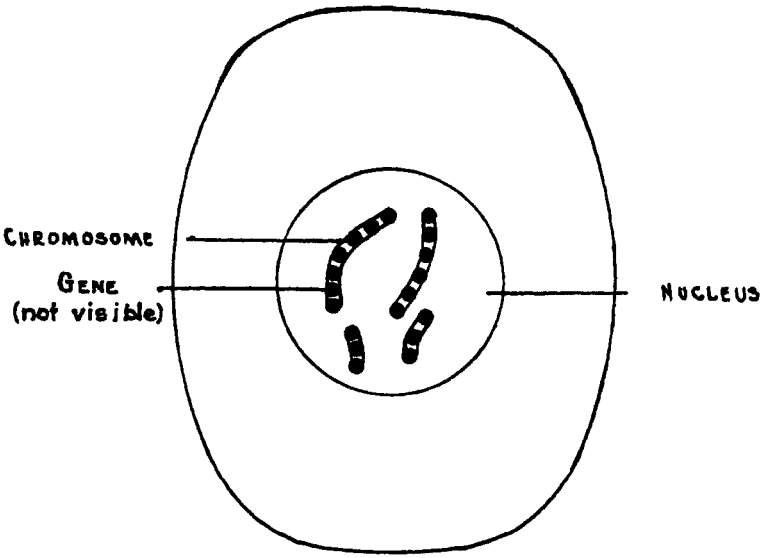

FIGURE 5. Schematic representation of chromosomes and genes.

plies (at certain times) as a result of the growth and division of its individual genes.

The reproductive cells of every species contain a definite number of chromosomes. In the case of man, a sperm cell contains twenty-four chromosomes; an egg cell, the same number. No two chromosomes within a given reproductive cell are alike in regard to their genes. The chromosomes of the sperm and egg cells, however, correspond with each other, as is often evident from a comparison of their sizes. For example, if the sperm cell contained three chromosomes of different sizes, say large, medium, and small, the egg

would also be found to contain three chromosomes of the same sizes.

The fertilized egg has twice as many chromosomes as the reproductive cells, since it arises by the union of two reproductive cells. For example, in man each reproductive cell has twenty-four chromosomes, and the fertilized egg has twenty-four plus twenty-four, or forty-eight chromosomes. These run in pairs. For, the reproductive cells had one chromosome of each kind; and therefore the fertilized egg has two. Thus, if the sperm and egg cell each had a short, medium, and long chromosome, the fertilized egg would have a pair of chromosomes of each size.

Consider now what the chromosomes do when the fertilized egg starts to develop by cell division. Before the fertilized egg divides, its chromosomes line up in the middle of the cell and each of them splits lengthwise into two (see Fig. 6). Next the split halves separate to opposite sides or "poles" of the cell. The division of the cell proper now takes place, in between the separated chromosome halves. Thus two new cells arise. The process of cell division, as just described, is known as "mitosis."

It will be seen that when the fertilized egg divides, each "daughter" cell receives a half of every chromosome present in the parent cell. The halves of any one chromosome, formed by splitting, are identical in kind with each other, because the genes are arranged in linear order within the chromosome, and further because the splitting of the chromosome involves the division of each of its genes, in the plane of the split.

The new cells formed by mitosis resemble the parent cell in every detail, as regards their chromosomes and genes. Each has the same number and kind of chromosomes as the fertilized egg. For, the one set of forty-eight in the fertilized

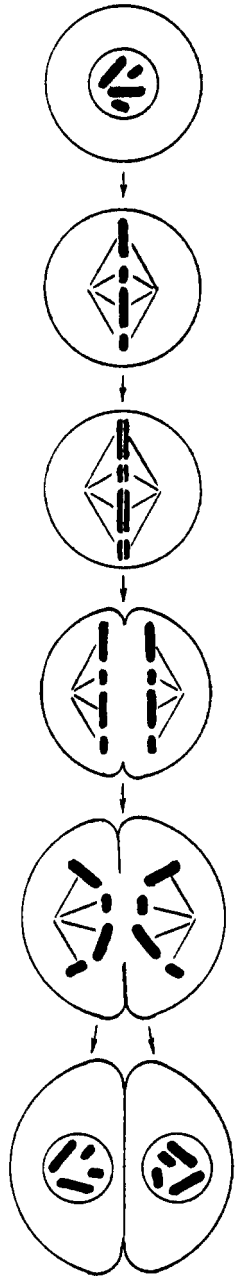

FIGURE 6. Cell division.

egg became two sets of forty-eight through the splitting of its chromosomes, and one set went to each of the daughter cells. Thus the fertilized egg divides to form the first two cells. These in turn divide in the same way as the fertilized egg. As a rule, whenever a cell divides, all of its chromosomes first split into two and it then forms two new cells identical with itself in chromosomal make-up. Therefore, all the hereditary material comes to be distributed among all cells of the adult body that arise through mitosis.

The reproductive cells, like other cells, arise through division. But there is an important difference in the way they receive their chromosomes in cell division, as compared with other cells. The formation of the ripe reproductive cells is preceded by a special type of cell division, known as the "reduction division," whereby the chromosome number is halved. In the case of man the number is reduced from forty-eight to twenty-four.

The reduction division takes place in a very definite way (see Fig. 7). First the chromosomes move to the middle of the cell, but instead of splitting lengthwise into two, they come together in pairs, forming twenty-four pairs (still using the numbers that apply to man). Next, the members of each pair separate to opposite poles of the cell so that there are now twenty-four chromosomes at each pole. Cell division then takes place in between the two sets of twenty-four. Thus two cells are formed, each with twenty-four chromosomes instead of forty-eight. If the number were not reduced, but remained forty-eight in the sperm and egg cells of a given generation, a fertilized egg of the next generation would have forty-eight plus forty-eight or ninety-six chromosomes, and so would have double the number characteristic of the previous generation. But the reduction division prevents a doubling in chromosome number from one genera-

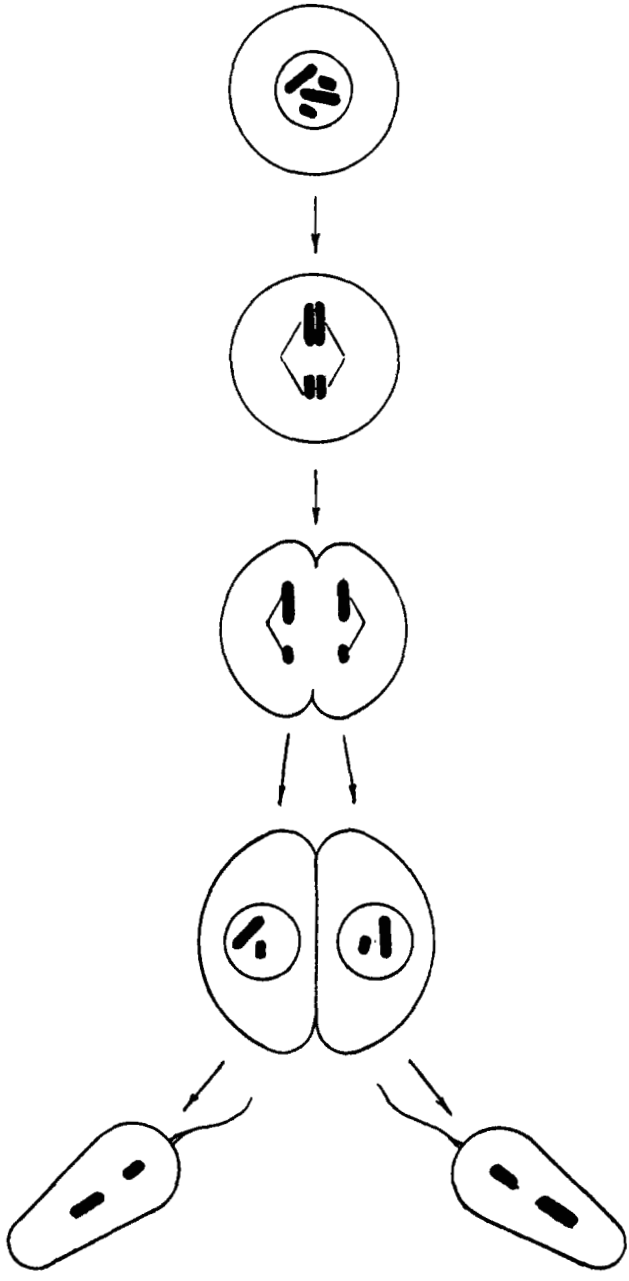

FIGURE 7. The reduction division.

tion to the next. The reproductive cells always have twenty-four chromosomes, the fertilized egg forty-eight (in man). Moreover, the reduction division results in separating the members of each pair of chromosomes from each other, so that a given reproductive cell has only one member of a pair, not both.

The fertilized egg requires for its development certain outside conditions, such as food, air, a certain temperature, etc. These we may refer to as the environment. During the course of development, traits appear, such as eyes, eye color, stature, etc. The traits of an individual are the product of both heredity and environment. This we know from the fact that the fertilized egg cannot develop either in the absence of its chromosomes or in the absence of certain external conditions.

Some people do not believe in heredity. They claim everything is a matter of environment. Such a viewpoint is hardly tenable. A man's dog does not resemble him to the extent that his child does, even though dog and child may have been living in very much the same environment. Obviously, there is such a thing as heredity. It varies with different species, and even within a given species, though to a lesser extent. Child and dog do not have the same kind of chromosomes. That is why they develop differently, even though they grow up in substantially the same environment. On the other hand we know that a child's development is influenced by food, air, education, etc. Therefore, environment also plays a part in development. It is, in fact, absurd to set environment against heredity, and ask which is the more important. The individual begins his life as a miniature bag of chromosomes—the fertilized egg. Change either his chromosomes or his environment, and you change his development.

It is not strictly correct to say that a child inherits his blue eyes; for blue eyes are not in the fertilized egg. What the child really inherits are the genes for blue eyes. These cause blue eyes to develop under a certain set of external conditions. By heredity we mean the transmission from parent to offspring of certain material bodies that cause the offspring to resemble their parents under similar conditions of development. Traits are not inherited. They develop.

Any trait is dependent in development upon numerous genes. For example, in the insect Drosophila, eye color is dependent upon at least twenty genes. So are wings, bristles, etc. The genes for a given trait are not all bunched together in a given chromosome. On the contrary, they are scattered quite at random throughout all the chromosomes. Neither are the genes for two different traits arranged in any definite manner with regard to each other. An eye gene might be next to a wing gene in one chromosome, but next to a bristle gene in some other chromosome. A given gene does, however, occupy a definite position in a chromosome. This is known as its locus. In Drosophila, the loci of many genes have actually been determined. This has been done through breeding experiments.

Genes usually remain unchanged from one cell division to the next, and from one generation to the next. But occasionally a gene changes; that is to say, it *mutates*. As a result, a new type of animal or plant might arise; as, for example, a wingless race of flies, or a brunette of pure white parents.

We cannot actually see a change in a gene itself, because genes are too small to be visible. All that we can see is the effects of the change on the development of an animal or plant, such as the change in the wings or in color, just mentioned. We speak of the change in the gene itself as a

mutation; and of the new type that results from that change, as a *mutant.*

Striking changes, due to mutation, have been known to practical breeders for a long time and have been referred to as "sports." An example of breeders' sports is the short-legged race of sheep known as the Ancon breed.

More recently, the small insect, Drosophila, has been intensively studied for mutations. The genes affected by mutation have been located in the chromosomes, through breeding work. Drosophila has four pairs of chromosomes. These have been arbitrarily numbered and referred to as the first, second, third, and fourth chromosomes. Several dozen mutations have taken place in each of the larger chromosomes during the period that Drosophila has been under observation in the laboratory. For example, a mutation in the first chromosome caused the eyes to change from red to white. The mutation took place in a gene located in the "left-hand" end of the chromosome, at locus 1. Another mutation, at locus 33, caused the wings to change from long to "miniature." A third mutation, at 56, caused the bristles to change from straight to "forked."

A mutation as a rule takes place in just one cell of a given individual and in just one gene of that cell. It may spread to other cells through cell division. The extent to which it spreads depends on the extent of the cell division. In general, the earlier a mutation occurs in development, the greater the number of cells to which it spreads.

A mutated race can be crossed to the normal race, and so hybrid offspring can be produced. For example, a wingless race of flies might be crossed to the normal winged race. The offspring are hybrids. They contain both the mutated gene of the wingless race, and the unmutated gene of the normal race. When the hybrids breed with each other, they

reproduce both the normal and the mutant races, usually in the ratio of 3 normal: 1 mutant. From the fact that the hybrids are capable of producing mutant offspring, we conclude that the mutated gene did not mix with the unmutated gene, in the hybrid.

It is possible to combine different mutant types by crossing. For example, you can cross a white-eyed race of flies with one that has short wings and in a later generation get a race that has both white eyes and short wings (instead of the normal red eyes and long wings). To the white short race still other mutant traits can be added by crossing, so that eventually a new type may be got that contains many mutations and looks extremely different from the normal race.

Not all departures from the normal are due to mutations, even in a pure stock. Everybody knows, for example, that an exceptionally well fed animal may be larger than normal, even though it comes from a pure stock. The increased size of the well fed animal is an *acquired trait*. It is not due to mutation, and is not inheritable. Before any variation can be definitely regarded as a mutation, it must be shown that it is inheritable. Most variations from the normal, in a pure bred stock, are acquired traits. Mutations, on the other hand, are rare in origin. They may, however, become abundant through reproduction.

In Darwin's day the changes that were constantly being produced by the environment were not clearly recognized as acquired traits. They were referred to as "fluctuating variations." Darwin thought that they were due to a constant variation of the germ plasm, and that they were inheritable. Darwin knew of mutations, but he thought that they were exclusively large. He thought too that as a rule they could not lead to evolution, both because they were large, and because they were rare. The fact that they were large, he

argued, would as a rule make them injurious; and the fact that they were infrequent would lead to their gradual elimination, since they would have to cross with the more abundant normals and in so doing they would gradually approach the normals, through mixture of the germ plasms.

Darwin was correct in arguing that large changes, at a single stroke, would as a rule be injurious, for they would in all likelihood necessitate numerous readjustments in many parts of the organism, and they would not allow time for such readjustments. But we now know that mutations are not always large. We know too that they do not become "diluted" through a mixture of germ plasms. Finally, we know that we must distinguish between non-hereditary changes or acquired traits, and actual hereditary changes or mutations. The first kind of change (non-hereditary) cannot lead to racial change. The second kind (mutation) can.

A comparative study of the mutants of Drosophila brings out a very important point. It shows that there is no regularity of any sort connected with their production. Take the eye color mutations. Among various other changes produced by mutation one might observe some that lead to the lighter eye colors, and it is possible to arrange them in a series from red through the lighter and lighter shades to white. But they do not arise in this order. Thus, if we arrange the mutants in order from red to extreme white and number them 1, 2, 3, 4, 5, then 5 might turn up first, 2 next, etc. Moreover, if 3 turned up first, and itself mutated again, it would not necessarily mutate to a still lighter eye color, 4, but it might go back towards the normal. In other words, the occurrence of one mutation does not determine that the next shall be in the same direction.

Moreover, mutations cause all sorts of changes in an organ, not just one kind. For example, in Drosophila the

eyes sometimes become darker rather than lighter, or even change towards a different kind of color, such as purple. The wings might be shortened, bent, changed in venation, etc. Mutations therefore are of all sorts and in absolutely no relationship to each other; they are *random* changes. They are more often harmful than beneficial, but that is what one would expect of random changes in a complex organization.

How could the advance towards a higher type ever result from blind changes of this sort? We find our answer in the simple fact that in nature the bad mutants die, leaving only the occasional good mutants; that is, the ones that represent a better adjustment to a given environment. The dying out of some types and the survival of others we may call natural selection.

Until very recently the causes of mutation were entirely unknown. All attempts to produce them artificially had failed, though many agents had been used, such as drugs, mechanical agitation, light of different colors, temperature changes, etc. Most of the results were negative and in only a few cases were positive effects claimed. But neither positive nor negative results were conclusive. The experiments were performed in such a way that if any mutations had occurred they would have escaped detection, for the most part. Moreover, when mutations were found, the experimenter often failed to indicate how many of the observed mutations would have occurred without treatment. And usually the numbers were too small to warrant any conclusion. Thus the causes of mutation were, until recently, unknown.

But in 1926 Professor H. J. Muller definitely produced mutations. This he did by means of X-rays. He overcame all of the difficulties in the earlier experiments and showed conclusively that mutations can be produced artificially and

on a large scale. By subjecting flies to X-rays he produced a great number of mutations—in fact as the result of a few hours' treatment he obtained practically all the mutants that had previously been observed to arise naturally in the laboratory over a period of ten years. In addition he obtained many mutants never before observed.

The frequency with which the mutants appear is proportional to the dosage of X-rays employed. In one set of experiments the natural frequency was increased over one hundred and fifty times. In another set it was increased still further by greater dosage of X-rays. But when the dosage gets beyond a certain point, the sterilizing effect of the X-rays interferes considerably with the experiments. The source of the radiation used in producing mutations is a matter of indifference, provided the radiation is of sufficiently short wave-length. Thus radium also can cause mutations, for it gives off a form of radiation, known as "gamma" radiation, that is similar to X-rays, though of somewhat shorter wave-length.

How do X-rays cause the genes to mutate? Probably in the same way that they alter inorganic matter—by knocking electrons out of atoms. They thereby chemically "activate" the atoms, and make them capable of chemical change. If one or more atoms of a gene are activated, the gene itself might mutate through chemical alteration.

It is possible for X-rays to activate genes indirectly. For the X-rays might hit a molecule of some cell substance close to a gene and expel an electron from the molecule. The expelled electron in turn might strike the gene and deprive it of one of its electrons. Measurements show that the indirect effect is much greater than the direct effect.

Radiations similar to X-rays exist in nature and Professor Muller pointed out that such natural radiations must produce

mutations in organisms not subjected to any artificial treatment. Some natural radiation comes from the earth, and is due to radium and other radioactive substances contained in rocks, such as pitchblende. Some rays, known as cosmic rays, come from the outside world, and are even more penetrating than the earth rays. Finally, animal and plant tissues themselves contain an element (potassium) that is slightly radio-active. The problem now was to find out whether all the various sources of natural radiation were sufficient to account for all the natural mutations.

Calculations made by Professor Muller in collaboration with Dr. Mott-Smith, of the Rice Institute, showed that natural radiation, from all sources, did not exist in sufficient amount to produce more than a small fraction of natural mutations. For the amount of the radiation coming from natural sources is somewhat less than 1/100,000 that of the radiation produced by the X-ray machine used in Professor Muller's experiment. If radiation is the sole cause of mutation, then the natural mutation rate should be under 1/100,000 that of the X-ray rate. It was found, however, that the natural mutation rate was disproportionately high (about 1/100 that of X-ray rate) showing that there must be important causes for mutations in nature, in addition to radiation.

Yet natural mutations are similar in their manner of occurrence and in their general character to X-ray mutations, and so it is very likely that the causes of the two are fundamentally of the same general character. Natural mutations are undoubtedly caused in part by radiation. But they are probably caused also by other ultra-microscopic disturbances of a random character, consisting of collisions between particles of matter (electrons, atoms, molecules). The work of ferreting out the various remaining causes of natural muta-

tions is now being prosecuted along the lines thus suggested.

Heat is the only other agent thus far known to produce mutations, in addition to radiations of the shorter wavelengths. An experiment by Professor Muller and the writer in 1919 suggested that the mutation rate is doubled by an increase in temperature of ten degrees Centigrade. It has since been definitely shown by several other workers that heat produces mutations.

Now that mutations can be artificially produced, it can no longer be logically held that mystical causes are back of racial change. We see that a physical agent can produce mutations. The agent itself is definite. But the changes that it produces are of many different kinds; they are random changes.

It is conceivable that certain agents in the environment produce definite mutations. But in the present state of our knowledge we cannot predict what kind of mutations a given agent or a given environment will produce. For example, conceivably moisture might produce some definite kinds of mutations, but what these would be like, we do not know. It is true that animals which live in a moist environment often have webbed hands, but it does not follow that the moisture specifically causes the webbed mutations. In fact, we know that webbed hands occasionally appear in man and in other animals living in a dry environment, and it therefore seems reasonable to conclude that wetness does not necessarily cause the mutations in question. But wetness might *select* them, after they had arisen. In other words, wetness does not necessarily produce the mutations that it selects. The same thing is true of other environmental agents. We do not know at present whether all environmental agents can produce mutations. But even if we assume that they do, then we can be reasonably sure that if a given agent produced

mutations of one kind, let us call them "a," it would in all likelihood not select "a," but rather some other kind, "b." In brief, the environment is not the same in its *causal* influence on mutations, as it is in its *selective* influence.

Since races change at present through mutation, it is reasonable to assume that they also changed in the past through mutation, and that they became adapted to their environments through the survival of mutations that happened to be effective; that is, through natural selection. In brief, the evidence as it now stands indicates that mutation in conjunction with natural selection is the method of evolution.

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