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Evolution, heredity and eugenics

John Merle Coulter

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Wild cabbage and some of the forms derived from it. The tall form is wild cabbage. At upper right, brussels sprouts. Top center, collards. Below collards, kohlrabi. Lower left, cultivated cabbage. Lower right, kale. Above kale, cauliflower. *From Coulter's Elementary Studies in Botany. Copyright, D. Appleton & Co.*

EVOLUTION, HEREDITY AND EUGENICS

BY

JOHN MERLE COULTER

UNIVERSITY OF CHICAGO

SCHOOL SCIENCE SERIES

JOHN G. COULTER, Publisher
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1916

PREFACE

This little book is the result of an expressed need on the part of high school and college teachers for a more simple and compact treatment of organic evolution than has heretofore been available. Such monographic treatment the elementary textbooks, by virtue of their organization, do not supply. On the other hand, the covering of this topic adequately by supplementary reading has proved too large a task for the time available. So the design of this little book is to be supplementary to elementary biological texts; to furnish in brief and simple form a serviceable idea of modern conceptions in this great field, and of their significance in human life.

In the whole history of thought nothing is more significant than the conception of evolution. When the evolution of organisms became an accepted doctrine, all fundamental ideas had to be recast in the new light. This is more than historic. It is an affair of today as well as of yesterday. The thinking of today that is most significant is thinking in terms of evolution. Intelligent interpretation of life depends upon it.

Yet it is a fact that the "average citizen" has but the vaguest ideas of what evolution is. It is in our teaching of elementary biology in high schools that we have the best opportunity to correct this state of affairs. But it is a neglected opportunity. Certain present tendencies in science teaching leave small space in the elementary courses for anything which is suspected of being "abstract." Unfortunately evolution is under this suspicion. The most fundamental and far reaching conceptions that science has achieved are ruled out of some science courses if they fail to seem to be of immediate interest to the student. Into the merits of such ruling there is not space here to enter. There is only space to say that such very brief treatment of evolution as is presented herewith may find place even in courses in which the weeding out of the "abstract" has been very thorough. For, after all, evolution has practical aspects which cannot be denied, and these are emphasized in this little book.

The text is organized into what have been tested and found to be serviceable "assignment units"; short chapters which may also be welcome to the general reader.

Chapters 21 to 24 are by Dr. S. W. Williston, of the University of Chicago. Acknowledgment is made of the courtesy of the American Book Company in connection with the use of illustrations that are on pages 95, 96, 101, and 107.

JOHN M. COULTER.

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EVOLUTION, HEREDITY, AND EUGENICS

CHAPTER ONE.

WHAT IS EVOLUTION?

Meaning of evolution.—When you see a tadpole swimming in the water, you know that presently it will become a frog hopping about on the land. When you see a caterpillar crawling about over a leaf, you know that presently it will become a butterfly or a moth flying freely through the air. If you had not seen or heard of these changes you would not think them possible. The tadpole **evolves** into a frog, and the caterpillar **evolves** into a butterfly. By means of great changes occurring in the body, animals very different in appearance and in habits come from the tadpole and caterpillar. This is one kind of evolution. **Evolution means the production of new things through change of old ones.**

Evolution in plants.—Plants are so motionless as compared with animals, that one might conclude that they are not so easily changed. When you look at a cultivated rose, you see many brightly colored petals, which in the wild rose are represented by stamens. This means that a structure may develop into a petal or a stamen, according to circumstances. Cultivated pansies are very different from wild pansies, and yet every one knows that they were once wild pansies, and have been changed by cultivation.

Origin of new kinds of plants and animals.—These facts suggest that plants and animals can be changed. They are not rigid like figures cast in a mold. If they can be changed at all, how much can they be changed? Can a plant or an animal change so much that it becomes another kind of plant or animal? If so, then new kinds of plants and animals can be produced by evolution.

Belief in evolution.—The idea that evolution is a process at work everywhere has grown so that almost every student believes in it. The effects of this belief on human thought and action have been very great. Some of these effects are so important that they must be mentioned here. They will show why evolution is worth understanding.

Reasons for understanding evolution.—In the first place, it is often said that **evolution has revolutionized modern thought.** This means that every subject that is worthy of study and that is worthily studied is considered now from the standpoint of evolution. Before the idea of evolution began to control thinking men, a fact was considered by itself, without reference to any other fact. Now facts are accumulated in order that they may be put together and made to explain one another. We observe a fact and ask what other fact causes it; and so facts are linked together in a continuous chain, each fact dependent on facts that have gone before, and responsible for facts that come after. Therefore, we hear not only of the evolution of the solar system, of the earth, of plants, and of animals, but also of the evolution of language, of society, of government, and even of religion. It is evident that the idea of evolution does not belong to any particular subject, but that it suggests a method of studying any subject. If the idea of evolution has had such an influence upon thought and work, it is clear that thoughtful people should understand it, at least in a general way.

In the second place, **the meaning of evolution is very generally misunderstood.** It is surprising how many people have opinions about evolution who do not know what it means. At one time in its history evolution was accused of being destructive of religion; that is, it was claimed that no one could believe in evolution and in religion at the same time. This old accusation has given the word a bad flavor for many people, and therefore, without trying to understand it, they condemn the idea. It is hard to outgrow an evil reputation, but evolution is outgrowing it, for more people are learning what it really means. One of the most important and difficult things for any one to learn is to express no opinion until it is based on knowledge. To keep an open mind is what every student must learn to do.

In the third place, **the study of evolution has led to results of immense practical importance.** For example, the study of evolution of plants has led to discoveries that have revolutionized the cultivation of plants, so that it is possible now to secure more desirable plants, and to make them produce more certainly and more abundantly than it ever was before. Since the production of better crops is our means of solving the food problem, no other illustration is needed to show how the study of evolution has contributed in a most important way to human welfare. For this reason, if not for its own sake, evolution deserves to be understood.

No one man responsible for the idea.—There seems to be a general impression that some one man is responsible for the idea of evolution. For example, many think that Darwin was the author of the "theory of evolution," the impression having arisen because Darwin's name is so commonly associated with evolution, and because Darwin's study of evolution came at a time when it was regarded as destructive of religion. This bad reputation, therefore, was associated with Darwin's name, and it was, perhaps, natural to conclude that he was responsible for the idea. Of course Darwin was a very distinguished student of evolution, but he was only one among very many. In fact, the idea of evolution is as old as our records of men's thoughts; it is an idea that thinking men seem always to have had. In modern times it has become more definite and precise, but the enduring idea has always been the same. The author of the "theory of evolution," therefore, is the human race, so far as we have any evidence, and the human race must have caught the suggestion from what was seen taking place in nature.

Organic evolution our topic.—It is not our purpose to discuss evolution in general, but to use plants and animals as illustrations of evolution. After all, it is the evolution of plants and animals that attracts chief public attention, and concerning which people are most sensitive. No one seemed to object to the idea of the evolution of the solar system, or of the earth; and perhaps the evolution of plants would not have attracted much public attention; but when the idea came to involve the evolution of animals, from which man could not separate himself, the public was aroused to attention. Since plants and animals are living things (organisms), their evolution is called **organic evolution,** to distinguish it from other applications of evolution.

This book, therefore, will be restricted to the discussion of organic evolution, and with this restriction it is possible to suggest a preliminary definition. **Organic evolution means that the many kinds of plants and animals living today are the modified descendants of earlier forms.** The old view was that each kind of plant and animal sprang into existence by a "special creation," and held no relation to the other kinds of plants and animals. Evolution contradicts this, and claims that the different kinds of plants and animals have come from older kinds, and that in this "descent" they have become so changed that they are no longer the same kind as their ancestors. Of course, if organic evolution is true, it is fair to ask how the original plants and animals came into existence. Although this is a fair question, it cannot be answered now. One can believe that a stream is flowing because one sees it, without knowing anything about its source.

CHAPTER TWO.

PERIODS IN THE STUDY OF EVOLUTION.

The period of speculation.—The history of the idea of organic evolution may be divided into three general periods, each characterized by a method of study. The first was that of speculation, when evolution was an idea without any definite basis of facts to rest upon. Men thought about it, and discussed its possibilities, but they did not work at it in the attempt to prove it or to disprove it. It was a subject to talk about rather than to investigate. Of course something observed must have suggested the idea, but after the suggestion, the fact and the process were left to the imagination. "To sit still and think a thing out" may do for some subjects, but not for organic evolution. How the mind of man can run riot in imaginary explanations of evolution may be seen in the Greek and Roman mythologies.

The period of observation.—The second period began near the close of the eighteenth century, and it may be called the period of observation. Men began to observe plants and animals with the definite purpose of collecting facts bearing upon their evolution. They compared the different kinds, and noted their resemblances and differences. Those that resembled one another most they concluded were most nearly related, and they inferred that this relation could only be explained by descent from some common ancestor. They observed not only the plants and animals about them, both wild and domesticated, but some observers extended their observations into distant regions, often through many years of travel, so that the whole world was explored for facts bearing upon organic evolution. For example, Darwin spent five years in a famous voyage around the world, accumulating facts that after twenty years he used in an explanation of evolution.

This wide search for facts made the study of evolution scientific, and the real history of organic evolution began when it became a history of scientific investigation. When an observer accumulated what he regarded as a sufficient number of facts, he would fit them together and infer that in a certain way one kind of plant or animal could produce another kind. It will be noticed that the observations were really facts, but that the conclusion was an inference, something not demonstrated, but regarded as probable. The greater the number of facts, the more probable and more difficult would be the conclusion. It is easy to draw a conclusion from one fact, a little more difficult when several facts are involved, and often impossible when facts become numerous. One of the most impressive features of Darwin's work is that he marshalled such an enormous array of facts, and all of them seemed to be consistent with his conclusion.

The period of experimentation.—The third period began near the opening of the twentieth century, and it may be called the period of experimentation. Men began to experiment with plants and animals, and to watch them produce new forms. They did not stop with **inferring** that new forms can be produced by old ones, but they **actually saw** them produced in connection with their experiments. This is the present period, a period that has only begun, but has already brought into view great possibilities. Many competent observers throughout the world are cultivating plants and animals through many generations, are subjecting them to many kinds of treatment, and are discovering what they really do, rather than what they are supposed to do.

It is this kind of work that has resulted in many discoveries of great practical importance. For example, watching the growth of corn critically, generation after generation, suggested how the yield and quality of the crop could be improved. Watching some one crop suggests not only methods of improving it, but also methods that may be applied to any crop. The period of experimentation, therefore, has made the study of evolution not only more rigidly scientific, but also, on account of this fact, of great practical importance.

Comparison of the three periods.—These three periods will explain the gradual change in the attitude of biologists towards evolution. During the period of speculation, before there were any real biologists, the known facts were so few that speculation was unlimited. The discussion of evolution included not only speculation as to the origin of one kind of plant or animal from another, but as to the evolution of the plant and animal kingdoms, from the lowest forms to the highest; and speculation was free to reach out still further and imagine the method by which plants and animals evolved from the inorganic world. Of course all this belongs to organic evolution, and so large a perspective was very interesting. Men are interested in it yet, but it is unprofitable because it begins and ends in speculation, and cannot reach knowledge.

During the period of observation and inference, the period dominated by Darwin's theory, biologists restricted their interest to the origin of all plants and animals from one another, inferring not only how new forms are produced, but also how the animal and plant kingdoms evolved from the lowest to the highest. Since they inferred from observation how certain plants and animals were produced, they merely extended their inferences to include all plants and animals; but they could not include inferences as to the origin of plants and animals from inorganic material, because there were no observations to furnish a basis. They probably speculated, but they could not infer.

During the period of experimentation, the present period, biologists are no longer interested in the origin of the whole series of plants and animals, for this is entirely beyond the reach of experiment. They are simply trying to discover how plants and animals produce new forms; beyond that organic evolution is an inference or a speculation. For example, during the second period the discussions of evolution included the question as to the origin of man, and it was a natural inference to connect him with the most man-like animal, the ape. It was this inference that made so many people sensitive about organic evolution; in fact, some people even today seem to think evolution means "that men came from monkeys." Today, however, no such question enters into the discussion of evolution by biologists, for it is beyond the reach of experiment.

The change in the attitude of biologists during the three periods may be made plainer by a simple illustration. In the days of speculation, such plants as oaks were pictured in the imagination as being derived by descent from ferns; ferns in turn were imagined as coming from mosses; mosses were thought to be derived from algae (simple water forms); and algae were thought to arise through the chemical reaction of certain inorganic materials contained in the water. In the days of observation and inference, the whole series from oak to algae was inferred, but the origin of algae was omitted. At the present day, under the domination of experimental work, the long series has been abandoned, and the effort is to discover how one kind of oak gives rise to another kind of oak. The field seems to be narrowed, but in fact speculation gave place to inference, and inference has given place to knowledge.

CHAPTER THREE.

THE FACTS THAT SUGGEST EVOLUTION.

It will be helpful to know the kinds of facts that attracted the attention of the earlier observers and transformed organic evolution from a speculation to a scientific subject.

(1) **Intergrading species.**—Almost as soon as plants and animals began to be classified, it was observed that the various kinds **(species)** are not always sharply distinguished from one another. For example, there are approximately 150 species of asters in the United States, but if they were all assembled in one place it would be impossible for any one to separate them clearly, for the kinds would seem to grade into each other. This is what is called the **intergrading of species.** It must be remembered that a species is something man has defined, and that individual plants constantly appear which do not agree exactly with the descriptions; they seem to be intermediate between two closely related species. These intergrading forms have always given trouble to students of classification, for they are continually upsetting the definition of species.

For a long time these troublesome **intergrades** were disregarded, and only "representative" or "typical" individuals were collected. What made these individuals "representative" or "typical" was that they happened to conform to the published description of the species. For example, if a species of plant had been described as having blue flowers, a white-flowered individual would be disregarded because it was not representative or typical. If the species had been described first as having white flowers, all blue-flowered individuals would be disregarded.

The constant occurrence of such intergrading forms suggested to thinking men the possibility that they might represent individuals of one species that were becoming changed into another species. The idea then grew that species are not separated from one another, but are connected, and that the boundary of a species is an imaginary one, or rather one of convenience.

(2) **Adaptation.**—It was observed also that plants and animals become changed by new conditions of living. For example, there are two species of smartweed easily distinguished from one another by the fact that one is hairy and the other smooth. The hairy one grows on banks of streams or ponds; the smooth one grows in the water. In a certain instance, both of these forms were growing in connection with an artificial pond, and after the water of the pond had been standing at an unusually high level for some time, it was found that **the hairy smartweeds of the bank had put out smooth branches under water.** It was found also that the smooth water form, grown on the bank, would develop as a hairy form. This ability to respond to changed conditions was called the **power of adaptation.** (It is better called **adjustment,** inasmuch as the word adaptation suggests a conscious act.) It was natural to think that if plants and animals change in this way, it is possible that one species can produce another.

This power to respond to changed conditions has been observed to be general among plants and animals. Perhaps the most familiar illustration of it is the change of plumage among birds, and of hair among mammals, that occurs with the changes of seasons. In any event, the power indicates that plants and animals are not unchangeable structures, cast in rigid molds, but are structures that can be changed. This was certainly very suggestive of the possibility of organic evolution.

(3) **Rudimentary structures.**—Man also began to observe, especially in animals, structures which were called **rudimentary.** For example, in the jaws of a young parrot, teeth begin to form but do not mature. In considering what this means, the conclusion seemed inevitable that the parrot must have descended from ancestors that had teeth. The legs of a horse have "splint bones" that occasionally develop little hoofs, suggesting ancestors with more than one hoofed toe, and fossil records of such animals have been found. Even the human body contains abandoned structures; among them the vermiform appendix has become remarkably well known. Somewhere among the ancestors of man this organ must have been useful rather than dangerous.

Our bodies have been called "walking museums of antiquity," and this seems to be true of most plant and animal bodies. It seemed to the older observers that it was impossible to explain these numerous abandoned structures except on the hypothesis that they represent structures that were once used by ancestors. Therefore, these ancestors must have been different from their present descendants. The word "rudimentary" is hardly appropriate for such useless structures, and they are coming more commonly to be called **vestiges.**

(4) **Testimony of geology.**—When the geological record began to be read, many were induced to believe in the possibility of organic evolution who had stoutly opposed it before. This impressive record shows that, during the earliest known period, plants and animals lived that were entirely unlike those of today. In the next period, different kinds of plants and animals appeared, usually some of the old kinds holding over. As period succeeded period, new kinds of plants and animals appeared, and the old kinds

disappeared, until, in the later fossils, resemblances to the present plants and animals can be recognized. These resemblances gradually increased, until finally, without any sensible break, our present plants and animals appeared. This suggested to many that a tremendous stretch of history confirms the idea that plants and animals have been changing from the first, and that the modern forms are the modified descendants of these earlier forms. Probably the geological record comes as near being a demonstration of the fact of evolution as anything can be except an experiment.

Before the idea of organic evolution was applied to the geological record, this long succession of floras and faunas was explained as a series of catastrophes, which destroyed practically all organisms, and alternated with a series of creations introducing new floras and faunas. Since geology has abandoned the idea of a series of sudden world catastrophes, the necessity for a series of creations has disappeared.

(5) **Testimony of embryology.**—Then there came the subject of embryology, which means the study of the development of plant and animal bodies from the egg to the adult condition, noting every stage in the progress. In many cases these developing bodies (embryos) show structures that disappear before maturity, but often these are structures that persist in other plants or animals and are features of the adult body. It is hard to imagine why structures appear in the embryo, only to disappear, unless among the ancestral forms these structures persisted and were used. These fleeting glimpses of abandoned structures suggest not only ancestry, but also relationship, and how plants and animals have become different from their ancestors. The conclusions suggested are the same as those derived from the rudimentary structures or vestiges mentioned above as occurring in adult bodies. In fact, these temporary structures of the embryo are

vestiges that have disappeared from the adult body, but still linger in the embryo.

(6) **Changes under domestication.**—Perhaps the strongest suggestion of the possibility of organic evolution came from the observed changes in plants induced by cultivation, and changes in animals induced by domestication. It was obvious that cultivated plants and domesticated animals often become so different from their wild ancestors that they look like different species. In some cases the changes have been so great that it has not been possible to recognize the wild representatives. In fact, when two plants are found in nature as different from one another as is many a cultivated plant from its wild original, they are regarded as representing two species. When one remembers the exceedingly different races of dogs that have all been bred from one wild stock, he must conclude that if man can bring about such great changes in animals, it is entirely possible that new forms may arise from old ones in nature.

Summary.—When one fits together the suggestions arising from these six facts: (1) intergrading species; (2) power of adaptation, (3) rudimentary structures or vestiges, (4) the geological succession of floras and faunas, (5) the evanescent structures observed in embryos, and (6) the changes induced in plants and animals by their cultivation and domestication, it is hard to resist the conclusion that they indicate organic evolution. In any event, such facts attracted the attention of thoughtful men. They determined to investigate the matter further, and so the modern work in evolution began.

CHAPTER FOUR.

EXPLANATIONS OF EVOLUTION.

Evolution a fact.—Before presenting the various explanations of evolution in detail, it is necessary to understand certain facts which will put the explanations into a clearer setting. One of these facts has to do with the present standing of evolution in the opinion of those who are competent to judge. As certain men became conspicuous for their conclusions in reference to organic evolution, the impression became current that they were **authors** of the theory of evolution. In fact, however, they are only **explainers** of evolution, attempting to show how evolution works. It is important to remember this. Failure to recognize the difference between an author and an explainer has led to much misunderstanding. For example, **Darwin's explanation of organic evolution is now held to be an inadequate explanation.** Since Darwin is supposed by many to have been the author of the "theory of evolution," any attack upon his views has been interpreted as an attack upon the whole idea of organic evolution; and so some have been misled into thinking that the idea of evolution has been abandoned by biologists. Nothing could be farther from the truth, for **evolution is the working hypothesis of every biologist today.** There is no discussion among biologists as to the **fact** of evolution, but there is much discussion of the proposed **explanations of evolution.** Darwin simply stood for one explanation. Every explanation that has been offered may prove to be inadequate, and still **the great fact of evolution remains.**

Different explanations possible.—Perhaps one of the mistakes made by most explainers of evolution and their disciples has been to claim that there is only one explanation; that if new forms are observed to arise in a certain way, all forms must have arisen in just the same way. When competent observers differ, there is probably some truth in the claims of each. Evolution has had many competent observers, and several explanations have been thought at various times to be convincing, but no one explanation of the origin of species has proved satisfactory for all cases. It is probable that new forms have arisen in all the ways that have been thought of by competent students of evolution.

An illustration of these statements may help to make them clear. Two engines are standing on the rails. They are observed to move along the rails, and their motion is an indisputable fact. Two men undertake to explain the motion, but they are certainly not authors of the idea that the engines move. Neither of the explanations may be right, but this does not contradict the fact that the engines move; the motion is still there to be explained. One explainer may show in a most convincing way that one of the engines moves by means of steam, and infers that the other engine moves in the same way. The other explainer shows that one engine moves by means of electricity, and infers that the other engine moves in the same way. The two views are in conflict, but both are right; the mistake was to infer that every engine has to move with the same motive power.

Adaptation a state, not a process.—One often meets the idea that plants and animals with their various structures are "perfectly adapted" to their various environments, but if this were true there would be no evolution. **Perfect adaptation means stagnation, for it removes all pressure**

for change. It is the fact that there is always room for improvement that results in progress. One might suppose that progress through countless ages should have resulted by this time in perfectly adapted plants and animals, **but the conditions of living have been changing also,** so that there has been a constant demand for more efficient structures. It is as if one had been approaching a goal with much expenditure of time and effort, and then the goal is shifted, and the effort must be turned in another direction.

So the word "adaptation" is often used in a sense that is misleading. When one says that a structure is adapted or is not adapted to a certain condition, the meaning is clear, for it is the statement of a fact; but when one says that a structure "has become adapted," or "has adapted itself," he implies a process that does not exist. Plants and animals do not "adapt themselves." That is, they do not change so that they will be better adapted. If adaptation means anything it means that individuals that are already adapted to a certain extent can exist in conditions that other individuals cannot endure. In other words, **adaptation is a state and not a process,** and to understand this will help to make more clear what is to follow.

Character of the explanations.—After the fact of evolution had impressed itself upon the minds of scientific men, the search for its explanation began, and there are now current a number of explanations, no one of which seems to be entirely satisfactory. So the search is being continued with increasing vigor and increasing experience. If the explanations are considered in the order of their appearance, it will emphasize the fact that as knowledge of the facts has increased, the more difficult the problem has become. Each explanation has benefited by its predecessors, and has attempted to remedy their insufficiency. It would not be profitable here to enumerate all of the proposed explanations of organic evolution, but there are a few conspicuous ones that stand out like landmarks, and around each of them there are grouped various modifications of view.

A general historical outline of the principal explanations will be given first, so that their relations to one another will be clear. Afterwards, the most important of these explanations will be presented more fully.

CHAPTER FIVE.

ENVIRONMENT.

The first explanation.—The first important explanation of organic evolution was the most obvious one, and it was very natural that it should have been thought of first. It was well known that many animals become changed with the different seasons, certain birds changing their plumage at the approach of winter, and certain mammals changing their coverings of hair or fur. It was concluded that these changes are **induced by the changing seasons.** In many ways, both plants and animals respond to the seasons. It was observed also that the plants of dry countries are quite different in structure from those of moist countries; and that plants of the lowlands differ decidedly from those of the high mountains. All such differences were supposed to be due to the effects of the different environments. Therefore, during the last decade of the eighteenth century it was announced that organic evolution is explained by the influence of **environment.**

Environment.—This has become a very popular word, and one seldom hears an address on any subject that does not include it, but it was used first in biology and as an explanation of evolution. This explanation assumes that plants and animals are plastic structures, capable of being molded by environment, as clay can be molded, and that in this way the various forms of plants and animals have arisen.

Environment is a very complex thing, made up of many factors, and the authors of this explanation were not critical enough to analyze it and to discover just what factors in the environment are doing the molding. In fact, environment is so complex that no one yet has been able to analyze it. It contains very many things that may influence plants and animals, and even when these things are separated from one another and experimented with in such ways that their effects on organisms are shown, we cannot be sure that their effects will be the same when they are working together; that is, the effect that any one factor of environment has upon an organism may be itself influenced by the effects of other factors.

Furthermore, these early observers assumed that after environment had changed a form, this change would be transmitted to the next generation, for otherwise the molding would have to be done over again. It is strange that they reached this conclusion, for it would mean, for example, that a bird in winter plumage would produce only young with winter plumage. This is a good illustration of a theory based upon very few facts, without any analysis of the conditions; but it was a start upon a very fruitful inquiry.

Authors of the theory.—It is interesting to know that the explanation of organic evolution by environment was suggested by three men almost simultaneously. They were **Erasmus Darwin** of England (1731-1802), a physician, a keen observer, of nature, with a very philosophical mind, and the grandfather of Charles Darwin, **Geoffrey Saint-Hilaire** of France (1772-1844), a distinguished zoologist and philosopher; and **Johann Wolfgang von Goethe,** who was a distinguished botanist, as well as the greatest of German authors.

It has frequently happened, as in this case, that when some subject reaches a certain stage of knowledge, identical conclusions occur to several students. In other words, when the time becomes ripe for certain conclusions, more than one man picks the fruit of thought.

This explanation inadequate.—It is evident now, and it became evident a century ago, that this explanation of organic evolution is inadequate, for it is superficial. Whatever effect environment may have in changing plants or animals is superficial and temporary. Something that can bring about more fundamental and permanent changes is necessary to explain their evolution. Belief in the influence of environment has not been abandoned, for it is proved by a multitude of facts, but it has come to be regarded as insufficient to explain the origin of species. Plants and animals do respond to changes in their environment, but that such responses can result in producing new kinds of plants and animals is no longer believed.

When the influence of environment in the production of new forms was a prominent idea, it was applied in other fields of study, as in sociology and education. There has been much discussion in reference to the influence of environment in the development of society, and in the development of individuals, and much more stress has been laid upon its importance than the biological facts have justified. In fact, in some subjects the theory that changes in organisms are chiefly produced by environment is still accepted, long after biology, which was the parent of this theory, has given it up and passed on to other explanations of evolution.

Role of environment.—It must be recognized, however, that environment is an important factor in evolution, even if it cannot explain the origin of new forms. There is no question but that environment is **responsible for the opportunity to develop.** In other words, if it cannot produce new forms, it does determine the opportunity for the development of new forms. The place of environment in influencing development may be illustrated in the development of children. It is always important to have a favorable environment for children, for it encourages proper development. The best that we can do for a child is to provide a stimulating opportunity, which means to provide proper environment and training. But there are also fundamental things in the structure of a child, obtained by inheritance, that often have more influence than environment in determining its development, and which may have their effects in spite of environment, rather than in accordance with it. Therefore, while the influence of environment is regarded as very real and always to be reckoned with, it is relatively superficial.

This point Professor Walter has discussed as follows:*

"Three factors determine the characteristics of an individual; namely, environment, training, and heritage. It may indeed be said that an individual is the result of the interaction of these three factors since he may be modified by changing any one of them. Although no one factor can possibly be omitted, the student of evolution places the emphasis upon heritage as the factor of greatest importance. Heritage, or "blood," expresses the innate equipment of the individual. It is what he actually is even before birth. It is his nature. It is what determines whether he shall be a beast or a man.

"Environment and training, although indispensable, are both factors which are subsequent and secondary. Environment is what the individual has, for example, housing, food, friends, and enemies, surrounding aids which may help him and obstacles which he must overcome. It is the particular world into which he comes, the measure of opportunity given to his particular heritage.

"Training, or education, on the other hand, represents what the individual does with his heritage and environment. Lacking a suitable environment a good heritage may come to naught like good seed sown upon stony ground, but it is nevertheless true that the best environ-

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**Genetics, pp. 2-4, H. E. Walter, The Macmillan Company.*

ment cannot make up for defective heritage or develop wheat from tares.

"The absence of sufficient training or exercise even when the environment is suitable and the endowment of inheritance is ample will result in an individual who falls short of his possibilities, while no amount of education can develop a man out of the heritage of a beast. Consequently the biologist holds that, although what an individual has and does in unquestionably of great importance, particularly to the individual himself, what he is, is far more important in the long run. Improved environment and education may better the generation already born. Improved blood will better every generation to come."

CHAPTER SIX.

LAMARCK.

Use and disuse.—In 1801 the great French naturalist, Lamarck (1744-1829) published an explanation of evolution which has been prominent ever since. By some Lamarck has been called the "founder of organic evolution," by which is meant that he first put the study of it on a scientific basis. This is hardly true, but Lamarck was certainly the most commanding figure among those who transformed organic evolution from a speculation to a science. Lamarck laid down certain laws, not all of which need concern us here. The most important one deals with what may be called **the motive power** of organic evolution, and this, as Lamarck interpreted it, may be called **the effect of use and disuse.** It is very common to refer to this theory as **Lamarckism.** This idea holds the same place in the teachings of Lamarck that environment holds in the earlier explanation of evolution.

The explanation.—Lamarck's idea may be illustrated by the blacksmith's arm, whose muscles become enlarged by use. Disuse of these muscles, however, causes them to dwindle, and may lead to complete loss of their power. The conclusion is that use develops an organ, and disuse causes it to dwindle until it becomes only a vestige, and may even disappear entirely.

The next step was to discover what determines use and disuse. Lamarck's conclusion was that environment determines them. Any change in the condition of living that calls for the increased use of some organ will result in its increased development. On the other hand, any change that calls for the diminished use of any organ will result in its deterioration. In other words, a changed environment puts the pressure of increased necessity on certain organs, and relieves the pressure on certain other organs. The rolė of environment, therefore, according to Lamarck, is not to mold plastic plants and animals, but to determine the relative amount of use to which their various structures are put. In other words, **environment is not an active agent, but a determining condition.**

Appetency.—The pressure of necessity Lamarck called a **desire** on the part of the animal; that is, the animal desired to do something because it was compelled to do it or suffer the consequences. For this reason he called his explanation **appetency,** or the doctrine of desires. The name was unfortunate, for in developing his illustrations Lamarck used terms that seemed absurd to most people, who were not in a position to appreciate the important fact underlying the words. As a consequence, the theory was a cause of mirth, rather than of serious thought, and the world laughed it to scorn. When the world laughs in such a case it usually means that it has missed the point. At the same time, a few illustrations will show that the world had some occasion for amusement.

Illustrations.—Among the illustrations used by Lamarck, the following are most often quoted. The ancestors of the giraffe had necks no longer than those of horses, and were grazing animals. A change in the conditions of living, or severe competition with other grazing animals, made it necessary, or at least highly advantageous, for these ancestors of the giraffe to feed upon the foliage of shrubs and trees. The repeated stretching of the neck to reach the foliage of trees would result in a certain amount of elongation, just as exercise of a muscle increases its bulk. This somewhat elongated neck, according to

Lamarck, was inherited by the next generation of giraffes, and was elongated still more by them, until finally the giraffes of today attained their very elongated necks. When such a story as this was condensed to the statement, in effect, that the long neck of a giraffe was produced by the desire of many generations of its ancestors to browse upon trees, the theory seemed more like a joke than a sober statement of truth.

In the same way the long hind legs and massive tail of the kangaroo were explained. It was claimed that this extraordinary equipment for leaping was gradually developed by the desire of generations of kangaroos to jump. Of course this meant that through changes in the conditions of living, jumping became a necessity, or at least a great advantage, and continuous use of the jumping structures developed them to high efficiency. It was also claimed that the stilt-like legs of certain wading birds have been developed by the efforts of their ancestors to obtain food in shallow water without wetting their feathers.

When plants came to be included in this explanation of evolution, the term **desire** becomes still more appropriate, but the underlying principle is the same. The pressure to use a certain plant structure results in its development; the removal of the pressure to use it results in its deterioration. In spite of the terminology connected with the first announcement of Lamarckism, the effects of use and disuse must be reckoned with in any explanation of organic evolution.

Acquired characters.—A very important part of Lamarck's explanation remains to be mentioned. It is evident, for example, that the neck of the giraffe could not have been developed as Lamarck described unless the additional length secured by one generation was handed on to the next. In this way each generation would start with a slightly longer neck than the one before. Such a character as increased length of neck, secured by the efforts of an individual giraffe, is called an **acquired character.** If Lamarck's theory is true, it would be necessary for this acquired character to be handed down to the next generation. The theory, therefore, depends upon the inheritance of acquired characters.

It is the general belief now that acquired characters are not inherited, such characters meaning those that have been acquired during the lifetime of an individual. For example, a scar or an amputated hand is an acquired character, and such a character is not inherited. In the case of the blacksmith's arm, the blacksmith's son does not begin life with his father's arm, but needs to develop his own arm. At the same time, it is impossible to state the limits of the effects of all acquired characters. Some of them are obviously superficial, practically surface marks, and therefore cannot affect inheritance. But some acquired characters may be more far-reaching in their effect, and **if the effect includes the reproductive cells, there must be some influence upon inheritance.** In any event, whether acquired characters are inherited or not, the theory of Lamarck has an important bearing upon the later theories, and in modified form **(Neo-Lamarckism)** has a large group of followers today.

Life of Lamarck.

Jean Baptiste Pierre Lamarck was born at Bazentin-le-Petit, a village of Picardy in France, his parents belonging to the nobility. The ministry was selected for him as his career, but he preferred a military life, and at the death of his father he enlisted in the French army. He served with distinction during the Seven Years' War, but met with an accident that ended his military career, and returning to Paris, began the study of medicine. He was led to the study of botany under Bernard de Jussieu, and in 1788 published a "Flora of France," which brought him immediate recognition as a scientific man. In 1871 he was appointed royal botanist, and was commissioned to visit the botanical gardens and museums of Europe. Upon his return he was appointed curator of the herbarium of the Royal Garden, to which he gave its present name of Jardin des Plantes.

In 1793 Lamarck became a zoologist, being appointed professor of invertebrate zoology in the Museum of Natural History, and it was in connection with this study that he developed his views on the origin of species, which were published first in 1801. His great work, however, published in 1815-1822, dealt with the natural history of invertebrates. He studied not only living invertebrates, but also fossil forms, and came to the conclusion that the fossil forms were the ancestors of the forms now living.

Lamarck's private life was filled with sadness and deprivation for he was financially embarrassed and neglected. Through his overwork he became blind, and for the last ten years of his life he had to depend upon an amanuensis; but he was a man of high courage and fine character, and has always been regarded as an epoch-maker. He died in 1829, at the age of eighty-five years.

CHAPTER SEVEN.

DARWIN AND DE VRIES.

Natural selection.—In 1858 Charles Darwin (1809-1882) made the first public announcement of his explanation of organic evolution, calling it **natural selection,** and for nearly fifty years it remained the dominant explanation. It was based upon many years of observation, and these years included a voyage around the world, during which many countries were visited. The enormous number of facts accumulated were described so clearly and marshalled so convincingly in support of the proposed explanation, that it was generally accepted by biologists, and at once exerted a commanding influence upon their work. No book has ever attracted such wide attention, and aroused such general discussion as Darwin's **Origin of Species,** published in 1859. It came at just the time when thinking men were ready for it. In connection with the Darwin Centennial Celebrations of 1909, ample testimony was given by students in many fields of investigation that the influence of Darwin's work has been almost revolutionary. Modern biology really dates from the appearance of The Origin of Species.

Definition.—Darwin's explanation of evolution by natural selection is so important that it will be made the subject of a separate chapter. It is based upon the fact that plants and animals vary so constantly that no two individual plants or animals are alike, even though they belong to the same species. According to Darwin, nature lays hold of these small variations of individuals and increases them until they become larger variations, and so on until they become so large that the individual must be regarded as representing another species. In other words, new species are formed by the gradual increase of small variations.

Mutation.—In 1900 another explanation of organic evolution was announced by Hugo De Vries of Amsterdam, and he called it **mutation.** It was in connection with the development of this theory that De Vries put the study of organic evolution upon an experimental basis, transforming it from a subject of observation and speculation to a subject of exact experimentation. This theory of mutation must be defined more fully in a subsequent chapter. The idea of the explanation came to De Vries in observing the behavior of a certain kind of evening primrose. He found it producing new species directly; that is, among its progeny there were a few individuals that represented species distinct from the parent. It was rather startling to discover that in such a case parent and child are not of the same species. Of course this is a case of variation, but variation of a definite kind that characterizes another species. Such variations De Vries called **mutations,** and therefore his theory of the origin of new species is called the **mutation theory.**

Constant variations.—The variations which De Vries called mutations are very different from those cited by Darwin in connection with natural selection. They occur in very small numbers and are **constant;** that is, they breed true generation after generation. They are not necessarily large or extreme variations; their distinction is that, whether large or small, they are constant. Variations which, according to Darwin, are increased by natural selection are called in contrast **fluctuating variations;** that is, variations which are not constant, but which may appear in one generation and disappear in the next.

According to De Vries, therefore, species do not originate by the gradual increase of small and inconstant variations, but appear suddenly, and are fully equipped species from the beginning. In other words, mutation is the sudden appearance of new species. This contrasts sharply with the idea of their gradual appearance through natural selection.

Complexity of the problem.—The explanations of organic evolution mentioned in the preceding pages, from environment to mutation, represent the general progress in thought and method. Only conspicuous explanations have been mentioned, those that are related in some way to epochs in the history of organic evolution. During the last twenty years work upon evolution has so multiplied and intensified that certain other views must be presented in a later chapter. Moreover, natural selection and mutation have merely been placed in their historical sequence here, and must be discussed more fully, since they are the chief evolutionary theories under discussion today. **As the whole subject of organic evolution develops, it is becoming more and more evident that there is probably a certain amount of truth in all the explanations that rest upon competent observation.** In all probability, to understand the production of new kinds of plants and animals by old ones, we need not only all the explanations that have been offered, but also additional ones. The problem is exceedingly complex, and new forms have doubtless appeared, and are continuing to appear, in a variety of ways.

Epochs in the history of evolution.—Before considering somewhat more fully the most important views as to organic evolution, it will be helpful to fix in mind the historical background. It may be stated as follows:

(1) **Ancient history,** which includes the whole history of man before the year 1800, during all which time organic evolution was a subject of speculation.

It was suspected to be a fact, but no work was done to prove it or to show its possible method. It could not be scientific while men only thought about it. It became scientific as soon as men began to work at it.

(2) **Medieval history,** which includes approximately the nineteenth century. During this period, organic evolution became scientific because men worked at it. Their method of work was observation and inference. They observed multitudes of facts about plants and animals, and then inferred how the facts could be explained. During the first half of this century the science of organic evolution was represented chiefly by Lamarck, but it made very little progress in public approval. During the second half of the century it was dominated by Darwin, and during this time belief in organic evolution became general.

(3) **Modern history** of evolution began with the present century, when De Vries added to observation and inference the method of experiment. The study of evolution had been made a science by Lamarck and Darwin, but it began to be an exact science when experiments began. An observation may be true, while an inference from it may be wrong; but the purpose of an experiment is to demonstrate the truth. The modern history of organic evolution has just begun, so that its chief discoveries lie in the future. They will certainly be far more important and satisfying than any that have been made heretofore.

Life of Darwin.

Charles Robert Darwin is regarded as the greatest English naturalist of the nineteenth century. His theory of natural selection as an explanation of organic evolution produced a revolution, not only in biology, but also in almost all departments of scholarship.

He was born at Shrewsbury, England, February 12, 1809, the son of Dr. Erasmus Darwin, who was also a great naturalist. His mother was a daughter of Josiah Wedgwood, the famous manufacturer of pottery. After studying in the public school at Shrewsbury for a time, he went to Edinburgh University, and then to Cambridge University, where he took his bachelor's degree in 1831. His father wished him to be a minister, but his tastes were for natural history. Soon after he graduated he was appointed naturalist to an expedition under Captain Fitzroy, which was to go around the world. The expedition lasted for five years (1831-1836), and Darwin had special opportunity to investigate the plants and animals of southern South America. His observations upon this voyage laid the foundation for his theory of evolution. One of the classics of travel is Darwin's account of his voyage, entitled "The Voyage of The Beagle." Unfortunately this expedition permanently injured his health, so that after his return he retired to his country place at Down, where he could do only a limited amount of work each day, but by steady application he prepared his epoch-making volumes.

It was in 1858, over twenty years after his return from the voyage of the Beagle, that he announced the theory of natural selection, and even then he only did so at the solicitation of his friends, because a paper had been received from Alfred Wallace, then in the East Indies, containing a strikingly similar explanation of evolution. Darwin had been working at the theory for over twenty years, and his friends felt that he should not fail to present it. As a result, the two papers were read at the same meeting of the Linnean Society of London in 1858. In 1859 the full presentation of the theory appeared in the book entitled "The Origin of Species," a book which aroused the most extraordinary interest. Darwin's subsequent work was dedicated to the demonstration of his theory in a series of studies dealing with both plants and animals. He died April 19, 1882, probably the most honored scientific man in the world.

Life of DeVries.

The name of De Vries is associated with the mutation theory of organic evolution, the most conspicuous theory since Darwin's theory of natural selection. The greatest contribution of De Vries, however, has been to put the study of evolution upon an experimental basis. Before his results were published, the theories of evolution were based chiefly upon observation, sometimes very extensive and prolonged observation, but not upon carefully guarded experiments.

De Vries was born at Haarlem, in Holland, in 1848, received his primary education at Leyden, and afterwards studied at the Universities of Heidelberg and Wurzburg. In 1871 he became connected with the University of Amsterdam as lecturer in botany, and afterwards as professor of botany, retiring from the active duties of the professorship in 1914. In the small botanical garden at Amsterdam De Vries carried on his extensive series of cultures, and in 1901 published the first volume of his great work on the mutation theory. His culture began with Lamarck's evening primrose, found naturalized in a field near Amsterdam, and its remarkable behavior supplied the facts that furnished the basis for the mutation theory.

De Vries has made three visits to the United States, chiefly in the hope of finding Lamarck's evening primrose growing in its native haunts, but this discovery has never been made, and the species seems to have disappeared as a native plant. Although having retired from his professorship, De Vries is still very actively at work, and his more recent cultures have put the mutation theory upon a firmer basis than ever before.

CHAPTER EIGHT.

CAUSES OF NATURAL SELECTION.

Darwin's theory of natural selection is so important that it must be understood. It is most clear when presented just as it developed in Darwin's mind, based upon a vast accumulation of facts. In the following paragraphs, therefore, the facts will be presented in the order which finally led Darwin to his conclusion.

Variation.—In the previous chapter it was stated that no two individuals are alike. We are familiar with this fact among human beings. Children of the same parents are unlike, and unlike the parents. Each individual can be distinguished from all others. This is true of all organisms, plants as well as animals. The principal reason that two grass plants or two squirrels look alike is that we are not familiar with the marks that distinguish them. Among human beings we have become familiar with these marks, and for this reason they look more unlike to us than kinds of plants and animals. If it is remembered that just as great distinctions occur in all kinds of plants and animals as occur in human beings we may appreciate how universal variation is. Variation means therefore, that although there are many kinds (species) of plants and animals, there are very many more kinds of individuals, no individual being the exact duplicate of any other.

Over-production.—When the individuals multiply, the number increases at a very rapid rate. If a plant produces only ten seeds a year, and each of these seeds produces a new plant, and none of the plants die, in ten years there will be a hundred billion plants descended from the first ten. When we remember that each species is represented by millions of individuals, multiplying in this same ratio, it is evident that if all survive there would soon be no standing room. If this **ratio of increase,** therefore, as Darwin called it, be applied to the countless plants and animals that exist, there would not be room enough in the world to contain them. The world is full of plants and animals now, and it is estimated that the number about holds its own, year after year, yet all of them are constantly producing great numbers of eggs and seeds, and other reproductive bodies. It is evident that only enough of the young animals and plants survive to replace the old ones that disappear. Suppose that some kind of plant is represented by a million individuals, and that each individual produces ten seeds. In the next season there are still only a million individuals. This means that ten million individuals have disappeared, and that the surviving million is made up of old plants that have continued to live, and just enough of the new plants to replace the old plants that have died. As this condition is approximately true of all plants and animals, it follows that the great majority of those produced do not survive. **Death is the rule and life the exception.**

Struggle for existence.—At first thought, when one realizes that wholesale destruction is a law of life, it seems to be a very wasteful arrangement. Darwin saw in this apparent wastefulness a result that suggested his explanation of evolution. Among the countless individual plants and animals produced, what determines the selection of the comparatively few that survive? When thousands of plants are produced and only one survives, it means that there is a competition in which for some reason this one individual is successful. Darwin called this competition the **struggle for existence,** an apt phrase that has been much in use ever since. Of course plants and animals do not struggle in a literal sense; they simply compete with one another for a living, and since there is not enough living for even a majority of them, only one from a great number wins in the competition. This one individual differs from all its unsuccessful rivals, for no two plants are exactly alike. The inference was that this difference, whatever it may be, gives the successful plant an advantage over all its rivals. In other words, in possessing this variation, the plant is better adapted to the conditions of living than are its competitors. In this way the favored variation survives and the unfavorable variations perish.

Survival of the fittest.—When this selected individual, selected by competition, produces progeny, the new individuals compete again, and the advantageous variation is again selected by competition to survive. So long as the conditions of living remain the same, it is evident that this same successful variation will be selected for survival, generation after generation. This is what is called **continuous selection.** It not only chooses the same variation from generation to generation, but in so doing it increases this variation. If the conditions of living should change at any time, the same variation would probably be no longer successful, for some other variation would now be better adapted to the new conditions.

Herbert Spencer called the result of this selection **the survival of the fittest.** The struggle for existence results in the survival of the fittest, and it is quite obvious that the struggle for existence is brought on by the ratio of increase described above. Some writers hold that the expression **destruction of the unfit** expresses the fact more accurately than survival of the fittest. In some cases it is not accurate to call those that survive the fittest.

Illustration of the theory.—The result of a continuous selection of a certain characteristic may be illustrated as follows. Suppose that an assemblage of plants of the same species differ among themselves in the breadth of their leaves, and that a broad leaf is a favorable variation. In the competition among these plants, those with the broader leaves would survive, and the individuals with narrower leaves would perish. These broader leaved individuals would then produce another generation of plants, much greater in number than could survive. In this next competition the broader leaved individuals would be selected again for survival, and so on, generation after generation. The result would be not only the continuous selection of individuals with the broader leaves, but the leaves would gradually become broader. In other words, **the continuous selection of any variation increases that variation.** A slight increase in breadth in one generation is added to the next, thus piling up small variations, until the result becomes large. The **inference** is that a variation may become so increased by continuous selection that finally we arrive at a different species, but it is just here that new evidence throws doubt upon the validity of this theory of species formation; there appear to be limits beyond which the variations of species do not go.

CHAPTER NINE.

EVIDENCES OF NATURAL SELECTION.

Effects of domestication.—The most important evidence that species originate in the way described by Darwin is obtained from the experience of men in cultivating plants and domesticating animals. This experience has extended through thousands of years, so that there has been abundance of time to show what continuous selection is able to do. Plants and animals have been brought from the wild state and subjected to the guidance of man, and in many cases remarkable changes have resulted. So different from their wild originals have many plants and animals become that the relationship to the originals is hard to determine. In some cases the originals appear to be entirely lost. There is many a cultivated plant which, if found growing among the wild plants from which it descended, would be regarded as a different species. Darwin seemed justified, therefore, in concluding that what may be regarded as new species have been produced by cultivation.

Illustrations.—For example, the wild original of the cabbage does not suggest the cabbage of the gardens at all. It is a plant with a rosette of small leaves at the base, from which arises a slender stem bearing a series of flowers, and later, pods. From this wild plant man has produced not only the cabbage, but also such dissimilar plants as cauliflower, Brussels sprouts, kale, and kohl-rabi.*

**See Frontispiece.*

Some of these forms are so much unlike that, if they had been produced in nature, they would hardly be regarded as the same species. Every one knows how unlike the various races of dogs have become, yet most of them are found to have been derived from a single wild species. A notable illustration is also furnished by the numerous varieties of pigeons that are so dissimilar, and still have all been derived from a single wild species. It is impossible to consider such cases and not conclude that species, by the manipulation of man, can be changed very greatly, and perhaps so much so that they result in what may be regarded as new species.

Control of changes.—It is important to know what man has done to produce such changes in plants and animals. That the changes are not merely accidents is shown by the fact that they are in the direction of the needs and tastes of men; in other words, it is evident that man has chosen the changes he wants. We have learned that plants vary in every direction. Man, in trying to improve plants, has selected some one direction among the many that are possible. He may select for large or small leaves, large or small flowers, large or uniform tubers, or for any character that is included among the variations, and by continuous selection he can increase this particular variation.

The cultivation of the potato furnishes a simple illustration of this process. The wild original of the potato, growing in the mountainous regions of western America, has very small tubers. Among all the variations shown by the wild potato man chose the variation of larger tubers. He selected larger tubers for propagation, and, continuing this selection from generation to generation, the average size of the tubers became larger until the present size was reached. Man might as well have selected for larger flowers, and the result would have been a potato plant with much larger flowers than any now known.

Just this thing has been done in the case of the chrysanthemum. The wild original of the cultivated chrysanthemum has very small flowers, but by continuous selection for size, remarkably large flowers have been secured, showing clearly that this process is under the guidance of man. Experiments have been performed also with plants whose flowers have been much increased, and this result has been reversed. Selection for smaller flowers was begun, and generation after generation the flowers dwindled until remarkably small ones were secured. It seems clear, therefore, that the changes produced in cultivated plants and domesticated animals have been guided by man.

The conclusion.—This process of continuous selection by man is called **artificial selection.** Darwin concluded that the same kind of selection is going on in nature, and called it **natural selection.** His explanation of evolution, therefore, is **that new species are produced by natural selection, just as new forms are known to be produced by artificial selection.** This means that nature continuously selects favored variations, just as the gardener does. Of course one must not personify nature, and say that it works like the gardener, selecting consciously for some favored variation. The way nature selects is by means of the competition among individuals (struggle for existence), and competition is brought about by a ratio of increase which results in producing many more individuals than can survive. The favored variation in the competition is the one that is best equipped to live in the conditions in which the competition occurs. So long as the conditions remain the same, the same variation will be selected and thereby increased.

Summary of natural selection.—Darwin gives such an admirable summary of his theory of natural selection in the closing paragraph of his Origin of Species, that no presentation of the theory would be complete without it.

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. These laws, taken in the largest sense, being growth with reproduction; inheritance which is almost implied by reproduction; variability from the indirect and direct action of the conditions of life, and from use and disuse; a ratio of increase so high as to lead to a struggle for life, and as a consequence to natural selection, entailing divergence of character and the extinction of less-improved forms. Thus, from the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed laws of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."

Isolation.—In connection with the consideration of natural selection, a statement may be made in reference to the **effect of isolation.** By many students isolation is regarded as a very important factor in organic evolution. By this is meant that through isolation from closely related forms, a variation may develop into a distinct species. The effect of isolation has been noted conspicuously in connection with the migrating forms, notably fishes. For example, if certain fishes have spread through a drainage system, some stream may be cut off from the rest of the system and its inhabitants isolated. This isolated group of individuals, separated from the great mass of its kind, may develop variations that are not merged and lost by crossing with numerous other kinds of individuals. This is a kind of natural selection that separates one kind of variation from others and permits it to survive. This isolated variation is likely to be emphasized from generation to generation, until finally the isolated group of individuals becomes quite different from those with which they had a common origin.

If the effect of isolation be analyzed it will be realized that it does not produce species, but gives them a chance to develop. It does not account for the origin of species, but may account of their variation from parent forms. It is really one kind of natural selection, for it is one of the methods by which nature may be said to select certain variations to survive. However, it is not a selection through competition, as is the struggle for existence, but selection through isolation.

CHAPTER TEN.

OBJECTIONS TO NATURAL SELECTION.

The beginning of doubt.—The theory of the origin of species by natural selection as explained by Darwin was so convincing that it was accepted for many years as an adequate explanation of organic evolution, and it stimulated investigation as no other theory of biological science has ever done. But as investigations multiplied and became more rigorous, doubts began to be expressed. These were not doubts as to the **facts** of natural selection, but doubt as to the **adequacy** of natural selection as an explanation of the origin of species. When these doubts were formulated it became evident that although natural selection must be in operation, in the sense that some forms survive and others do not, it is not clear that the result of this operation is the production of new species. Some of the objections to natural selection as an explanation of the origin of species are as follows:

Boundary of the species not crossed.—It has been claimed that natural selection cannot bridge the gap between one species and another. It deals only with those small variations that fluctuate from generation to generation. Although these may be increased in various directions by continuous selection, they have never been known to cross the boundary line of the species. This objection claims, for example, that the cabbage, with all of its surprising modifications under cultivation, has not produced a new species. The validity of this objection depends, of course, upon the definition of species.

Unfit forms survive.—It is also claimed that the forms selected have not always been the "fittest." In fact, many "unfit" forms survive. Natural selection seems to be haphazard, rather than determined by fitness and unfitness. If this be true, there would be in nature no continuous selection of a favored variation, hence no such increase of a certain kind of variation as occurs in artificial selection, and hence no production of new species. The idea of adaptation (fitness) is so bound up with the theory of natural selection, that if forms survive that are not adapted, natural selection loses a part of its machinery.

When the idea of adaptation was dominant, great ingenuity was displayed in explaining the fitness of every structure. For example, the thorns of plants were said to be selected for survival because their presence is a protection against grazing animals. In other words, thorny plants survive because protected, and conversely, thornless plants were destroyed. However, thorns chiefly prevail among plants in regions without grazing animals, and, even if grazing animals are present, the thorns do not appear in the early stages of the plant, when they are most needed. Conversely, the plants chiefly attacked by grazing animals are singularly free from thorns. Experimental work has shown that thorniness is largely a response to poor nutrition, and it may or may not be a permanent character.

Another illustration may be taken from the elaborate stinging hairs of the nettle. According to Darwin's explanation, these structures were built up by natural selection, with adaptation as the principle of selection. It has been found, however, that the nettle is indifferent to the presence of these stinging hairs; it gets along very well without them.

Many seeds, especially those of dry regions, develop a seed coat so hard that it interferes with the breaking through of the young plant. If selection is working in these cases, it is working towards over-adaptation.

Perhaps the most striking illustration in this connection has been developed by recent investigation of those plants which have nectaries (organs which secrete nectar) on other parts of the body than the flower. Over a hundred species of such plants were investigated. The old view in reference to these extra-floral nectaries was that they attract ants, which in turn defend the host plant from its enemies. Such plants were called **ant-loving.** Now it appears that any such use for these organs is out of the question. The sweet secretion often begins late in the life of the plant, so that any protection it affords is lacking when most needed. In some cases the secretion begins very early in the life of the plant, and soon fails, leaving the maturing and adult plant unprotected. Also the nectar of many of these forms is actually avoided by ants and other insects, and the honey-seeking ants are not combative, and never attack other insects visiting their hosts. In fact, these nectaries often attract insects of all kinds which damage the plants in many ways, so that if nature selected these structures, it has been selecting harmful structures.

Selection without distinct advantage.—Another objection to the theory of natural selection is that **it demands that the selection be made before the variation is large enough to be of real advantage.** In other words, the selection appears to be made with a view to future advantage, rather than present advantage; a thing which is obviously inconsistent with the rest of the theory.

This objection may be made clear by the simple illustration previously used. Imagine that a plant with narrow leaves would be more "fit" if its leaves were broad. According to the theory of natural selection, the broader leaved forms would be selected and the narrower leaved forms would be destroyed. As a result the breadth of the leaves would be increased gradually, and finally the more fit, broad-leaved forms would be reached. In other words, the really fit forms, those that would have a decided advantage over the others, and would be selected on the basis of a life and death advantage, appear only after generations of selection. It is a fair question to ask what determines this selection in a given direction before real fitness has been obtained. It is asking nature to pass upon a prophecy rather than a performance.

Selection cannot originate new characters.—Perhaps the most important objection to the theory of natural selection is that it cannot originate new characters, even if it can modify old ones. Each species of plant or animal is distinguished by a group of characters. Natural selection may be able to lay hold of this group of characters and so arrange them as to produce a new kind of individual, yet it is entirely incapable of introducing a new character. Its operations are limited to those characters that already exist. The situation may be illustrated by a pack of cards. Any combination of cards may be selected from a pack, but selection cannot introduce a new kind of card.

The great groups of plants and animals differ from one another in the presence or absence, not of a few, but of many characters. Closely related species may be likened to the individual waves that appear on the surface of a choppy sea, while the deeper seated changes, which involve the appearance of new characters, may be likened to the great oceanic currents, whose movement and direction proceed with no relation to the choppy surface. It seems probable that if natural selection produces new species, such a result is limited to groups of closely related species, and that the most important differences between large groups are to be explained in some other way. However, it is evident, even if natural selection does not produce new species, it must operate in determining the successful ones. In other words, if it does not produce species, it at least determines the fate of species.

CHAPTER ELEVEN.

MUTATION.

Lamarck's evening primrose.—De Vries is a botanist at the University of Amsterdam. About twenty-five years ago, during a botanical excursion, he discovered in a waste field an evening primrose which proved to be an American species that had been accidently introduced. It was rapidly taking possession of the field. This primrose curiously enough bore the name Oenothera Lamarckiana, given in honor of Lamarck. It will be remembered that he was the first great student of organic evolution, and this plant, named after him, was to become the basis of a great modern theory of evolution.

The fact that this American plant was establishing itself in Holland would have been interesting enough, but of far greater interest was the fact that two other species were found associated with it, and these proved to be new; that is, they had never been described. This suggested to De Vries that there might be some connection btween the American primrose and these new species that were growing with it.

Pedigree culture.—De Vries took the three kinds of primroses to his botanical garden and began a long series of pedigree cultures. This means that the pedigree of each individual plant was recorded, just as are the pedigrees of fine stock. Taking seeds from the American primrose, he obtained from them thousands of seedlings, and among these seedlings there appeared a few specimens of the two new species he had observed in the waste field. This was a demonstration which confirmed his suspicion that they were really derived from the American primrose. Continuing his series of cultures, generation after generation, through twelve or thirteen years, he not only found these new species appearing repeatedly, but he found others as well, so that finally about a dozen new species had appeared, all produced by the American primrose. These new forms occurred always in very small numbers, approximately about two among a thousand seedlings of true Oenothera Lamarckiana, so that they were really rare exceptions. What De Vries had demonstrated, therefore, was that these new species, instead of being built up gradually, according to the theory of natural selection, appeared suddenly in a single generation. Forms appearing in this sudden way are called **mutants**, and since De Vries found that new species might appear as mutants, his explanation of organic evolution is called **the theory of mutation.**

Breeding true.—One of the tests of a species is its constancy; that is, its tendency to breed true. In the case of these mutants from the American primrose, they continued to show their distinctive characters generation after generation, without any symptoms of reverting to the original parent form. In other words, the mutant had leaped over the boundary of the parent species, and none of its progeny ever fell within the boundary. A new species was evidently born full-fledged. This constancy was proved with all of the new species that arose as mutants. The same new species would reappear several times in different generations, so that the species were not born once for all, but might be repeated indefinitely by the parent form.

Ordinarily closely related species are indistinguishable in their early stages, so that botanists have learned to wait until maturity to be sure of the differences, but these new evening primroses are quite as distinct in the seedling condition as in the adult. This means that their difference from the parent form is not a small one, to be recognized only by trained botanists, but a very large one that is evident to the untrained eye.

Two kinds of variation.—It is often said that mutants are merely large variations, and that the difference between natural selection and mutation is that the former increases small variations and the latter uses large ones, such as were formerly known under the name of **sports.** This is a mistake that should be corrected, **for amount of variation is not the criterion of a mutant.** A mutant is a variation, whether large or small, which is constant through generations of breeding. A fluctuating variation is one, whether large or small, which is not constant. Natural selection calls for the gradual increase of fluctuating variations; mutations calls only for mutants.

Role of natural selection.—Even if species in general have been produced by mutation, the role of natural selection must not be forgotten. Quite a number of the new species produced as mutants by Oenothera Lamarkiana would not have been able to survive in nature. In nature they would have disappeared. It follows, therefore, that many mutants are doubtless produced which are incapable of continuing, and that natural selection determines which of them shall survive.

Results of artificial selection.—Before presenting this new explanation of evolution to the world, it was necessary for DeVries to explain many facts involved in the new theory. He had to make his view consistent with the new forms of plants and animals produced by artificial selection, the process that formed the principal basis for Darwin's theory of natural selection. If natural selection as an explanation of the origin of species can be demonstrated at all, it is by artificial selection. It is clear that by means of artificial selection man has improved the plants and animals he uses. He has modified them very much, and it is certain that he has modified them by increasing small variations. It was necessary for DeVries to examine the long records of plant breeding and to get at the facts in the case.

He discovered that the modifications fostered by artificial selection have resulted merely in improvements, and that these improvements are rarely constant. Whenever the fostering care of man is removed from these highly developed plants they revert; in other words, they are not constant. They do not stand the most obvious test of a species. It was natural for De Vries to conclude, therefore, that while species have been modified by artificial selection, new species have not been produced in this way.

Mutation in cultivated plants.—In looking through the records of cultivated plants, De Vries found that there are a few forms which seem, because of their constancy, to be entirely new species. If artificial selection could produce such different and constant forms, then natural selection might produce species. But upon tracing the records of these really new and constant forms, so far as records were available, De Vries found that in every case they always appeared suddenly, as solitary individuals, and not by any process of selection. It seemed to him quite clear that they were simply mutants. This means that the few new forms produced by plant-breeding have appeared as mutants, and not by selection.

A simple illustration is Burbank's lavender scented dahlia. Dahlias are not prized for their fragrance, and a lavender scented dahlia is quite a remarkable exception. Burbank cultivates plants by the thousands. In going through a field of dahlias he detected the lavender fragrance, and discovered that it came from a single individual. This individual was propagated and a race of lavender scented dahlias developed. This new kind of plant, therefore, was not worked for in any way; it simply appeared as a new kind among thousands of ordinary kinds, and pedigree culture multiplied it, for its characteristics proved to be constant. The general conclusion is that the great majority of improved races of plants are due to artificial selection and are inconstant; while a few forms are mutants and therefore constant.

CHAPTER TWELVE.

OBJECTIONS TO MUTATION.

Are mutants general?—It is evident that if mutation is the explanation of the origin of species, it should be observed not only in Oenothera Lamarckiana, but among plants and animals in general. The search for mutating forms in nature has not been strikingly successful, but it must be remembered that mutants can be recognized with certainty only after generations of pedigree culture. They cannot be recognized at sight. One may suspect that a certain plant is a mutant, as De Vries did when he first saw his evening primrose and its companions in the vacant field, but one must cultivate both the plant and the suspected mutant through several generations in order to prove it. To demonstrate that mutation is or is not a general process, therefore, will take much time and labor.

It has been proved more recently that other species of Oenothera are mutating freely, and this is probably a feature of the whole genus. Other plants that have been found to mutate as freely as the evening primroses are the common shepherd's purse (Capsella) and the violets. Work among the insects has also revealed certain kinds mutating freely, or at least giving rise to a great number of different forms which breed true.

How are intergrades accounted for?—If species appear as mutants, that is, are born full-fledged with all their distinctive characters fully developed, how are intergrades to be accounted for? It will be recalled that the occurrence of intergrades in nature was one of the very first facts that called attention to the possibility of organic evolution. An intergrade is a form that shows characters intermediate between two species, and frequently two species are completely connected by a series of such forms. According to the theory of mutation, intergrades can be explained only as being hybrids produced by the crossing of the mutants and the parent form. A hybrid usually shows characters belonging to both parents, and therefore would look like a form between the two species. In other words, according to Darwin an intergrade is a form **on the way** to becoming a new species; while according to DeVries an intergrade can appear **only after** a new species has been produced.

Is Lamarck's evening primrose a hybrid?—This leads to the very important question whether Oenothera Lamarckiana itself may not be a hybrid, and the so-called mutants from it merely species that have entered into the hybrid mixture. In that case mutants would not be new species. De Vries recognized this possibility and therefore sought to discover some sure test of a hybrid. In this search he made a most interesting and important discovery; he resurrected a long buried and very important piece of work.

Mendel's law.—**Gregor Mendel** was an Austrian monk who, about the middle of the nineteenth century, conducted experimental work in his monastery garden in the effort to discover the laws of heredity. It was work very far in advance of its time, and it remained in oblivion for nearly fifty years. Then it was discovered by De Vries and certain other investigators. Since then Mendel's law has become the best known and most used law of heredity. Not only has this law formed the working basis of most of the work in heredity since, but Mendel's name has given rise to such words as **Mendelian** and **Mendelize.** Since Mendel's law furnishes De Vries the needed test for a hybrid, it must be explained in this connection.

Mendel worked with hybrids because the contribution of each parent to the progeny is much more evident when the two parents are dissimilar, as is necessarily the case in hybrids. Crossing magnifies the result. A hybrid in the study of heredity is much like a microscope in the study of structures. Any law of heredity which applies to hybrids must also apply to their parents, so that it is a law of heredity in general.

Mendel found that hybrids combine the characteristics of both parents. Hybrids, however, do not breed true. The "children" combine the characters of both parents, but all the grandchildren do not continue this combination. The grandchildren include three different kinds of individuals; some resemble the male grandparent, others the female grandparent, and others continue the mixed character of the hybrid parents. The hybrid generation (the children) is called the F_1 generation, and the next one (the grandchildren) the F_2 generation. The F_1 generation includes only hybrids, while in the F_2 generation they split into the three kinds of individuals mentioned above. Mendel's law is that **in this splitting there is a definite ratio.** If a hybrid produces four individuals, one resembles the grandfather (one of the parents of the hybrid), one resembles the grandmother, and two the hybrid itself. This ratio is usually expressed as 1:2:1.

It follows that half of the F_2 generation (grandchildren) are not hybrids, but are pure forms. In other words, the original forms that entered into the hybrids are split off and are no longer a part of the hybrid mixture, which is continued by half the hybrid grandchildren. In the F_3 generation (great-grandchildren) the same splitting occurs in the same ratio, and so on, generation after generation. In each generation from hybrids, therefore, approximately half of the individuals produced are not hybrids, but pure forms. They bring back the type of the original parents.

Application to mutants.—Mendel's law supplied De Vries the test for hybrids he was seeking. When De Vries discovered that his evening primrose was producing mutants in each generation it was natural to inquire whether the primrose is not a hybrid, and the mutants the pure forms that split off in each generation. He recognized the possibility, but concluded that Mendel's law answered the question. The mutants appear in very small numbers, about two out of a thousand individuals; they do not appear in any definite ratio; and are by no means always the same kind of forms. It is obvious that no one of these facts accords with Mendel's law. The evening primrose was very far from behaving like a hybrid. It was concluded, therefore, that mutants are not to be explained as the splitting of a hybrid, and that Oenothera Lamarckiana is a pure form.

Hybrids in nature.—A great many hybrids exist in nature. Many so-called species are mixtures in which several kinds of individuals have entered. There are not only hybrids that result from the crossing of two species, but several species may enter into the hybrid mixture. That this is possible is illustrated by the triple hybrid produced by Burbank. This notable hybrid is the so-called Shasta daisy, in which there has been combined an American daisy, an English daisy, and a Japanese daisy, each contributing certain characters which may be recognized in the mixture. The American daisy is a free bloomer but has a very ungainly body, the English daisy has a handsome upright body, while the Japanese daisy has flowers of a pearly luster. The Shasta daisy combines the free blooming of the American form, the handsome carriage of the English form, and the pearly luster of the Japanese form. Such conspicuous mixtures, and even more complex ones, undoubtedly occur in nature.

According to Mendel's law, any so-called species may be tested as to whether it is a hybrid or a **pure strain.** By a series of cultures it is theoretically possible to discover whether a so-called species is a hybrid, and if it is, to reveal the species that have combined to produce it, for they should appear in pure form in each generation. De Vries distinguished, therefore, between species as generally recognized, which may or may not be hybrids, and **elementary species,** which are pure strains, and which may exist in nature as pure forms, or may be variously combined into hybrids. It is becoming a very important part of the work of plant-production to split up the mixtures represented by most of our crop plants and isolate the pure strains of elementary species that have been combined to produce them. It is much like analyzing a chemical compound and discovering its constituents.

Mutation on trial.—The explanation of organic evolution by the theory of mutation is still on trial. Far too little time has elapsed to make the experiments necessary to prove it or disprove it. Some biologists accept it unreservedly, and others reject it just as unreservedly; while others are waiting for more evidence. There is no question as to the facts recorded by De Vries in reference to the behavior of Oenothera Lamarckiana, or as to the fact that his mutants are true species. The questions that remain to be answered are as follows: Is mutation general among plants and animals or is it exceptional? Are the mutants really new species or old ones disentangled from the hybrid mixture? Mendel's law seems to contradict the idea that it is hybrids, in the forms studied, that produce mutants, but it still a question whether Mendel's law is infallible, or whether by it the behavior of such complex mixtures as must exist in nature may be always interpreted. In any event, it seems true that mutation is one of several ways by which new species have appeared.

Life of Gregor Mendel

Mendel was a monk and an abbot, but he was the founder of the modern science of heredity, usually called genetics. His experimental work in the cloistered garden of the monastery of Brunn, Austria, resulted in a view of heredity that has been made the basis of all modern investigation of this subject.

Mendel was born in 1822 in Austrian Silesia, in Hinzendorf, and in 1843 entered the Augustine convent at Altbrunn as a novice. He was ordained a priest in 1847, studied afterwards in Vienna, and in 1853 returned to the monastery, becoming a teacher of natural science in the high school (realschule) in Brunn. Soon he began his famous experiments upon the common pea, and after eight years of work, published his results in 1865, in the Proceedings of the Natural History Society of Brunn. The subject of the paper was announced as "Plant Hybrids," and this paper of 40 pages has become a great biological classic. For thirty-five years it remained unnoticed, for during that time scientific men were chiefly interested in the general theories of evolution, notably the one proposed by Darwin. In 1900, however, the paper was discovered and announced simultaneously by three botanists who were experimenting with plants. These botanist were De Vries of Amsterdam, Correns of Leipzig, and Tschermak of Vienna.

In 1868 Mendel was appointed abbot of his monastery, and for a time continued his experimental work, but in 1873 he abandoned it on account of the administrative cares of his position. He died in 1884, being denied the privilege of knowing the great fame that was to begin to come to him sixteen years later.

CHAPTER THIRTEEN.

ORTHOGENESIS.

Indeterminate variation.—Natural selection, either by means of competition or isolation, makes use of fluctuating variation, which is usually quite small in amount in any given generation, and is always inconstant. Mutation uses those variations which are constant, and which are usually relatively large in amount. In both cases the variations occur in every direction, and this has been called **indeterminate variation.** Variation of this kind has no definite determined direction. If such a variation appears, conditions must determine whether it will be allowed to persist. It is something like shooting at a small mark with a shotgun; some one shot may reach the mark, but most of them will not.

If we pass from the consideration of closely related species, which may have become separated from one another by indeteminate variation, either through natural selection or mutation, to the consideration of great groups, we discover a situation that indeterminate variation cannot explain. Of some of the great groups we have historical records and are able to trace the changes that have occurred in them through millions of years. The history of gymnosperms (pines and their allies) may be used as an illustration.

History of gymnosperms.—This history extends from before the Coal Period to the present day. Their changes through all this immense stretch of time are recorded in fossils. In studying fossil plants we are no longer dependent upon external appearance only for our knowledge of their structures. Methods have been devised by which they are sectioned as completely as are living plants, and their internal structure is as well known to us as is that of living forms.

This ancient group, the gymnosperms, stands among plants as one of remarkable rigidity. Its members seem to be about the least plastic of land plants, and least responsive to changes in external conditions. It would seem that natural selection among these rigid forms can hardly be more than the accident of overcrowding. Certainly we discover no kind of variation in them that even suggests the coming characters of another species. In spite of all this rigidity, which means lack of variation, the group as a whole shows series of progressive changes which can be traced without break or change of direction from the Coal Period to the present day. A few illustrations may serve to make this situation intelligible.

In pines the structure which produces the female sex organs is within the ovule. The ovule later becomes the seed. Not only is this female structure imbedded in this way, but the ovule, and later the seed, has a heavy wall. The ovules are in the cones, protected by over-lapping scales. If any structure is shut away from the influences of a changing environment, it would seem to be this female structure with its egg-producing organs; and yet, through the whole series of gymnosperms, this structure shows a gradual and a progressive transformation. This transformation involves the earlier and earlier appearance of the eggs in the history of the female structure. In the beginning of the history this structure reached full maturity before the eggs appear; at the present time the eggs appear almost as soon as this structure begins to develop, and between these two extremes every step in this progressive change has been discovered. This change is not a haphazard one that occurs here and there among gymnosperms; it is a change that belongs to the whole great group. It is beyond the reach of experiment, it seems to be beyond the influence of environment, and it maintains one steady direction.

The embryo of gymnosperms furnishes another illustration of a progressive change extending through an indefinite period, and the embryo is just as far removed from outside influence as is the female structure which produces it. It is sometimes claimed that such changes are due to the fact that these structures have ceased to be useful, and therefore are gradually being eliminated, according to Lamarck's hypothesis. No one can say how useful they are, but no one can deny that they are alive and at work. There is another structure, however, that cannot be open to any such objection. The vascular system, which constitutes the wood of gymnosperms, is the great water-conducting system, and shows the same kind of progressive change from the early forms to the present forms. No one would venture the claim that the vascular system has ceased to be useful.

Determinate variation.—These are but illustrations of many structures that show progressive changes, not only among gymnosperms, but in any group whose history has covered a long period. These changes are persistent in definite directions, through all imaginable changes of external conditions and competition. In other words, these progressive changes occur in certain directions, in spite of any conceivable effect of changed conditions, of natural selection, or of mutation. Such apparently predetermined and persistent variation in a definite line is called **determinate variation,** and the origin of new species by determinate variation is called **orthogenesis.**

Naegeli.—No investigator is so exclusively identified with the doctrine of orthogenesis as is Darwin with natural selection, or De Vries with mutation, but perhaps the earliest man to put this idea in form was Naegeli, a Swiss botanist, who became a professor at Munich. His publication on this subject appeared in 1883. He called his conception **progressive evolution,** which is briefly defined as **the transformation of species from internal causes.** What determines this persistent variation in one direction through countless ages scientific imagination has not been able to suggest. It is simply regarded as a fact which no explanation of evolution has been able to include.

Summary.—Natural selection, mutation, and orthogenesis are not mutually destructive; that is, one may believe in all of them. Natural selection deals with fluctuating variation that occurs in every direction; mutation deals with constant variation that occurs in every direction; and both result in developing groups of closely related species; but orthogenesis deals with the relatively few variations that persist and increase from generation to generation, carrying forward great groups as a whole. In other words, orthogenesis may be likened to the great oceanic currents that represent a deep mass movement quite indifferent to surface conditions; while natural selection and mutation may be likened to the wind that breaks up the surface of the water into waves.

CHAPTER FOURTEEN.

THE PROBLEM OF HEREDITY.

Variation.—If plants and animals did not vary, it is obvious that new species could not arise by any natural process. Therefore, evolution depends upon variation, whether it is to be explained by natural selection, mutation, orthogenesis, or any other natural method. It is one thing to explain how new species may arise by means of variation, but it is quite another thing to explain variation. Darwin, De Vries, and other students of organic evolution accept variation as a fact, without any attempt to explain it. It is more fundamental to inquire how variations arise, and this question must be answered by investigations of heredity. The study of evolution, therefore, has led to the study of heredity, and a vast amount of experimental work has been done. Laboratories and experimental farms and gardens have been established in various parts of the world for the study of heredity. It is becoming more and more evident that **variations are responses by the organism to the various conditions under which their development takes place.** Some of these conditions belong to the environment, to which structures respond in various ways. Other conditions undoubtedly occur within the structure of the plant or animal itself, the bodies of plants and animals being made up of very complex substances which react upon one another in a great variety of ways.

Insufficiency of ordinary observations.—In looking through the vast amount of data contained in the reports of investigations in this field, it becomes evident that they have to do with what may be called **end results.** The parents are observed and the progeny are observed, and inferences are drawn as to the laws of heredity, but all the processes that lie between parents and progeny, determining the character of the latter, are unknown. The situation suggests a train, observed upon leaving its station, and observed again upon arriving at its destination, but not observed at all upon all the long road between. The data we have about heredity show how the process is started, and the results secured, but just how a given start has produced a given result is not at all clear. We see the result but not the process.

Heredity is a seductive subject, for in the absence of exact facts its intense interest leads to much vague thinking and statement. When it is discovered what we really know concerning heredity, the result is generally disappointing, for the bulk of the literature is a record of inferences, and one glides insensibly from fact into fiction. It must be remembered that neither vague statements nor technical phrases explain anything. Once I was speaking of the resemblance of certain children to their grandparents or more distant ancestors, and a gentleman remarked that "this phenomenon is merely **atavism.**" He thought he was explaining it, but he had confused terminology with knowledge. To him the technical name of a phenomenon stood for its explanation. The literature of heredity is full of "explanations" that do not explain; facts have received names, but names are not explanations.

A difficult problem.—Heredity is probably the most important and the most difficult problem in biology. It means the transmission from parent to offspring of a similar structure, but not an identical one, for the child varies in such a way that it can be distinguished from any other individual. Heredity involves therefore the transmission, not only of similarity, but also of dissimilarity, which we call individuality. Some of the physical machinery of heredity has been brought to sight in our biological laboratories, but the motive power that drives the machinery and secures the results is illusive. In other words, our knowledge is like that of one who has become acquainted with the parts of some machine, but has never discovered what makes the machine run.

Reproduction.—It is well to realize what the production of a new individual involves. Among the lowest plants and animals every cell of the body has the power of reproduction, but among the higher plants and animals, with more complex bodies, most of the cells have lost this power, and the reproductive cells are comparatively few in number. They are often thought of as highly specialized cells; that is, cells that have become very different from ordinary cells; but really **they are the only ones that have retained the primitive power of all cells.** It is the other cells of our body that have been modified, and in the process they have lost the power of reproduction. A reproductive cell, therefore, is a primitive type of cell, and not a specialized type.

Four stages.—In the production of a new individual by a reproductive cell four general stages may be recognized. **One stage** is that of cell-multiplication, by means of which the single initial cell (the fertilized egg) produces a multitude of similar cells. It is evident, however, that the completed body is not merely a mass of similar cells. **A second stage** is that of cell-differentiation, by means of which cells become unlike, forming in the human body, for example, such dissimilar cells as muscle cells, nerve cells, bone cells, etc. It is evident, however, that the completed body is something more than a mass of cells of different kinds, just as a house is more than a mass of different building materials. **A third stage** is that of cell-organization, by which the various kinds of cells are organized together in the formation of organs, as hands, eyes, etc., in the human body. It is evident, however, that the completed body is more than a collection of various kinds of organs. **The fourth stage** is that of body organization, by which the various organs are related to one another and come to work harmoniously as parts of one machine, the completed body. This long process, from the division of the fertilized egg to the completed body, is under such directive control that the series of changes, once initiated, follows a perfectly definite path and reaches a definite result. It is this far reaching, directive control that baffles explanation as yet.

CHAPTER FIFTEEN.

MACHINERY OF HEREDITY.

Characters.—A brief account of the visible machinery of heredity will help to an understanding of some of the phenomena. When the cell divides to form two new cells, the characters of the parent cell are transmitted to the new cells. What happens in this case may serve as an introduction to what happens in the transmission of characters from one individual to another.

The use of the word "character" in discussions of heredity may need some explanation. A **character** is any feature that characterizes an individual, and especially those features that serve to distinguish it from other individuals. A white flower is one of the characters of certain plants, especially as contrasted with other colors which characterize the flowers of other plants. Hairiness is a character of many plants, as contrasted with the smoothness of other plants. An individual, therefore, is a group of characters and the study of heredity is the study of the way in which these characters are transmitted from parent to offspring. It must be understood that characters are not things that can be handed down bodily from one generation to the next, but they are features that appear in an individual for some reason, and when it is said that they are transmitted to offspring it is simply meant that for some reason these same features reappear in the offspring.

Protoplast.—A living cell consists of a minute bit of living substance called **protoplasm**, the only material in which life manifests itself. On this account **Huxley** called it the **physical basis of life.** The only substance that is alive and working in our bodies is this protoplasm, which is organized into innumerable cells. When it stops working the body is dead. The protoplasmic unit, organized into a cell, is called a **protoplast.** In other words, protoplasm is the material and the protoplast is the working body made of this material. Our living body, therefore, is simply made up of a countless number of protoplasts. In plants the protoplast usually surrounds itself with an elastic wall, composed of a material called **cellulose;** while usually in animals no such wall is formed. This accounts for the fact that plant bodies in general are more rigid than animal bodies.

Organs of the protoplast.—The protoplast is not homogeneous protoplasm, but comprises at least two very distinct protoplasmic organs, **nucleus** and **cytoplasm.** The nucleus is relatively compact, usually spherical, and centrally placed. The cytoplasm invests the nucleus and forms the bulk of the cell. All that these two cell organs do is not known, but the cytoplasm is conspicuous in the nutritive work of the cell; while the nucleus is conspicuous in the division of the cell, which may be called its reproductive work. This means that the nucleus is the organ for the transmission of characters of the parent cell to the new cells. In other words, **it is the organ of heredity.** If this be true, some further understanding of the nucleus is necessary.

The nucleus.—A nucleus is an exceedingly complex structure, possibly the most complex of all living structures. No attempt will be made to describe it, further than to say that the densest material it contains is called **chromatin.** This name, which really means **color body,** refers to the fact that when a nucleus is stained it is the chromatin that appears as a network of broad threads, in the meshes of which the more fluid material of the nucleus is stained; this network stands out sharply on a clear background. When the nucleus divides in connection with cell division, this chromatin passes through a series of changes. In the first place, the chromatin network becomes transformed into a continuous band which loops back and forth through the body of the nucleus. Later this band breaks up into a definite number of pieces, which are called **chromosomes.** These chromosomes are the organized units of chromatin, just as protoplasts are the organized units of protoplasm, and if protoplasm can be called the physical basis of life, chromatin may be called **the physical basis of heredity.**

Definite numbers of chromosomes.—A notable fact in reference to chromosomes is that in each nucleus of each kind of plant and animal there is always a certain definite number of chromosomes. In different plants and animals the number ranges from as low as two in a nucleus to over one hundred. Whatever the number may be, it is always the same in a given kind of plant or animal. This is important to remember, for it is one of the several features in the process of heredity which illustrate its remarkable uniformity. Whenever experimental work has succeeded in disturbing the number of chromosomes, abnormal progeny has resulted, which simply means that the machinery of heredity has been disturbed.

The spindle.—During the changes in the chromatin, that is, while it changes from a network to a continuous band, which breaks up into chromosomes, a set of fine fibers is formed by the nucleus, arranged like the parallels of longitude about the earth, so that there are two poles where the fibers come together, and an equatorial region where they are farthest apart. (See Figure.) This arrangement of fibers is called a **spindle.** After the chromosomes separate, thus breaking up the chromatin band, they become lined up around the equatorial region

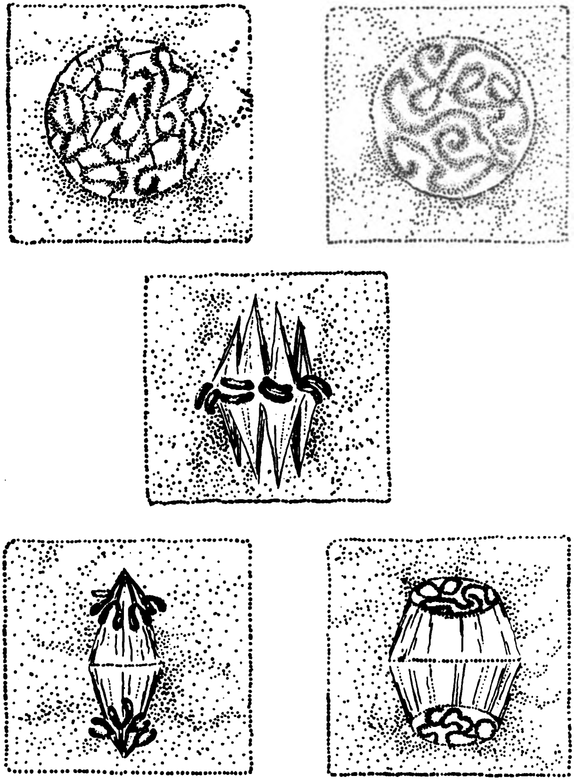


Diagram of the process of division of the cell nucleus. In the first picture the spherical nucleus is seen in the cytoplasm that surrounds it; the net-like arrangement of the chromatin is indicated. In the second the chromatin is in a continuous band, this being the first stage in the division process. In the middle picture the chromatin has resolved itself into definite chromosomes which are dividing at the middle of the spindle. In the fourth picture the newly formed chromosomes are migrating toward the poles of the spindle. The last picture shows the formation of the daughter nuclei and the beginning of the new cell wall. The spindle fibers soon disappear.

of the spindle and attached to the fibers. In this position each chromosome splits lengthwise, that is, in the plane of the equator, and each half is attached to a spindle fiber. The spindle fibers then seem to shorten, being anchored at the poles, and pull the half chromosomes toward each pole. Finally, the half chromosomes reach the poles, become united end to end in a continuous band, and thus two nuclei are formed. In the meantime a cell wall has formed through the equatorial plane, and two new cells are the result, each with its new nucleus.

Result of chromosome division.—From the above account it is apparent that in cell division each chromosome is divided into halves, and that each half forms a chromosome of a new nucleus. Therefore, if chromosomes are the carriers of heredity, it is easy to understand why the two new cells should resemble the parent cell and each other, and why all the cells of the body should have exactly the same number of chromosomes. If each chromosome may be supposed to contain a certain number of hereditary characters, it is evident that these characters will be transmitted with each cell division. In fact, the machinery looks so exact that the difficult thing to understand is not why cells are alike, but how they ever become unlike.

Doubling of the chromosomes.—With this account of ordinary cell division as an introduction, it will be possible to understand in a general way what happens when sexual reproduction occurs, by means of which two individuals produce another, just as in cell division one cell produces others. In the sexual act two cells unite to form one, the fertilized egg. It is evident that this act doubles the chromosomes, for the fertilized egg has received chromosomes from both sperm (paternal cell) and egg (maternal cell). For the sake of simplicity it may be assumed that there are two paternal and two maternal chromosomes, which means that the fertilized egg contains four. When this egg divides it is also evident that four chromosomes will be transmitted to each new cell, and so on through successive cell generations, until the new individual is complete. Each cell of the new individual, therefore, contains two chromosomes contributed by the father and two contributed by the mother.

Behavior of chromosomes.—In the case just described not all of the four chromosomes will be equally influential, and in general half of them will dominate over the other half. In our illustration, if two of the four chromosomes dominate in determining the characters of the new individual (child), it is evident that there are four possible combinations: (1) the paternal pair of chromosomes may dominate, in which case the child will resemble the father; (2) the maternal pair may dominate, in which case the child will resemble the mother; (3 and 4) one paternal and one maternal chromosome may dominate, in which case the child will resemble both parents; in other words, it will be a mixture. If these combinations be expressed in a ratio it would be 1 (paternal): 2 (mixture): 1 (maternal), which is exactly the ratio of Mendel's law.

In stating that a child resembles the father or the mother, it does not mean that the determination of sex is involved. The resemblance has to do with the general structure of the body, and not with sex. It is within the experience of every one, for example, that a daughter resembles the father more than the mother, which means that the paternal chromosomes have dominated in determining the general structure of the body, but have not determined its sex.

It should be kept in mind that the illustration used is extremely simple, for we have not taken into account that the chromosomes involved are usually much more numerous, and that the chromosomes of each parent have descended through a long series of generations, so that they represent the contributions of very numerous ancestors. Yet even complex cases, upon analysis, reveal the simple Mendelian ratio, and children in general are of the three types indicated.

Reduction of chromosomes.—It is evident that if the chromosomes are doubled in the act of fertilization, provision must be made for reducing the number again somewhere in the life history of plants and animals, for doubling the number with every generation would soon lead to an impossible situation. Among animals in general this reduction occurs in connection with the formation of sexual cells, so that sperms and eggs are the only cells of the body that contain the half number **(haploid)**; while all the other cells of the body contain the double number **(diploid)**. The number of chromosomes is reduced by a kind of cell division called the **reduction division,** in which the chromosomes are not split, and half of them move to each pole of the spindle, so that the sexual cells which are formed contain half as many chromosomes as the parent cell which produces them.

Alternation of generations.—In the case of most plants, the reduction division occurs in connection with the formation of **spores,** and since spores are not sexual cells, but produce new individuals directly, the results differ from those in animals. It follows that among plants there are two kinds of individuals, one produced by spores, and therefore haploid individuals, that is, individuals with the half number of chromosomes; the other produced by the fertilized eggs, and therefore diploid individuals. It is the occurrence of these two kinds of individuals in the life histories of plants that is spoken of as the **alternation of generations.** Putting this fact in other words, the two individuals in the life history of plants may be called the sexual individual which produces **gametes** (a gamete is a sex cell, being either egg or sperm), and the sexless individual which produces spores, and each in turn produces the other. Therefore, from this standpoint, the two chief epochs in the life history of every animal and plant are **fertilization,** which doubles the number of chromosomes, and **reduction,** which reduces the number.

Chromosomes and gametes.—Using again our illustration of an individual with four chromosomes, two of them paternal in origin and two of them maternal, when reduction occurs in connection with the formation of the sexual cells, as in animals, the chromosomes may be distributed among the sperms and eggs in three combinations. Either the egg or the sperm may contain the pair of paternal chromosomes, or the pair of maternal chromosomes, or one chromosome of each kind. In other words, a sperm is just as likely to pass on maternal chromosomes as paternal chromosomes, and an egg is just as likely to pass on paternal chromosomes as maternal chromosomes; and either egg or sperm may pass on both kinds of chromosomes. When one remembers that only certain chromosomes dominate in connection with the germination of an egg, and also that the chromosomes may be distributed variously in the reduction division, it becomes evident why the children of the same parents may be so variable; in fact, probably the great significance of sex is that it multiplies variation, but this will be discussed later.

CHAPTER SIXTEEN.

SOME FACTS OF HEREDITY.

Transmission of characters.—When it is remembered that chromosomes have been passed on through an indefinite succession of generations, it can be realized that the characters transmitted in any given case cannot be foretold. Characters present in neither parent may appear in the child, and these may be traced to a grandparent or to some more distant ancestor. This reappearance of ancestral characters is called **atavism.** In these cases, for some reason, certain chromosomes have remained latent throughout a generation or more, and then for some reason they have become dominant.

It is not known just what role the chromosomes play in heredity, but their behavior suggests some definite connection with it. This behavior fits into the results, as has just been described, and it either produces the results, or is an index of the real process. It is more than probable that the process is a series of chemical and physical changes, and that the chromosomes are the bodies in which these changes occur, the carriers of the process, rather than the causes of the process. In other words, they may be likened to cartridge cases, which do not cause the explosion, but carry the material that does.

The X-chromosome.—In certain animals an odd chromosome has been discovered in the sexual cells, which is often quite distinct in appearance from the ordinary chromosomes. Experiment has indicated that this chromosome is in some way connected with the determination of sex. For example, the X-chromosome occurs in all eggs; while it is absent from approximately half of the sperms produced. If a sperm containing an X-chromosome mates with an egg, the fertilized egg contains two X-chromosomes, and the result is a female. On the other hand, if a sperm without an X-chromosome mates with an egg, the fertilized egg contains only a single X-chromosome, and the result is a male. In other words, the sex is determined by the character of the sperm, whether it contains or does not contain an X-chromosome. The function of the X-chromosome is probably the same as that of the other chromosomes, in the sense that it is the carrier of whatever determines sex, but just why two of them should result in a female individual, and one of them in a male must be left at present to the imagination. This emphasizes the distinction that was made earlier in the chapter that sex and bodily resemblance are quite independent of one another.

Parthenogenesis.—In connection with sexual reproduction, the phenomenon of **parthenogenesis** should be considered. This means the production of an individual by an egg which has not been fertilized. Parthenogenesis has been discovered among plants of all grades, as well as among animals. In some cases of parthenogenesis the egg contains the reduced number of chromosomes as usual, and therefore it produces an individual with a haploid number, but apparently this individual differs in no other particular from the usual diploid individual. In other cases of parthenogenesis, notably among the higher plants, the reduction division fails so that the egg is diploid and produces the usual kind of diploid individual. It has been found that when reduction fails and the egg is diploid, it is incapable of fertilization, apparently since it already has the double number of chromosomes. In the case of parthenogenesis by haploid eggs, the behavior of the egg in producing a new individual without fertilization is simply recalling the power possessed by all cells among primitive plants and animals. There is no historic reason why any egg should not be able to produce a new individual; though the fact is that ordinarily it does not do this without fertilization.

Significance of sex.—Since sexual reproduction is entirely unknown among the lowest plants, and is rare in certain other great groups, and since parthenogenesis occurs among plants that ordinarily reproduce sexually, the significance of sexual reproduction becomes a question. In fact it is one of the biological problems that has not received a satisfactory answer. Among plants it was the last kind of reproduction to appear, and even among the highest plants there is much reproduction by other methods.

There are three conspicuous methods of reproduction among plants. The first in order of appearance is what is called **vegetative reproduction,** which means that a plant can produce a new individual, either by cutting its own body in two, or by separating some of its ordinary body cells. This is the only kind of reproduction among very many of the lower plants, and has not been abandoned by the higher ones. As is well known, new plants are produced from potato tubers, from slips of grape vines or raspberries, and even from leaf fragments of such plants as the begonia.

A second method of reproduction is by means of spores, a spore being a cell set free from one individual to produce another one. Very many plants have vegetative and spore reproduction, and no sex at all. Reproduction by spores is also continued throughout the whole plant kingdom after its introduction. Even the highest plants, the flowering plants, produce spores. The pollen of flowers is simply one kind of spore.

Sex reproduction appeared last of all. It is evident, therefore, that this method of reproduction is not **essential** to reproduction, and that it must have some other significance associated with reproduction. It has been suggested that the sexual method, combining as it does the characters of two cells, and usually of two individuals, multiplies variation, and of course, variation is the basis of evolution. In any event, the other methods of reproduction produce a more invariable result than does sexual reproduction. A fruit tree grown from seed, which means sexual reproduction, varies more from the parent form than does a graft, which means vegetative reproduction; and potatoes "come true" from tubers when they do not come true from seeds. The multiplication of variations may not be the only meaning of sex, but sex certainly favors it. It is at least one answer to the question, what causes variation?

When one remembers that in every kind of reproduction the chromosomes are handed down in one continuous stream, and that in every sex act two such streams unite, it becomes obvious that sex reproduction must result in more variations than any other kind of reproduction. According to this view, the plant and animal kingdom could not make such progress, or at least not very rapid progress, until the introduction of sex.

CHAPTER SEVENTEEN.

METHODS OF PLANT-BREEDING.

Importance of the problem.—The study of evolution has led to the study of heredity, and the study of heredity has led to a revolution in the breeding of plants. This is only one of the many illustrations of the important practical results following the investigations of pure science. For years the ratio of increase of our population has been much greater than the ratio of increase of food production. This has already reached a serious stage, and is one of the important causes for the increased cost of living. It is of vital importance that this inequality of the two ratios be stopped, and that the increase of food production overtake the increase of population. This is a problem of practical plant-breeding, and some progress toward its solution has been made. This progress is perhaps slower than the public would like, but plant-breeding is a slow process, and the public must wait patiently, even after hearing that striking results are being obtained.

Purposes of plant-breeding.—The intelligent breeding of plants is undertaken for two reasons, a scientific reason and a practical reason. The scientific reason is to secure facts that may help to an understanding of heredity and evolution. The practical reason is to improve old forms and to produce desirable new ones, thereby increasing crops, insuring them against failure, and extending the area of crop production. A distinction must be made between improving an old form, which means making it better for some purpose, and producing an entirely new form. In the one case something that we already have is made better; while in the other case something that we have never had is added to our stock of useful plants. The chief methods of securing these results will be described briefly.

Mass culture.—The oldest method of plant-breeding had in view the improvement of plants, attempting to make them more suitable for the use of man. It is commonly referred to as **mass culture.** It was described briefly in the account of artificial selection (see page 43). This method is still in general use. An illustration of it may be taken from the breeding of wheat. A plant-breeder who desires to secure by this method an improved race of wheat, begins by sowing a field with the best and purest seed he can obtain. When the crop matures he secures seed from the plants that best suit his purpose. Enough seed is obtained to produce another crop, so that many individuals are necessarily selected. This selection of numerous individuals is what constitutes mass culture. The result of this method is to secure an average of the better individuals. It does not secure a kind as good as the best individual. It results in a good average rather than in the best possible. Such selection, continued year after year, gradually raises the average with respect to the desired character, so that presently an improved **race** or **strain** is secured, and is put on the market. When such an improved race comes into the hands of the ordinary farmer, who does not continue careful selection for seed, it runs back; that is, it deteriorates. So in the course of two or three years the farmer returns to the plant-breeder for what is called **guarded stock;** that is, seed which has been protected from deterioration. Of course this inconstancy of improved races is profitable to the plant-breeder, but not profitable to the farmer.

This method of mass culture has been applied to nearly all cultivated plants, and is responsible for most of the improved races used today. It has accomplished much, and it will continue to be extremely useful, but something more is needed.

Hybrids.—The production of new forms began with the production of hybrids, and this method has been developed extensively, resulting in many useful forms. A hybrid is an individual which results from the crossing of different breeds or species. One of the purposes in producing a hybrid is to secure a combination of desirable qualities belonging to the two parents. It is evident that a hybrid is a new form, rather than merely an improvement, for it combines in a single individual characters that were separated before in different kinds of individuals. The characters may not be new, but their combination is. No one has developed the technique of this method more successfully than Luther Burbank, of California, and a few illustrations from his results will make the method clear.

Burbank.—Probably the most important factor in Burbank's success with hybrids is his use of immense numbers of individuals. When a hybrid is produced with a view to securing the combination in one individual of two qualities belonging to different kinds of individuals, it does not follow that every hybrid shows the combination. In fact, the desired combination is usually the rare exception rather than the rule. If a score of hybrids are produced at a time, the plant-breeder may never secure the desired combination; if hundreds of hybrids are produced, he may secure the combination in the course of time; but if thousands of hybrids are produced, the desired combination is likely to occur in at least one of them. In other words, increasing the number of hybrids increases the chances of the occurrence of the desired form.

A simple illustration is that of the white blackberry.

There is a wild blackberry with a small whitish or cream colored fruit, and this was crossed by Burbank with the large cultivated blackberry (Lawton). The two characters desired to be combined were the color of the wild blackberry and the size of the cultivated one. Producing a sufficient number of hybrids, the desired combination was secured, and then propagated.

Seedless apples have been known ever since apples have been cultivated, but they were of poor quality. It seemed possible to combine the seedless quality of the poor apples with the good quality of apples with seeds. Finally the combination was secured, so that now we have seedless apples of good quality.

The cactus family is notably spiny, but individuals without spines occasionally appear. Those species which produce spineless individuals most abundantly are not succulent; while the prickly pears (a form of cactus) are notably spiny. By means of crossing, the attempt was made to secure a combination of succulence and spinelessness. The attempt resulted in the somewhat famous spineless cactus, a plant useful for forage, but rather limited as to the range in which it can be grown.

Many hybrids are larger and more vigorous plants than either of their parents. It is becoming more generally recognized that this feature of hybrids may be used to great advantage. The making of hybrids, therefore, is coming into use, not merely to secure desirable new combinations, but also to increase the vigor of the plants we already have. Advantage has been taken of this fact to produce some interesting results. For example, the California dewberry and the Siberian raspberry are both worthless seedy fruits, but a hybrid from the two develops fine fruit. A conspicuous feature on Burbank's experimental farm is a row of gigantic walnut trees, produced as hybrids from an American walnut and the English walnut.

Effects of Mendel's law.—In propagating hybrids one must remember the operation of Mendel's law (see page

58). If the hybrid is propagated by seed it will split in a definite ratio, approximately only one-half of the progeny continuing the hybrid characters. Therefore, only one-half of the crop continues to be the desired kind. On the other hand, if the hybrid is propagated vegetatively, as potatoes by tubers, or fruits by grafting, the Mendelian law is inoperative, and all of the progeny show the combination. New forms produced by hybrids, therefore, are of most value when they can be propagated vegetatively. This excludes the cereals, our most fundamental crops, since they are propagated only by seeds. Of course hybridizing of cereals is practised to secure combinations of qualities and vigor, but for the reason indicated it is not the most desirable method of securing new forms whose reproduction depends on seeds.

Pedigree culture.—Another method of securing new forms began to be used when the mutation theory became current. It is known as **pedigree culture.** It deals with single individuals, while mass culture deals with multitudes of individuals. The wheat field illustration used for mass culture may be used also to illustrate pedigree culture. When it is remembered that no two individual plants in a field are exactly alike, it will be realized that the range of variation is very great; in fact, all crops from ordinary seed are extensive mixtures. If the plant-breeder has in mind some kind of variation that he wishes to secure, he searches the field for some individual that shows it. The range of choice is so great that the desired individual is very probably discovered. Then his individual plant is pedigreed, just as fine stock is pedigreed, and its progeny is kept from mixing with inferior individuals.

By this method the very best plant is secured and propagated; while in mass culture an average of the better plants is secured. In mass culture continuous selection is used to build up gradually a desired type; while in pedigree culture the desired type is simply discovered.

The Swedish station.—The experience of **Nilsson,** director of a famous Swedish experiment station, illustrates pedigree culture. It was at this station that pedigree culture was first practiced upon an extensive scale. Among Nilsson's problems was the development of races of barley suitable for cultivation under the extremely diversified conditions of Sweden. All attempts to develop these races by mass culture proved unsatisfactory, but when the principles of pedigree culture were applied, individual plants were found showing exactly the characters needed. These were propagated, and in a remarkably short time Nilsson secured, not merely all of the races needed, but many more new races besides. The same method has been applied with the same success to the other important crop plants of Sweden.

It must not be supposed that pedigree culture has entirely supplanted mass culture, but it has supplemented it in a very important way. It enables plant-breeders to secure much more rapidly a much larger range of desirable forms. When these forms are secured and propagated, mass selection can be used to improve them still further. In other words, **pedigree culture can secure the best forms, and mass culture can make them better.**

CHAPTER EIGHTEEN.

RESULTS OF PLANT-BREEDING.

Races related to regions.—The rapid multiplication of desirable forms by pedigree culture is an important advance toward the solution of the food problem, for it makes possible the securing of races of plants adapted to every region, so that each area may produce its maximum yield. At present the same race is usually grown on a great variety of areas, many of which may not be suitable for the maximum production of that race. By obtaining the maximum yield from every area, the total production from such a diversified country as the United States would be enormously increased.

Drought-resistance.—Next to securing races of plants most suitable to each area, perhaps the most important character to secure is **drought-resistance.** Drought is the most general and the most dangerous enemy of plants. It is most serious in connection with cereal crops, for they are fundamental food crops. Especially is corn endangered by drought during a certain stage in its development. Areas may be grouped under three categories, dependent upon their relation to drought. Drought is **possible, periodic,** or **perpetual.**

The regions of possible drought include most of the land of ordinary cultivation, which may either escape drought for a succession of seasons, or may be devastated by drought at any time. In such regions the crop producer takes his chance, hoping that drought will be much less frequent than a well distributed water supply, and in general his hope is well founded. In the region of periodic drought there is a regular alternation of dry and wet seasons, and crops are related to them as definitely as they are to summer and winter in other regions. The regions of perpetual drought include the so-called arid lands, as for example, the southwestern states along the Mexican border. In such regions crop production depends upon irrigation.

If drought-resistant races can be secured, important crops will be insured against drought in regions of possible drought, and the area of cultivation can also be extended into the arid regions. Such a result would increase the crops to such an extent that the food problem would be far less serious. Drought-resistant races of plants have been sought chiefly for use in arid regions, and many have been secured. It is most important to secure drought-resistant races of cereals, since they furnish what are known as staple crops.

Wild wheat.—The recent discovery of the wild original of wheat has led to the expectation that races of wheat suitable for arid regions will presently be available. Races of wheat more or less suitable for semi-arid regions have already been developed. Wild wheat was discovered in Palestine in 1909 by Aaronsohn, and he has had it under experimental culture ever since. It has been found to be frequent in Palestine in thin soils among the rocks, and it is drought-resistant.

When wheat was first brought under cultivation by the human race it was removed gradually into better and better soil. This has gone on through the centuries, until our modern races of wheat have become pampered races, unable to resist drought or disease. In other words, our cultivation of wheat has resulted in developing less hardy plants. The wild wheat of Palestine is the original drought-resistant stock, and it is expected that from it drought-resistant races can be derived. This would increase immensely the area of possible wheat cultivation, and this experience with wheat is likely to be duplicated with other important cereals.

Drought-resistant corn.—A drought-resistant race of corn has been found under cultivation in China. This is a remarkable fact, because the original wild corn is native in the high lands of Mexico, where it was brought into cultivation by the early populations of that region. That a race of corn found its way into China before the so-called discovery of America raises interesting speculations. But once established there, there ensued apparently a case of unconscious pedigree culture, for the race now found there is unlike any in cultivation in this country.

The chief danger to corn from drought comes at the pollination stage, and that period is one of annual anxiety to farmers. The exposed silk receives the flying pollen, and in order to do this it must be moist. If a drought strikes the corn at this period, the silk is dried out, the pollen cannot do its work, and the grains do not mature. In the Chinese race of corn the pollen collects in drifts in the axils of the nearly erect leaves, before the silk becomes exposed. On account of this late development, the silk grows through the accumulated drifts of pollen, and therefore does not become exposed to the drying air until after the pollen grains have become attached. If this race of corn can be bred into good quality it should insure against failure of corn crops from drought, and should permit the cultivation of corn in arid regions where sufficient moisture is supplied by irrigation.

Corn breeding.—Corn has proved to be the most difficult cereal to breed. It is an exceedingly variable plant, so that the ordinary field of corn is a very complex mixture of individuals. As a result, mass selection is very indefinite, and has made little or no progress in improvement. A number of years ago Hopkins of Illinois discovered that the selection of seed by judging individual ears is more effective than selection based only on judgment of the plants as a whole. This "ear-by-ear" selection in the field, combined with judgment of the plant as a whole, has resulted in a large increase of yield.

Corn differs from other cereals in two important particulars. The ears are so large that selection is easy, but the open pollination, requiring four or five days for a single ear, makes control in breeding exceedingly difficult. For example, the selected ear may have some hybrid grains, sometimes recognized by a color difference, so that after ear selection there must follow a continuous selection of individuals to weed out hybrids. The vagueness of the experimental work with corn is realized when it is remembered that while the pedigree on the female side can be known, and kept under control, the pedigree on the male side (flying pollen) can be only vaguely known.

Recently experiments have been conducted to isolate **pure races** or strains of corn by rigid pedigree culture. This of course involves **close breeding,** or in-breeding; that is, the silks must receive pollen only from the tassels of the same plant. It is found that **this results in deteriorating the vigor of the individuals produced,** generation after generation, until they reach a fixed level. In other words, a pure race or strain of corn is less vigorous than a hybrid race. It follows that breeding corn is quite a complex proceeding. It involves, first, the selection of the most desirable ears; then a rigid pedigree culture of the selected individuals; then a continuous weeding out of chance hybrids; and finally a crossing of desirable races to secure vigor. In other words, out of mixed individuals, pure strains must be isolated, and then pure strains must be combined. It may be asked why so much trouble is taken if the combinations already exist; why first deteriorate plants by separating them from combinations, and then recombine them to new combinations? The answer lies in the great difference between **chance** combinations and scientific combinations.

Disease-resistance.—Second only to the danger from drought is the danger from various diseases. The government has expended millions of dollars for the study of plant diseases in the hope of discovering successful ways of combatting them. This work has resulted in acquiring much knowledge concerning the parasites which cause diseases, and very successful methods of checking diseases have been discovered. Pedigree culture, however, has made possible a more fundamental method of combatting disease, namely, by developing disease-resistant races.

When some ravaging disease attacks a crop, certain individual plants will be found that have not been attacked. In other words, they are **immune** to the disease. It is found that immunity to disease can be inherited, so that by pedigreeing an immune individual, an immune race can be secured. For example, this has been tried successfully in connection with a certain destructive disease of cotton, and immune races have been secured. The subject is too new as yet to have determined how long a race will retain its immunity, or whether it will remain immune under all conditions. In any event, if immune races of plants can be developed, there is some foundation for the hope that the important plant diseases can be stamped out. The wild wheat of Palestine is not only drought-resistant, but also disease-resistant.

To breed immune individuals and to let the others disappear is certainly an effective way of stamping out disease. The method can be applied to plants, but not to human beings, for there is a natural sentiment against it, and the advance of medicine is making it more and more impossible. Before medicine was a science, susceptible individuals disappeared, and thereby immune individuals were unconsciously pedigreed; but now the immune and susceptible individuals are both kept alive, and live together, so that disease is perennial. With plants, however, there can be rigid pedigree culture for immunity.

Summary.—A summary of the aims of plant-breeding is as follows: (1) to secure the best possible races by pedigree culture from the best individuals; (2) to multiply the number of races so that each region may secure the races best suited to it; (3) to secure drought-resistant races so that crops may be insured against drought in regions where they are now grown, and so that the possible area of crop cultivation may be extended into arid regions; and (4) to secure disease-resistant races, so that the annual loss of millions of dollars' worth of crops may be prevented. If all of these factors are combined in a general result, it is obvious that the use of pedigree culture will multiply our food production many times.

CHAPTER NINETEEN

THE EVOLUTION OF NON-VASCULAR PLANTS.

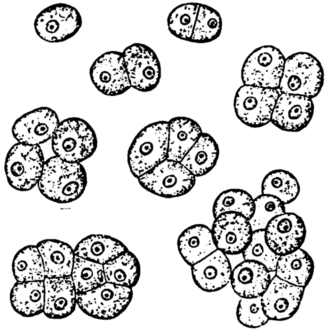
In the preceding chapters we have considered the various explanations of evolution. This is important, but it may be more interesting to picture an evolutionary history as it has actually happened. Thus we may picture the history of the plant kingdom. We do not know the details of this history, but we know its general outline. Not only can we infer the history of plants from their structures, but we can read much of their history recorded in the rocks. Very many plants have been preserved as fossils, and the order in which these fossil plants appear in the rocks is the order in which they appeared upon the earth. In other words, it is the order of their evolution. This long history of plants can be presented in four pictures, each picture representing a stage of progress.

The first plants.

Water as a medium.—We do not know the plants that were actually the first to represent the plant kingdom. They have probably disappeared and left no record. Even the first picture of the plant kingdom which the geological record permits us to construct would not suggest to most people that there were any plants. No land surface is seen occupied by them, nor, in any general view of the landscape, is any vegetation seen rising from the water. In fact, the whole plant kingdom of that time **was** in the water, or in very moist places, but the individual plants were so inconspicuous that they would not have been seen even if any one had been there to see them. The plant kingdom, as we know it now, began in the water; and more than that it is now thought that **it began in fresh water.** The fresh waters are still swarming with just such plants as we think the earlier plants to have been, and they are called **algae.**

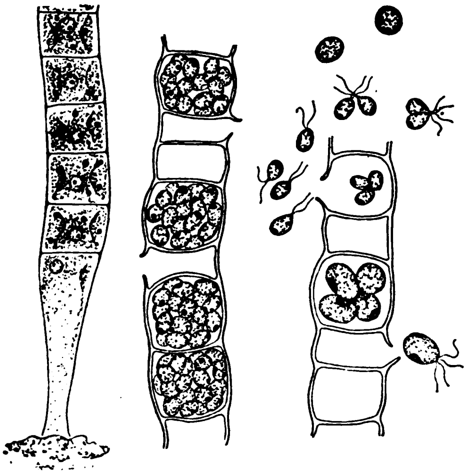
To live in the water is much simpler than to live on land, for plant bodies must be kept moist, and life on the land demands protection from the drying air. Therefore, it seems quite clear that the very simple forms that started the plant kingdom lived in the water.

Simple bodies.—The bodies of these plants were very simple, the simplest of them consisting of a single cell. The cell is often called the unit of structure; in somewhat the same sense that a brick is the unit of structure of a wall. Our own bodies consist of millions of such units; while the bodies of these first plants are only single units. But these one-celled bodies gradually produced forms whose bodies were made up of many cells. The favorite form of body among these fresh water algae is thread-like, and these green thready growths, especially in quiet waters, must be familiar objects to most people. Some of the algae, however, developed flat green bodies that suggest leaves; in fact, a very common alga on the sea coast is called "sea-lettuce." In our first picture, therefore, if we could look into the water as through a microscope, we would see swarms of green



Pleurococcus, a common one-celled plant, as seen under the microscope.—*Coulter's Plant Life and Plant Uses.*

plants, some of them very minute green cells, and some of them looking like fragments of leaves, but most of them resembling green threads that are very simple or branching.



Ulothrix, one of the filamentous algae. The figure at the right shows the production of both spores and gametes by the same individual.—*From Coulter's Plant Life and Plant Uses.*

Reproduction.—These algae worked out three methods of reproduction. In the first method, the only one possessed by the simplest forms, the body cut itself in two. This is called **vegetative multiplication**, meaning that the working (vegetative) body produces (multiplies) new individuals. In the second method, added to the first by the algae that are a little more complex, certain reproductive cells are separated from the body. These have been named **spores.** These spores usually can swim freely by means of hair-like swimming appendages **(cilia).** Finally a third kind of reproduction was added, two spore-like cells **(gametes)** coming together and fusing into one cell, the **fertilized egg.** This is sexual reproduction. The algae, therefore, although possessing very simple and inconspicuous bodies, worked out all the kinds of reproduction that belong to the plant kingdom.

Evolution of sex.—Algae not only originated sexual reproduction, but they developed it much beyond the original process. At first the pairing cells (gametes) looked so exactly alike that no distinction of sex could be recognized. Later the pairing gametes became very much unlike in appearance, the large and passive one being called the **egg,** and the small and very active one being called a **sperm.** This second step is usually spoken of as the **differentiation of sex.** At first gametes were produced by the ordinary working cells, but later they came to be formed by special cells, called **sex organs.** At first both kinds of sex organs appeared on the same individual, but later they became separated on different individuals, so that there were male and female plants.

The first land plants.

Air as a medium.—The second picture in the historical series shows plants occupying the land surface, but they are either prostrate plants like liverworts, or very low plants like mosses. Such a display of plants would hardly be thought of as vegetation by the ordinary observer, and yet these lowly plants represent what may be regarded as the most important epoch in the history of plants. They were the first plants that lived on the land surface, exposed to the air. In other words, liverworts may be regarded as algae that have acquired the land habit.

The danger.—The ordinary alga taken from the water and thrown on the land dries out and perishes. It is as much out of its "native element" as a fish would be when thrown on the bank. How could algae come to live on land? They must certainly protect themselves from the drying effect of the air. One may picture how the gradually increasing exposure to air may have occurred. Probably it began with occasional exposures on muddy flats, and by gradual migration shoreward ended in continual exposure. Even when exposure to air became continual, plants must have been for a long time restricted to moist and shady places. Life in the open meant extreme danger from loss of water. It is one thing to live in protected places, as these first land plants did, and a very different thing to live and work in the open. It remained for still more advanced plants to solve this problem.

Conditions for work.—There are two general facts in this connection that should be kept in mind. One is that a plant may work in a protected place, but its opportunities for work are not so great. The progress of plants, therefore, requires that they must learn to use the largest opportunities. Another fact is that work and endurance are not the same thing. Plants may endure conditions of exposure, but not be able to work, except so far as it is necessary to maintain life. An ordinary tree, for example, endures the winter, but it works in the summer. In considering the progress of plants, therefore, it is not a question of the conditions which they can endure, but of the conditions in which they can work.

Protection.—The algae could not acquire the habit of life on land merely by becoming accustomed to it after repeated trials. They had to develop protective structures that would reduce the loss of water to a minimum. In the first place, the thready forms were hopeless, because such forms would expose more cells to the drying air than any other form. The algae that succeeded in maintaining themselves on land long enough to become liverworts were the forms with flat, compact bodies, leaf-like in appearance. In such a compact body the cells protect one another from exposure. The prostrate position was also a protection, reducing the surface exposure to the air by one-half. Most important of all, there was developed an outermost layer of protective cells, known in all plants and animals as the **epidermis.** This layer is very resistant to the passage of water from the interior of plants to the surface. The epidermis is in effect a waterproof layer, not to prevent water from entering the plant, but to prevent water from leaving the plant. A compact, prostrate body, covered by an epidermis, is well equipped for exposure to the air, especially if the air is not very dry.

This second picture, therefore, shows plants on the land surface, but they appear only as flat green bodies here and there, or as low mossy growths; no plants rising well above the ground are seen; no plants with flowers or seeds; and no plants that are of service to man today, either in the way of use or ornament.

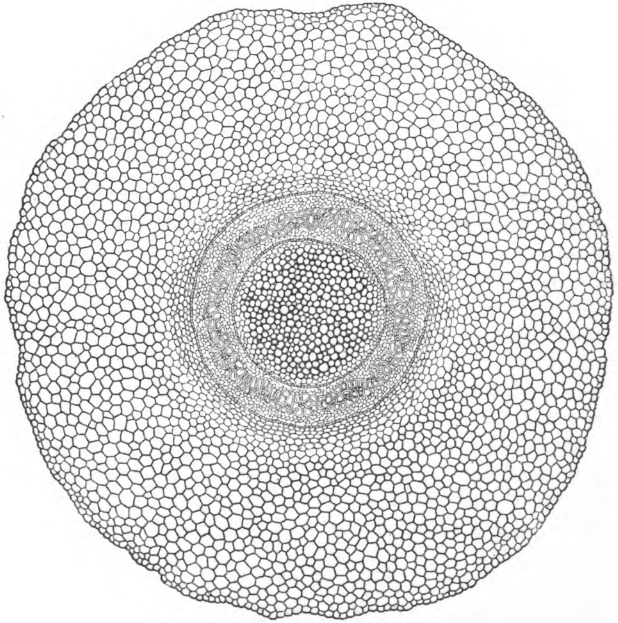
CHAPTER TWENTY.

THE EVOLUTION OF VASCULAR PLANTS.

The first woody plants.

Vascular system.—In the last picture we saw that the liverworts and mosses came to live upon the land in a somewhat cautious way, but in the third picture we find that plants have begun much more extensive possession of the land surface. Any observer would say that the picture shows real vegetation, consisting of herbs, shrubs, and trees. An examination of the plants, however, would show that there are no flowers or fruits or seeds, but that the plants are almost all like the ferns and club mosses of today. It is believed that this first conspicuous vegetation was produced by the liverworts. We do not know how this was done, but we do know how the plants became so much larger. In some way there was developed in their bodies what is known as a **vascular** system, the so-called vessels being what we ordinarily speak of as wood, or woody fibers. The chief business of this system is to carry water through the plant, and so the working cells can be kept supplied with water, although they rise some distance above the moist ground. Of course, water moved through the bodies of the liverworts and mosses, but it moved very much like water makes its way through a swamp. A vascular system provides a channel for the water, so that it moves with much greater rapidity and precision. It was the appearance of this water-conducting system that enabled plants to become larger and more freely exposed to the air.

Roots and leaves.—Two very important structures are always associated with this water system; namely, the roots which obtain water from the soil, and the leaves to which the water is carried for use. In these first vascular plants, therefore, we find the first roots and the first real leaves. This equipment enabled plants, not merely to



Cross section of the stem of a fern, showing the differentiation of the vascular system.—***Coulter's Plant Life and Plant Uses.***

rise more or less freely into the air, but enabled many of them to become even trees.

Cones.—In addition to the appearance of these successful working bodies, a close view of the vegetation would show a feature that is very significant. In some of the forms, notably the **club mosses**, which were often trees, some cones may be observed, which are the so-called "clubs" that appear in the name. The interesting fact about these cones is that they are the precursors of flowers, which are to appear in the next picture. This vegetation that we are examining, therefore, contains a prophecy of the vegetation that is to appear.

Two kinds of spores.—In addition to this prophecy there is another one which is perhaps more important, but not so easy to see. It could not be shown in a landscape picture. The cones referred to produce the spores, and in some of the cones there are two kinds of spores. When a plant produces two kinds of spores it is making a start toward the development of the structure we call the seed, which is the great feature of the plants represented in our last picture.

This third picture, therefore, shows three important facts: a vascular system which enables plants to rise from the ground and really work in the free air, a prophecy of flowers, and a prophecy of seeds.

The seed plants.

Familiar plants.—The fourth picture represents the highest achievement of the plant kingdom, for a glance shows that the abundant and conspicuous vegetation is that with which we are familiar. It was the ferns shown in the last picture that gave rise to this vegetation. The picture shows plants of all sizes and habits, but the distinguishing mark is that they all produce seeds, and most of them produce flowers. We did not realize that the ferns produced the seed plants until recently. There is recorded in the rocks very abundant fern-like vegetation that was associated with our coal beds. Naturally these plants were thought of as ferns. Only recently it was discovered that although they look like ferns, most of them produce seeds, and so the connection between ferns and seed plants was made clear. In this last picture we recognize not merely the most conspicuous and familiar vegetation, but also the vegetation that is of the greatest service to man.

These four pictures suggest to us in barest outline the evolution of the plant kingdom, from the minute algae in the water, to the crowd of flowering plants in which the plant kingdom has culminated.

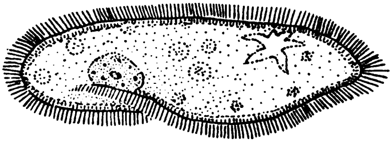
CHAPTER TWENTY-ONE

THE BEGINNINGS OF ANIMAL LIFE.

First living thing plant or animal?—The beginnings of animal life were as simple as those of plant life. We may not say positively that either was the more primitive or the earlier. **Probably the first life was neither animal nor plant, but something combining the most primitive characters of both** Indeed as to some simple organisms now living it is difficult to decide whether they are really plants or animals. As a whole, however, animals are much more diverse than plants; they have reached a much higher plane of development, and it follows that their evolution has been more complex than that of plants. We do not know all the details of their evolution, and probably we never shall, but we do know the general outlines of it, and much that we do not **know** we can reasonably **infer** from the comparative study of animal structures.

Earliest animals unknown.—As is the case with plants, so with animals the earliest ones are quite unknown to us. They left no fossil records that have been discovered. Yet it may be that somewhere in the world there are undiscovered animal records which are of greater antiquity than any yet found. Inasmuch as careful study of very ancient rocks has recently revealed fossils of bacteria, it is not too much to hope that some time we may discover records of the earliest animals. However, the chance of this is very slight, and geologists believe that both plants and animals lived long ages upon earth before they first left those records in the rocks that we call fossils. So we believe that the most ancient animals of which we have positive, rock-recorded knowledge were far from being the first that lived on earth. **Indeed it is probable that the known history of the animal kingdom is not more than half of its whole history**; in other words, more than a half, if not more than two-thirds, of the history of life on earth, as measured by time, is yet unknown to us from any positive records of it.

Simplest animals now living.—In spite of lack of their fossil remains we can infer with much probability of accuracy what the first animals were like. This is because there are animals now living that are of such extreme simplicity that we cannot conceive of much simpler forms in the past. These simplest of modern animals are believed to have survived through all the long ages with but very little change. They are known as **protozoa**, a word which means "first animals." Their structure and their habits both indicate that they would have been capable of living under such conditions as are believed to have existed in the very ancient, pre-fossil days.



Paramecium, one of the protozoa, much magnified. This is a common, one-celled animal, abundant in stagnant water. It reproduces rapidly by division of the whole body into two offspring. Occasionally fusion of two individuals occurs. Paramecium moves actively by means of the lashing movements of its cilia, indicated in the drawing by the fringe of lines.

Like the simplest plants, protozoa live in water, and, for the most part, in fresh water. Usually they are so small as to be quite invisible to the naked eye; or, in other words, they are of microscopic size. The individual protozoan is composed of one cell only. From such independent cells, performing all the functions of the individual, it is believed that all the higher animals were evolved.

The first step in this long process was probably the simple and rather accidental grouping together of some of these one-celled organisms into what are called "social colonies"; of such colonies we find numerous examples today. It is believed that later in their evolution the individuals composing such colonies came permanently to retain their connections with one another. Then gradually a sort of "division of labor" was accomplished by them; certain cells of the colony became specialized for certain work, other cells for other work. In other words, "they diversified their functions into distinct structures or **organs,** and thus gradually there arose a degree of differentiation in which the union of different cells was not only convenient but was absolutely necessary for existence." It was somewhat thus, we think, that there occurred the evolution of **multicellular** organisms from **unicellular** ones.

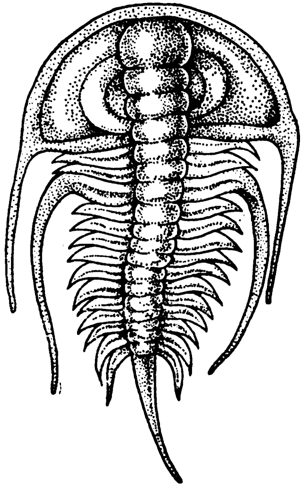
The reproduction of protozoa is either by simple division into two individuals, or by division into a number of spore-like young that increase in size. Occasionally the fusion of two individuals occurs, a sort of rudimentary sex-act, but this is the exception rather than the rule. Regular sexual reproduction appears to have begun in the sponges which represent that branch of the animal kingdom (porifera) that is next above protozoa in complexity. This sex reproduction was at first hermaphroditic, that is, both eggs and sperms developed in the same individual. This state of affairs is also found among some of the higher animals.

Parallelism to plant evolution is seen in higher forms of animals which have both eggs and sperms in the same individual, yet which can accomplish fertilization only by crossing; that is, the eggs and sperms of the same parent are infertile with reference to each other, but fertile when they unite with the eggs or sperms of other individuals.

Beginnings of other branches also aquatic.—You have noted that the earliest and simplest animals probably lived in fresh water. Now note the striking fact that most of the other great branches of animal life probably also had their beginnings in fresh water, whence they extended out into the salty seas. So animals, coming from aquatic beginnings, invaded the land and the air not once for all, but many times, and by means of intermediate, amphibious forms representing different branches of the kingdom.

The earliest recorded fauna (that of Cambrian times) **included members of all the chief branches of animal life, except the highest, the vertebrates.** And yet among all these varied forms there were none that were terrestrial or air breathing.

The members of this earliest recorded fauna that were most advanced in their evolution were the **trilobites.** These were primitive crustaceans that have long since become extinct. They had organs of sight, of touch, of respiration, and limbs for crawling, running, and swimming. The production of these organs must have required long ages of evolution, long ages of whose plant or animal life we know practically nothing.



One of the Cambrian trilobites. *Redrawn from Blackwelder & Barrows.*

In this ancient Cambrian fauna there were no lobsters, crabs, or higher crustaceans, (to which the trilobites are evidently related); nor were there any myriapods, spiders, or insects, which also belong to the same branch (arthropods) as the trilobites. Of the mollusks there were only bivalve and univalve kinds; that is, clam-like or snail-like forms. So also the sponges, corals, and jelly fishes were all of the lower kinds of their respective types. The **brachiopods**, a simple kind of bivalve now almost extinct, were abundant in this Cambrian fauna, and tracks and borings indicate that the worms, too, were represented. But all these forms of life stood low in rank in their respective branches as compared with the forms that came after them, the forms to which they themselves gave rise.

The great fact to note is that already in this earliest-recorded fauna we find almost as much differentiation as to great branches of the animal kingdom as we find today. The great lines of progress had already been determined. Somehow in those dim, mysterious ages that lie behind the fossil record, the great directions of animal differentiation were determined. So it is that fossils do not reveal to us the beginnings of life. Rather they roll up for us, as it were, a curtain that, withdrawn, reveals the stage of life already set and the principal actors playing their parts.

CHAPTER TWENTY-TWO.

APPEARANCE OF AIR-BREATHERS AND VERTEBRATES.

Air-breathing animals probably did not appear till after plants had clothed the surface of the land. The first of them that we know were hemiptera (bugs), one of the lowest groups of insects, and the highest type of animal life in existence at that time. The first evidences are scanty, consisting of wings only. Probably there were earlier land insects of which we yet have no knowledge; insects which were more terrestrial, and flightless, for flight was a mighty advance in evolution. Doubtless the earliest insects passed the larger part of their existence as water-breathing larvae, just as the first land vertebrates were water-breathers in their larval or tadpole stages. Spiders, myriapods, and scorpions were the next higher animals that appeared upon the land. Still later appeared air-breathing worms, mollusks, snails, and low crustaceans like the common sowbugs of today.

So far had the evolution of aquatic animal life progressed by the time of the first appearance of land life, that some, perhaps many, of the water animals had already grown old, had reached the zenith of their evolution, and had begun to decline or had disappeared. The trilobites are examples of such.

Thus we see that **the higher forms of succeeding ages are never the direct descendants of the highest or more specialized forms of preceding ages.** They have always developed from the lower or more generalized forms. These forms gradually reached higher planes, giving off successively from their simpler stages branches which reach higher and higher planes in other directions of development.

The explanation is simple. Organisms cannot retrace their steps, cannot re-acquire parts or organs once lost. Specialization of structures in any direction limits the possibility of specialization in other directions, for it is only the more generalized forms that have the potentialities of evolution in various directions. Horses, for example, under no conditions nor after the lapse of ages, could give rise to cat-like or dog-like animals, for cats and dogs have five toes and horses have but one, and **organs once lost are lost for ever.**

Appearance of vertebrates.—About the time that the first invertebrates became air-breathers and inhabitants of the land, there appeared in the waters, probably fresh waters, the first representatives of the last and highest branch of the animal kingdom, the vertebrates. We yet know very little of them because they had no bones in the skeleton, and the softer parts of their bodies are only rarely and imperfectly preserved as fossils. Also there is still some doubt as to which class of invertebrates gave rise to this new group, destined to become of such vast importance. The usually accepted theory is that it arose from that group (often classed with the crustaceans) to which the modern horseshoe-crab or Limulus belongs. This group also shows relationships with the spiders and scorpions, so that its true position among the arthropods has been a matter of debate.

The lowest vertebrate of modern times is the lancelet or Amphioxus, a creature but a few inches in length which has no skeleton, no skull, no brain, no lower jaws, no limbs or fins, and whose blood is colorless. It is a marine form which is found along the south Atlantic coast. Lancelets are doubtless the little-changed descendants of the most remote ancestors of fishes and all higher vertebrates. They are not quite unchanged, for it is impossible for any organisms to remain through long ages without some changes. But, like the simple protozoans of the present time, we can not conceive of much simpler organisms that we could call vertebrates; and really the lancelets are not true vertebrates, because they have no vertebrae.

In the evolution of lancelet-like forms into real fishes, the cartilaginous rod (which held the place of the back bones) divided into separate segments, or vertebrae, at first formed of cartilage, later of bone. The three or four vertebrae at the anterior end became expanded and modified to inclose the expanded front end of the spinal cord. Thus we see the first step towards the future brain, and its enclosing skull. Next, and before the cartilaginous skeleton had begun to ossify, the bony scales that developed in the skin joined over the head with the expanded front end of the spinal column. Thus the brain was enclosed and the cranium evolved. Finally, one of the cartilaginous rods on each side that protected and supported the gills or breathing apparatus divided into segments. The first of these segments became attached to the back part of the skull and articulated with the second segment. The front part of this second segment was covered with bony plates of the skin. Thus the jaws

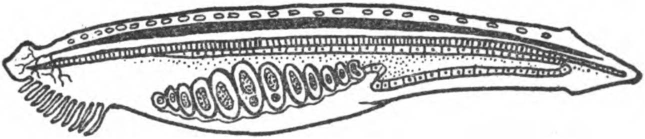


Diagram of the structure of the lancelet (*Amphioxus*). The heavy, dark line indicates the position of the central nervous system; note that there is no differentiation of a brain. The shaded part next beneath represents the *notochord*, the forerunner of the spinal column. Gillslits are indicated below. The mouth is surrounded by fringe-like tentacles.

were evolved, and the skull was completed in its general structure.

Reduction in number of bones.—Since the occurrence of the changes indicated, the whole process of evolution in the vertebrate skull has been to perfect and complete the structure thus begun, and to adapt it to manifold and various uses. In all probability there have been no new bones added to it in all the ages since. On the contrary, many have been lost or so fused with adjacent ones as to lose their identity. The skull of the first land vertebrates had nearly eighty separate and distinct bones in the adult; we have fewer than thirty in ours. The fishes ancestral to the amphibians had at least fifteen separate and distinct bones in each half of the lower jaws. The early amphibians had ten, the earliest reptiles eight, late reptiles five, and two or three of these were vestigial in those forms that gave origin to the mammals. Mammals have but one bone on each side. Some of the earliest vertebrate skeletons had more than a thousand separate bones; we have but two hundred and fourteen.

CHAPTER TWENTY-THREE.

THE EVOLUTION OF VARIOUS ORGANS.

Limbs.—The lancelet has only folds of skin along the sides of the body to aid it in swimming. It is now believed that from similar folds of the ancestral vertebrates the fins and limbs of higher vertebrates were evolved. First there was the development of rods of cartilage to support the folds. Next there was the loss of the middle portions of the folds. Finally the rods of cartilage divided into separate pieces, articulated with each other, and were converted into bones. This explanation is consistent with the fact that front and hind legs are built on the same general plan.

Teeth.—As has been stated, the earliest vertebrates, even the early fishes, had no bones in the skeleton. And the first bones to appear, as we have seen, were not of the internal skeleton, but on the exterior, in the skin. These were probably for protection, since armor plate was more needed among sluggish animals than speed. Our modern sharks are thought to be the survivors of a very ancient group, because they have no real bones. Their skeletons are composed of hard cartilage, but the skin is covered with numerous scales, which under the microscope are seen to have precisely the structure of teeth. The epidermis in which they develop extends into the mouth as far as the pharynx; and that explains the origin of teeth.

When the fishes acquired real mouths with lower jaws, they had grown so large that the minute plants and animals swallowed whole no longer sufficed for their nutrition. Hard organs became necessary for the seizure and crushing of larger bodies. The "placoid scales" covering the internal surface of the mouth served those purposes and became real teeth. At first these teeth were loosely attached in the mucous membrane or skin of the mouth; later they became attached by ligaments to the harder parts beneath them; still later, when the cartilages became bone, they were united to the surface of the bones; finally, as in ourselves, the teeth were inserted in sockets. The scales of sharks and the early teeth were replaced perhaps as often as they were needed when worn out or lost. Later, in reptiles, five or six sets (about the number of loose fangs found on each side in the mouth of a rattlesnake) succeeded the original one.

The earliest mammals may have had three or four sets, but we know of none with more than two sets, the "milk" teeth and the "permanent" teeth; some mammals have only a single set; and some, like the anteaters, have none. In the fishes, teeth covered the whole inner surface of the mouth over the hard parts; in the early reptiles they were restricted to the bones of the palate and lower jaws, and there may have been a thousand or more; in the early birds and in mammals they are inserted in sockets along the margins of the jaws only.

Lungs.—The purification of the blood in water-breathing animals is effected by the passage of water containing gases over the small blood-vessels, and by the interchange of gases through the thin walls of these vessels. The earliest vertebrates probably breathed everywhere through the skin, just as the frog in water does. In fishes there is a circulation of water forced by the mouth through the gills, which are lined by numerous small blood vessels. In the tadpoles of amphibians there is movement of water over the fringed external branchiae.

All that is necessary for the interchange of gases through the walls of blood vessels is that the surface should be kept moist. In the lungfishes of today, which have the habit of breathing air some of the time, the air is swallowed into air bladders whose surfaces are kept moist. To develop these air bladders into real lungs required only a much greater extension of the moist surface, and this was acquired by their division into smaller and smaller cavities till they became the minute cells of lungs.

Circulatory organs.—In the lowest vertebrates the heart is merely a contractile bulb, like the bulb of a syringe, which forces the colorless blood onward. In fishes the heart has two contractile bulbs, strengthening the current and improving the circulation. However, with the development of lungs in the lung-fishes, and in the amphibians and reptiles, there appear two auricles. One of these receives the venous and the other the arterial blood; both kinds of blood are mixed in the single ventricle and forced alike through the body and the lungs. But in birds and mammals there are not only two auricles, but two ventricles also; one sends the venous blood to the lungs, the other sends the arterial blood to the body. These changes did not come about suddenly, but very gradually. The heart of the crocodile for instance has, like the birds, two ventricles, but nevertheless the venous and arterial blood are only partly separated in the circulation through body and lungs.

General principles.—To follow in detail the evolution of all the organs of the body would require too much space and be somewhat tedious. Suffice it to say, that, in general, **organs may acquire new uses yet they remain merely modifications and developments of pre-existing organs.** Similarly, they may cease to be of use, like the vermiform appendix or the pineal body, which are organs we all possess but never use. The pineal body, for instance, is a vestige of a sense organ which once had a function perhaps like that of the eye. But, it has not been functional for millions of years.

On the other hand, organs that cease to fulfill their original functions may be converted into new uses. The following example illustrates this. In the reptilian lower jaw, as we have seen, there are five separate bones on each side; in the mammals there is but one. What became of the others? Some of them disappeared absolutely, but one of them, that part of the original rod which articulated with the first segment attached to the skull, when it ceased to be of use in the lower jaw, became converted into an ear bone, and serves to transmit sound to the improved internal ear of mammals. Furthermore, the first bone of that original rod which was attached to the skull, after it ceased to be of use in articulation, also slipped up into the ear and became another ear bone in the mammals. Thus it happens that while reptiles and birds have but one ear bone in each ear (the stapes), mammals have three (stapes, incus, and malleus), the latter two with very different functions from their original ones in the reptiles. It took many years to convince anatomists that this is the true explanation for the additional ear bones of the mammals, but they nearly all believe it now.

CHAPTER TWENTY-FOUR.

REPTILES, BIRDS, AND MAMMALS.

The migration from water.—Fishes venturing into muddy or stagnant water, possibly to escape their enemies, perhaps to get more food, learned to breath air by swallowing it into the moist air bladders. So the evolution of the amphibians, which as adults breathe air only, is not mysterious. The evolution of limbs with fingers and toes occurred at the same time and this too is not difficult to understand. The lung fishes, which can move about somewhat on land, have fins much more like legs than are the fins of water breathing fishes.

It is curious that the earliest amphibians that we know had five fingers on each hand and five toes on each foot; and no animals which have since lived have had more than five real fingers or toes. For a long time the earliest records that we have of the amphibians are foot prints. For a much longer time the amphibians were the only land vertebrates. They were the rulers of the land and the fresh waters; the sharks were the rulers of the seas. These ancient amphibians reached great size; fifteen, perhaps twenty feet in length; and they were of many and diverse kinds. Their living descendants are the toads, frogs, salamanders, and blind worms, relatively few in number and small.

The change from amphibians to reptiles was gradual, and we know so many connecting links between the two classes that it is sometimes hard to decide to which class some of them belong. The reptiles began as small creatures descended from the less specialized amphibians long before the latter had reached the zenith of their evolution. After the amphibians had declined in numbers and in powers, the reptiles in their turn became the rulers, not only of the land and the air, but some went back to the water again as air breathing creatures, and ruled there also. Some, the dinosaurs, attained the largest size of all land animals of the past or present. They became a hundred or more feet in length and forty or more tons in weight. In the seas some were fifty feet in length, and in the air the pterodactyls attained an expanse of

Restoration of *Allosaurus*, an American carnivorous dinosaur about twenty-five feet in length. Only skeletons are preserved, but from them the external appearance and habits of these animals may be deduced with much probability of accuracy.—*After Knight*.

leathery wings of nearly twenty-five feet, twice that of the largest bird.

Birds and mammals.—Even as the amphibians reached their greatest development, perhaps a million years or so after the reptiles had begun as small creatures, so, also, the birds and mammals began their independent existence a million or more years before the reptiles reached their greatest power and diversity. The earliest known birds had a long tail of bones, had teeth in the jaws like those of reptiles, and clawed fingers on their wings. After the glory of the reptiles on the land and in the air and water had departed forever, the birds came into their own. There are more kinds of birds now living than there are of all other air breathing vertebrates combined. Many reptiles of the past went into the seas and waxed mightily in power. Similarly there have been not a few birds that returned from the air to the land, and forgot how to fly, became runners again, and some of them achieved great size. Thus some extinct members of the ostrich tribe were twelve or more feet in height.

The birds were a branch from the reptiles, probably from the immediate ancestors of the dinosaurs, and while not all the connecting links between the two classes are known, their intimate structure is so nearly alike, notwithstanding that one is cold blooded and the other warm blooded, that there is no doubt of their relationship.

Even earlier than the birds, the first mammals appeared. They were animals so nearly like their ancestors, the reptiles, that it is difficult to say just what distinguishes one from the other. Indeed **no two classes of vertebrates are so closely united by known connecting links as are reptiles and mammals.**. About all that positively distinguishes them is the possession of the two new ear bones that have been mentioned in the mammals, and the remaining vestiges of them in the jaws of the reptiles.

The mammals lived long ages in a very humble condition, on the ground and in the trees. They were then not larger than rats and mice, and so they remained until after the decline of the reptilian horde. Then they in their turn came into their own upon the earth and flourished mightily. Perhaps they drove out the reptiles by eating their eggs. Perhaps the reptiles had grown old and decrepit as a class, and were no longer able to withstand their active and brainier little enemies. Mammals also have invaded the air and the seas, but not very successfully in competition with the birds, though in the water they include the most gigantic animals the world has ever seen, the whales.

Survivors of ancient races.—We have observed that some of the simple and old fashioned animals have persisted for long ages, continuing to occupy positions away from the competition of their higher relatives. There are a few such mammals yet living. Such are the duckbill and the echidnas of Australia. They resemble the reptiles in so many respects that if they did not possess hair we might call them veritable "connecting links." They are not fully warm blooded, they lay eggs and hatch them like reptiles, and some parts of their skeletons are more like those of reptiles than those of the higher animals.

Connecting links.—The evolution of the mammals is a tremendous subject all in itself, and we can not give even the briefest outline of it here. In no other branches have the evolutional lines been traced in so many directions; of no other class do we know so much of the actual stages of evolution along different lines. Thus, in the case of the horse, between its little four-toed ancestor of a million or two years ago and the modern one-toed horses dozens of connecting links have been found. From the primitive elephant, not much larger than a sheep and with teeth nearly like those of other mammals, and only a flexible nose, to the great elephants of recent times with enormous tusks and extraordinary proboscides, nearly every important stage has been found. And so, too, the genealogy of rhinoceroses, pigs, deer, camels, oxen and many others have been traced in more or less detail.

Only of man is the early history yet meager, but not nearly so meager as it was a few years ago. Two or three new species have been discovered, and sometime we doubtless shall find, probably in Asia, the real connecting links between him and his ancestral, ape-like forms.

Of the principles of animal evolution the following should be remembered. First, that **evolution is irreversible,** that is, organs or structures once lost can never be regained by descendants of the animals that lost them. Thus no descendant of living horses can ever have more than one toe on each foot, nor have more teeth. No future birds can have clawed fingers on the wing like the oldest known birds had, nor more than four toes on each foot.

Second, **the forerunners of all branches, groups, or classes of animal life were small.** Animals may remain small through ages, but if they decrease in size it means approaching extinction, and small races are never descended from races of large animals. The first horses were about a foot high, the first camels not much larger, the first deer were small and had no horns; the first of the human race were smaller than we are, and so on.

Finally, **there was increase in brain capacity among mammals, and doubtless among all the higher animals.** The early horse was more stupid than the living ones; the early dogs and cats were less intelligent than the living ones; and prehistoric man, judging by analogy, possessed less brain power than historic and modern men.

CHAPTER TWENTY-FIVE.

EUGENICS.

Importance of the subject.—A practical outgrowth from the study of heredity and evolution has been the subject of eugenics as applied to the human race. The word means "well born," and it has been thought that our growing knowledge of the laws of heredity may enable us **to secure for children the right to be well born.** Every one is interested in the subject, and rightly so, and this interest has begun to express itself in a demand for customs and legislation which will tend to improve the race.

The study of heredity has passed from the stage of crude observation and inference to the stage of rigidly controlled experiments. It follows that there are some things we really know about heredity, but it should be remembered that this knowledge has also brought into view, as never before, the vast stretches of our ignorance in this subject. **There is a temptation to regard things as settled which are not settled,** so that proposed legislation, commendable in purpose, is sometimes thoroughly unscientific and futile in fact.

The greatest gap in our knowledge in reference to eugenics must not be forgotten. While careful experiments in heredity have been carried on with the simpler plants and animals, especially those that are very short-lived, human beings cannot be experimented with in the same way. We can simply observe and infer, and even our so-called observations of the human race are really records that may not be accurate, and certainly do not include all the information necessary to reach a safe conclusion. The subject is so vital to the best interests of the race that we are in danger of being swept into rash actions. Knowledge in this field accumulates very slowly, and the interested public must be patient. The subject of eugenics is too new and too complex to be presented here, but it may be helpful to say certain things in reference to it.

Some facts.—We know that certain things are likely to be inherited and others are not. For example, certain diseases of the parents are likely to be transmitted to the child, while an acquired character, such as a scar or a lame leg, is not transmitted. We have learned, also, that inheritance involves not only the transmission of characters that make a child resemble its parents, but also characters which make it different from its parents. In other words, inheritance includes the transmission of dissimilarity as well as similarity, and this dissimilarity results in what we call individuality. No two human beings are exactly alike, and it is this fact that frees a child more or less from being doomed by its inheritance. Otherwise, heredity would be a machine-like expression of predestination, and human responsibility would have been reduced long since to a minimum.

It is the sense of obligation developed by the facts of heredity that has led to the growth of the subject of eugenics, which perhaps as yet can hardly be regarded as a science. For, as to human heredity, we have not yet facts enough to prove our theories.

Unit characters.—Any familiarity with the machinery of inheritance is full of hope, as well as of danger. The reproductive cells are the most generalized cells of the body, and are not narrowly limited in their possibilities. They may express themselves in the greatest variety of ways. When fertilization occurs, two of these very potential reproductive cells unite to form a single new cell, the fertilized egg. Each of the reproductive cells entering into such a union contains the accumulated inheritances from a long list of ancestors, and the combination may well be regarded as a new one, at least it did not exist in either of the parents.

Of course a character is not literally inherited, although it is convenient to say so. The thing inherited is **something** that determines the character, a convenient name for it being a **determiner.** Another significant fact is that the characters seem not to be inherited in groups which cannot be broken up, but they seem to remain independent of one another, as is illustrated when a child possesses some of the characters of its mother, but appears to lack others entirely. This fact is expressed by the phrase **unit characters.**

The aggregation of characters.—All the determiners inherited from both lines of parents represent so great an aggregation of characters that it is hard to imagine all the possibilities or capacities contained in a fertilized egg. The important question is as to **which possibilities and capacities will get expression.** Heredity determines the limitations placed upon the possibilities of a child, for the child can develop no other capacities than those it has received. It must be remembered, however, that the parents themselves possessed many possibilities that remained undeveloped in them; in fact, it is certainly true that none of us have called upon more than a small fraction of the possibilities we have inherited. These "undeveloped possibilities" may be transmitted to children as well as those which have been developed. It follows that the child may develop very different possibilities from those that were developed by either parent. Even a limited knowledge of families bears out this statement.

The selection of characters.—If parent responsibility, so far as inheritance goes, consists only in determining the number and character of capacities transmitted, what determines the selection of capacities for cultivation? It is this second factor that those untrained in biology are in danger of omitting in their eagerness to see that parents are "fit." It is evident that they may be unfit so far as their own development is concerned, but at the same time they may be able to transmit capacities that are very fit for development. This second factor that determines the selection of capacities may be expressed as **opportunity.** This opportunity includes what is commonly thought of as environment, but it also includes much more. Inheritance determines the number and character of capacities, but opportunity determines those that are to be developed. This second factor does not lessen the responsibility of parents, but it gives great hope to the child. It means that the child is not doomed to one form of development, but so long as its capacities can be stimulated by opportunity, it may respond by development in any direction. It is this second factor that furnishes the biological basis for the claim that no man is past hope on account of his inheritance, or even on account of his previous development.

Social obligations.—With these facts in mind, certain social obligations become clear.

(1) The responsibility of the parents in the matter of inheritable diseases is evident, and should be made the basis for legislation. It must be remembered, however, that the maximum danger is not avoided by safeguarding marriage. The far more subtle form of this danger comes from the social evil, on account of which thousands who may be fit at marriage may become unfit afterwards.

(2) The responsibility of parents in the matter of the inheritance of undesirable tendencies must be taught persistently, for the evidence is clear that a strongly developed tendency in a parent may be the tendency most likely to develop in the child.

(3) Perhaps the most important social obligation in

connection with eugenics is to **see to it that every child shall have a chance to respond to a stimulating opportunity.** This will save thousands, where the regulation of marriage will save one. It is a tremendous problem, for it involves the total exposure and interests of the child.

CHAPTER TWENTY-SIX.

LESSONS FROM EVOLUTION.

Knowledge of evolution develops an attitude of mind that is extremely important. It results in a kind of mental training that is rarely obtained in any other way. This training is valuable because it gives a new perspective, a new outlook on the problems of life.

Rigidity.—Plants and animals are generally thought of as rigid things; things whose structures are duplicated, generation after generation. Their various structures are defined and catalogued. These definitions seem to give to the structures the unchangeableness of the words in a dictionary. A definition always seems to make a thing rigid, and since much of our education consists in learning definitions, our knowledge is in danger of becoming sorted into pigeon holes; we have a tendency to separate facts from one another by rigid partitions which we call definitions. Evolution teaches us that there are no pigeon holes in nature; that definitions are temporary conveniences to help us hold on to our knowledge; and that no definition is final.

The inference is that other experiences, not included in what we call nature, are to be regarded in the same way. In other words, nothing is absolutely rigid, but is capable of change. Everything is in a state of possible action; that is, it is **dynamic.** Nothing is immovable; that is, **static.** A static world would be a hopeless sort of place to live in, but a dynamic world means all sorts of possibilities. This conception of the world, which evolution has introduced, is of the very greatest importance, because it makes us feel that work is worth while, and that things apparently rigid can be changed.

Responses.—Experimental work in evolution and heredity has shown that the structures of plants and animals are not inevitably determined in advance by what they inherit. It is found that these structures are responses to the conditions that prevail during their development. Our impression that they are inevitable has arisen from the fact that in nature the conditions during development are remarkably uniform. In other words, a given structure, so far from being inevitable, is a record of the conditions that prevailed during its development. Uniformity in conditions results in uniformity in structures, and uniformity in structures gives the impression that the uniformity is a fixed thing.

We have learned by experimental work that uniformity is not fixed, for if we change the conditions, the result changes. A single illustration will emphasize this fact. There seems to be nothing more fixed than the life periods of plants, and these periods are recognized by the appearance of certain structures. For example, in certain algae there are three well-marked life periods. The first is the vegetative period, during which the plant grows; then there is the spore period, during which the plant produces spores; finally there is the sexual period, during which the plant produces sexual cells. These three periods succeed one another so uniformly that it was natural to conclude that the succession is inevitable. Now it is found that these three periods are simply responses to three different conditions of living, and these conditions can be controlled experimentally. It is possible to make such algae continue in the first period indefinitely, producing neither spores nor sexual cells; to induce the production of spores or sexual cells at any time; to stop the production of sexual cells and induce spore production; in short, to play upon the conditions in which the plant is living and obtain a corresponding response.

There are no structures more fundamental than those referred to in this illustration, so that if they are responses to conditions, any structure may be. The suggested lesson is that things in general are responses to certain conditions; and that it is our business to discover these conditions. As suggested by the illustration, when the conditions are discovered, it may be possible to control the results. There is nothing more important in our lives than the discovery of the conditions that determine things we wish to change or control; and our study of evolution assures us that this is possible. The trouble has been that we have been content "to take things as they are" and not try to change or control them.

Proof.—A study of evolution emphasizes the nature of proof. What it takes to prove a thing is one of the most important things for people to learn. In general, people are subjected to all sorts of appeals to belief and to action, and unless they are able to recognize the differences between a claim and a proof, they may become victims. To infer is one thing; to demonstrate is quite a different thing. For example, in the account of Darwin's theory of Natural Selection, it will be recalled that it was said to be based upon a series of facts. There can be no differences of opinion as to these facts, but the single inference, namely that new species may arise by natural selection, has led to much difference of opinion. The inference seems extremely probable, but the splendid argument does not prove it.

Two kinds of plants resemble one another so closely that we infer that they have had a common origin, but this is not proof. In this case, proof would consist in actually seeing these plants produced by a common ancestor. It is for this reason that evolution and heredity have reached the experimental stage. We had compared and inferred long enough, for this could never reach demonstration. We began to experiment, which means that we watched plants and animals actually doing or not doing the things concerning which we had been making our inferences.

Evolution emphasizes not only the difference between an inference and a demonstration, but also that inference must keep close to the facts if it is to be worthy of consideration. People have imagined that one can start with a single fact, and by some logical machinery add inference to inference and thus teach a reliable conclusion, no matter how far we travel away from the original fact. In this way many so-called "systems of belief" have been constructed, and they are fortunate when they can claim to rest upon even a single fact. A study of evolution makes it clear that a fact is influential only in its own immediate vicinity. The farther one travels away from a fact, the less influential does it become in any conclusion. Like the light from a candle, as one travels away from it, it becomes less and less until the vanishing point is reached. Many an elaborate system of belief has been constructed entirely within the region beyond the vanishing point of facts. Facts are like stepping stones. If they occur in a sufficiently close series, we can step from one to the other and make progress; but if we undertake to pass beyond them we flounder. Evolution, therefore, teaches us to stick close to the facts even in our inferences.

The open mind.—The easiest thing to cultivate is prejudice. Prejudice is not only belief without proof, which may be innocent enough; but it is chiefly shutting one's eyes to any facts which may disprove the belief, which is inexcusable. There may be some excuse for ignorance; but there can be no excuse for a refusal to know the facts when they are presented. The prejudiced mind is in sharp contrast with the open mind. The one deliberately closes its eyes to truth; the other opens them wide to truth from every direction.

If all men had been prejudiced, there would have been no science of evolution, with all its results in knowledge and usefulness. The eyes of certain men were open to facts, even though the facts seemed to contradict all their previous belief. Even after evolution became a subject of investigation, no explanation of it closed the eyes of the investigators. They reached for other facts, and these facts led to other explanations. With all the explanations offered, we are still searching for others, and will not be satisfied until every fact is observed that tells anything about evolution. This emphasizes the fact that prejudice means stagnation, and that the open mind means progress.

It is an interesting fact that the greatest leaders in evolution have probably been the least prejudiced. For example, Darwin and DeVries were certainly less prejudiced in favor of their theories than are many of their followers. No one saw more clearly than these men the weak points in their explanations of evolution. The open mind is the scientific mind, the mind that wants to know. The man of science who is so convinced that his conclusions are right that he will not admit any evidence to the contrary may be effective in some narrow field, but he has blocked his own progress.

The mind open to facts and open to receive facts from every source is our most valuable asset; and to multiply such minds is the hope of any people, for it is the measure of progress.

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