GENERAL BIOLOGY

BY

LEONAS LANCELOT BURLINGAME

ASSOCIATE PROFESSOR OF BOTANY AND GENETICS

HAROLD HEATH

PROFESSOR OF ZOÖLOGY

ERNEST GALE MARTIN

PROFESSOR OF PHYSIOLOGY

AND

GEORGE JAMES PEIRCE

PROFESSOR OF PLANT PHYSIOLOGY

AT STANFORD UNIVERSITY

NEW YORK

HENRY HOLT AND COMPANY

First printing, December, 1922

PRINTED IN THE U. S. A.

V

Dedication

THIS BOOK IS RESPECTFULLY DEDICATED

TO

PRESIDENT RAY LYMAN WILBUR

WHOSE SYMPATHETIC ENCOURAGEMENT AND HEARTY COÖPERATION

MADE IT POSSIBLE TO ATTEMPT

THE ESTABLISHMENT OF SUCH A COURSE

AND LED EVENTUALLY TO THE

PUBLICATION OF THIS TEXT

PREFACE

This text is the outcome of a course of lectures given to Lower Division students at Stanford University in satisfaction of one of their requirements. The course has been conducted by a committee with the assistance of a number of their colleagues, acknowledgment of which is made below.

The idea underlying this book which was adopted by this committee has been set forth at some length by Professors Burlingame and Martin in *Science* for May 7, 1920. The idea is substantially this. Biology has now reached such development that it comprises a large amount of information and knowledge which is not only of the first practical importance to the layman but is also susceptible of being organized into a coherent set of principles suitable for presentation to the ordinary freshman or to the lay public. This necessarily involves stressing principles rather than factual details and limits discussion to such topics as do not put an undue strain on the reader's knowledge of related sciences such as physics, chemistry, and geology.

An inspection of the table of contents will show that the thread which runs through the whole is the interdependence of organisms, especially in relation to man. This it seems to us naturally involves a discussion of the following topics at least:

I. The nature of the living substance, protoplasm, and its division and differentiation into the specialized cells of complex organisms.

II. The rôle of green plants in the synthesis of the primary food and fuel compounds as a source of material and energy for all living things.

III. The maintenance of life of all sorts by the utilization of the materials and energy of foods. This involves of course some consideration of the machinery by which metabolism is carried on.

IV. The mechanisms by which plants and animals adjust their various organs to one another and themselves to their environment both physical and biological, involving a consideration of the general structure and function of nervous systems and of hormone secretion.

V. The interaction of organisms with one another, involving such topics as family and herd relationships, human society, symbiosis, parasitism, and disease.

VI. Death of organisms and of protoplasm.

VII. The decomposition of organic remains and the consequent enrichment of the soil, involving a discussion of the biological and chemical processes involved and their relation to the cycles of energy and material.

VIII. The growth and reproduction of organisms.

IX. The mechanisms and laws of heredity and their application to the breeding of domesticated plants and animals and to the progress of the human race.

X. The facts, the principles, and the results of evolution.

XI. The facts and principles which are involved in the distribution of organisms in time and space.

XII. Man's place in nature, involving on the one hand a discussion of the facts which make man an animal, and on the other hand a setting forth of those even more important facts which lead us to believe that man alone of all animate things is master of the destiny of his race.

A course of this sort necessarily involves a carefully organized laboratory course illustrative of the principles developed in the lectures. At Stanford the student may elect to take such a course, maintained for the purpose, or to substitute for it an equivalent amount of elementary botany or zoölogy.

Although the authors of this text have borne the chief burden of these lectures they are deeply indebted to their colleagues both for able and willing assistance in the presentation of the lectures and for helpful suggestions in the preparation of the text. Where so many have been of great assistance it is practically impossible to make acknowledgment of each separate favor. The general nature, however, of our obligations will be indicated by the following. President Wilbur has regularly given three lectures on disease in animals and one on the relation of human progress to scientific discovery. Professor Doane has given generously of his time and advice in connection with the lecture on insects and disease, and Professor McMurphy has been similarly helpful with plant diseases. Dr. Alsberg of the Food Research Institute has been helpful in our discussion of the structure and functions of protoplasm. Professor Walter Fisher, of the Hopkins Marine Station, has regularly presented the subject of distribution of land animals, as well as having been of service in the general organization of the course. Professor Abrams has regularly given the lecture on geographic distribution of plants and has likewise been of service in the discussion of many other matters. The contributions of Dr. Vestal, director of the laboratory, have been so numerous and varied as to defy specification, but their value is evidenced by the frequent use made of them. They range all the way from the delivery of lectures on ecological distribution of organisms to the selection of suitable illustrations. Dr. Becking, who will henceforth be associated with Dr. Vestal in the direction of the laboratories, has also already made many stimulating suggestions, many of which have been of immediate use in writing this text. Professor J. P. Smith has assisted in various ways in connection with geological distribution of organisms. We are also indebted to various authors and publishers for permission to reproduce figures from their books or for original photographs. Specific acknowledgment is made of each such favor in connection with the figures in addition to this general one. Professor Terman has not only delivered the lectures on the relation of heredity and environment in man but has also written chapter 42 in entirety. It is to be understood that the authors assume full responsibility for the statements and views expressed in the text.

L. L. B., H. H., E. G. M., G. J. P.

Stanford University, California.
December, 1922.

CONTENTS

CHAPTER I

Introduction

PART I

Section 1. The Living Substance

CHAPTER II

Protoplasm and the Cell

CHAPTER III

Multicellular Organisms and Division of Labor

Section 2. The Rôle of Green Plants

CHAPTER IV

The Manufacture of Foods and Fuels

CHAPTER V

The Building of the Living Machine

CHAPTER VI

The Income, Movements, and Outgo of Materials in Plants

CHAPTER VII

The Storage and Digestion of Foods in Plants

Section 3. The Maintenance of Life

CHAPTER VIII

The Utilization of Food

Section 4. Adjustment of Organisms

CHAPTER XII

How Plants are Adjusted to their Environment

CHAPTER XIII

Movement in Animals

CHAPTER XVI

Chemical Correlation

CHAPTER XVII

Diseases Due to Maladjustment

Section 5. Association of Organisms

CHAPTER XVIII

Association of Organisms

CHAPTER XIX

Diseases of Plants

CHAPTER XX

Diseases due to Harmful Organisms

CHAPTER XXI

Insects and Disease

Section 6. Death

CHAPTER XXII

Death and the Duration of Life

Section 7. The Rôle of Microörganisms

CHAPTER XXIII

Decomposition

CHAPTER XXIV

The Fertility of the Soil

PART II

Section 8. Growth and Reproduction

CHAPTER XXV

Cell-Division

CHAPTER XXVI

Reproduction in Animals

CHAPTER XXVII

Reproduction in Plants

SECTION 9. HEREDITY

CHAPTER XXVIII

MENDEL'S LAWS

CHAPTER XXIX

THE LAW OF INDEPENDENT ASSOCIATION

CHAPTER XXX

LINKAGE PHENOMENA

CHAPTER XXXI

The Character Expression of Genes

CHAPTER XXXII

Plant Breeding

CHAPTER XXXIII

Animal Breeding

Section 10. Evolution

CHAPTER XXXIV

Evidences of Evolution

CHAPTER XXXV

Theories of Evolution

CHAPTER XXXVI

The Results of Evolution

Section 11. The Distribution of Organisms

CHAPTER XXXVII

Plant Distribution

CHAPTER XXXVIII

Distribution of Land Animals

CHAPTER XXXIX

Distribution of Life in the Ocean

Section 12. Man

CHAPTER XL

The Evolution of Man

CHAPTER XLI

Human Inheritance

CHAPTER XLII

Inheritance of Mental Traits

(By Lewis M. Terman)

CHAPTER XLIII

Man's Place in Nature

GENERAL BIOLOGY

GENERAL BIOLOGY

CHAPTER I

INTRODUCTION

Biology is the science which treats of living things. The number and diversity of organisms in the world is so great as to be almost incredible. It is said that there are more than a half million kinds or species of insects alone already known and that there are undoubtedly a great many as yet undiscovered. Of Diatoms, a sort of one-celled plant, there have been named more than ten thousand species. Altogether, it is well within the limit to say that there are more than a million kinds of animals and plants.

Not only are organisms immensely numerous and highly diversified but their activities are also extremely numerous and complicated. Even apparently simple processes frequently turn out to be complex and very difficult to understand. This makes it necessary in order to accomplish much in the way of new knowledge for investigators to confine their attention not merely to a few kinds of organisms but also to a single one or a few of their activities. To add to the difficulty of the matter, it is usual to have a great many different chemical reactions going on in one small bit of living matter so close together that it is difficult to realize that they can possibly avoid interfering with one another. For this same reason it is difficult to isolate a single activity for study.

It is very obvious that no person could possibly become familiar with all the different kinds of living beings. It is necessary, therefore, to subdivide so vast a subject.

One of the most natural of these subdivisions separates animals and plants into two distinct sciences, Zoölogy and Botany. Very little intelligent work could be done with such large numbers of plants unless they were first carefully classified. There must also be a definite and fixed plan of naming them so that they can be readily and certainly referred to. Thus there arises a science of Classification, sometimes called Taxonomy.

Both Botany and Zoölogy are further subdivided according to the point of view, into several sciences. Where the chief interest lies in form and structure the animal or plant must usually be cut up for examination, which often requires special tools and special training. This constitutes the science of Morphology, as distinguished from the study of function, or Physiology. Students of heredity require a different sort of equipment for their investigations. They must have gardens and breeding-pens to rear their plants and animals, and may require a laboratory in which to carry out microscopical or chemical investigations. This constitutes the science of Genetics. Some investigators are concerned with the relations of plants and animals to one another and to their environment, and so do most of their work in the field. They are called Ecologists. The object in mentioning these special sciences is to show that each requires a special equipment and much training, so that it is not easy for one individual to do active work in more than one field of study.

Besides the pure sciences of Biology there are many fields in which biological principles are applied practically. Medicine is one of the most conspicuous of such applications of the results of pure science to the affairs of every-day life. Sanitary biology, concerned with drainage, the abatement of insect pests and similar matters, is another. Public health work involving the regulation of buildings, the handling of food, and many other things, is still another. Plant breeding and plant pathology are both of great importance in modern agriculture, the one to provide new and improved sorts of plants and the other to find means of checking the enormous losses due to the attacks of parasitic fungi and bacteria on crop plants. A list of this sort might be greatly extended, but it is probably already clear that modern Biology has become a vast and complicated subject, one in which the ordinary citizen can hope to know only the general facts and principles.

General Biology aims to bring together and present to the non-specialist those aspects of Biology which it is important that everyone should understand in order to perform his duty as a citizen in an intelligent manner. Whereas the professional biologist must limit his field and specialize in order to keep the range of investigation within such bounds as will permit him to become a master of all that is known concerning it, the general biologist strives to bring together the most important facts and principles and so relate them that the average person can usefully apply them to his ordinary affairs. In an elementary course many interesting and important subjects must be omitted or curtailed because they are too difficult, or the student's previous training has been inadequate, or because the time is not sufficient. In conformity with these limitations the following subjects have been chosen for consideration in the belief that they are of such importance that no educated person can afford to be ignorant of them:

1. The Living Substance, Protoplasm. — It will be shown that every living thing is alive because it is composed in whole or part of a peculiar substance called protoplasm. Furthermore this protoplasm is not only of universal occurrence but it is very similar even in the most diverse organisms. It is certainly worth our while to understand the physical, chemical, and physiological characteristics of this most wonderful of all substances.

2. Green Plants play a peculiar and most important

rôle in nature in that they are the chief sources, directly or indirectly, of nearly all the energy (aside from that generated by falling water and wind power) which man uses in his operations. From them are derived all the foods and all the fuels, besides a host of other useful products. It is surely important, therefore, to understand how they are able to catch and store up the energy of the sunlight in foods and fuels.

3. The Maintenance of Life in Animals and Non-Green Plant Cells is wholly dependent on food manufactured by green cells. This they use to build their bodies and from it they derive the energy to do all sorts of work. In liberating the energy stored up in foods animals decompose them into the carbon dioxid and water from which they were originally manufactured. Some foods are used to build living protoplasm. This very gradually breaks down in the course of its life activities and a portion containing the element nitrogen is thrown off as waste and excreted from the body. Eventually it also returns to the soil to be used over again.

4. Adjustment of Organisms to Their Environment is necessary to their continued existence. A plant must be able to direct its roots into the soil and its leafy stems into the air if they are to perform their proper functions. In like manner, an animal must be able to find and recognize suitable food in sufficient quantity, or it starves. The very fact that they can do these things shows that there is some sort of mechanism for securing proper adjustment of organisms to the environment. It will be shown that this depends on certain characteristics possessed by all protoplasm, but which has become highly specialized in certain organs of the higher plants and animals. It may appear somewhat startling to the beginning student to realize that his organs of special sense (sight, taste, smell) and the system of muscles and bones and joints, the organs of locomotion, are but the ultimate developments of a food-getting mechanism and that they

rest fundamentally on the power of all protoplasm to respond to certain outside influences and to execute forcible movements by the utilization of energy liberated from food. The nervous system and the brain itself are likewise to be included in this mechanism of adjustment of the body to its surroundings and of its various parts to one another.

5. The Interaction of Organisms on one another is likewise a most important subject. Every plant and animal is more or less influenced by its neighbors, but in some cases the association is so close that both benefit from it, or one benefits at the expense of the other. The former constitutes the relation of symbiosis (from the Greek *sym-* with, and *bios-* life) and the latter that of parasitism. The first is less common and of slighter importance. The latter relation very commonly gives rise to a condition of disease in one of the parties to the association. This is of enormous importance in both plants and animals. Every year millions of dollars worth of crops are lost through the attacks of parasites. The loss and suffering due to the action of parasitic bacteria on animals — including man — is too familiar to need more than bare mention.

6. Death comes to all highly organized living beings sooner or later. Each begins as a single small bit of living matter (a cell) which by repeated divisions and specialization finally grows into the mature individual. This may live but a few hours or it may live thirty centuries, but in the end it reaches its span of life. Of course most organisms meet death in nature from violence — injury or disease — but nevertheless it has not been possible so far for the biologist to prolong life indefinitely in any highly organized type. It is in consequence a very interesting and important problem to ascertain just what are the conditions which determine that protoplasm is alive one moment and dead the next.

7. The Decomposition of Organic Remains is one

of the prime necessities for the continued existence of life on earth. Otherwise the earth would shortly become completely covered with dead bodies. The raw materials which are combined by the green plants must eventually be returned to the air and soil. Although these decompositions are chemical reactions, like those occurring in living bodies, they do not occur spontaneously any more than water and carbon dioxid will spontaneously form sugar. In both cases the presence of living organisms is necessary under ordinary natural conditions. Decomposition is brought about by small non-green plants chiefly, although animals in liberating energy for doing work return large quantities of water and carbon dioxid to the soil and air. The proper treatment of soils to secure the most desirable growth of these small plants and the maximum enrichment of the soil through their action forms a most interesting chapter in modern achievement.

8. THE REPRODUCTION OF PLANTS AND ANIMALS is just as necessary as their ability to live and maintain themselves. The means by which this is attained are most varied, interesting, and important. In fact they are so diverse that they can be treated in a book of this sort only in a most general way.

9. HEREDITY. — Although so familiar as to have lost its novelty, it is nevertheless a most curious and interesting fact that offspring closely resemble their parents but are never exactly like them. This is said to be due to heredity. Although our knowledge of the laws of heredity has been acquired almost wholly in the last twenty years, the last ten of them have seen more rapid advance in the understanding of the mechanism of heredity than in almost any other line of biological investigation. Not alone from its human and scientific interest but also on account of its great practical utility (in breeding economic plants and animals) does this subject deserve discussion in this course.

10. Evolution. — This term is used by biologists to describe the facts that the numerous varieties of both animals and plants can be readily arranged into more or less complete series gradually increasing in complexity from simple one-celled forms at one end to the most highly organized plants and animals at the other end; and further, that these series closely parallel the arrangement of the fossil remains of past geologic ages which are found embedded in the rocks. Since it is obvious that these series represent a gradual development of organisms, many theories have been propounded to explain the facts of evolution. Theory and fact must be carefully distinguished by the student. The series of plants and animals are unquestioned facts, whereas the explanations are only more or less probable theories. The observations and experimental data which have been collected within the last twenty years have tended to eliminate many of these theories because they do not agree with our new knowledge, and to strengthen others because they are more in accord with it.

Evolution is linked in the minds of most people with the name of Charles Darwin because he was the first to put clearly before the world evidence in support of the idea that all protoplasm is related; that the present forms of life are descended from previously existing forms; and that in the course of descent variations have occurred which were inherited; and finally, that those inherited variations which were well fitted to their environment have survived. This idea has proved and still is a most potent and fruitful stimulus to biological investigation in all fields.

11. The Distribution of Animals and Plants has also long offered interesting problems both to the layman and the scientist. The biologist must account for two sorts of facts. In the first place he finds that widely separated regions of the earth with similar climatic and soil conditions have animals and vegetation of very simi-

lar appearance, although the actual species are rarely the same or even closely related. For example, there are no cacti in the Sahara Desert but there are plants closely resembling them which are not nearly related. On the other hand, related species are usually found in the same general region although they may not resemble one another in appearance or live in similar habitats. This study of the adaptation of organisms to their surroundings has a practical side also, in that successful agriculture consists very largely in providing the most suitable environment for each particular crop. Thus, the U. S. Department of Agriculture experts are often able to predict what sort of crops will do well under cultivation on wild lands by observing the plants growing on them in nature. This is, of course, only a beginning, for the chief object of the scientific agriculturist is to devise still more favorable conditions of growth for his animals and plants.

12. Man's Place in Nature is certainly one of the subjects of greatest importance and interest to himself. It is, therefore, well to understand in what ways he is subject to the same limitations as other animals, and in what ways he differs from them and is their superior in molding and transforming his environment to suit his needs or convenience. It may be disappointing to find that he has far more in common with them than otherwise. However, the differences, small as they are, make him largely the master of the destiny of his race and an important influence on all nature.

PART I

SECTION 1

THE LIVING SUBSTANCE

CHAPTER II

PROTOPLASM AND THE CELL

Universality of Protoplasm. — It is a curious fact that though the surface of the earth is enormously diversified there is almost no square foot of its area that is without life. It is almost as striking a fact that throughout the enormous range of living things there is present a single living substance, *protoplasm*, which is fundamentally alike wherever found. Some organisms consist entirely of protoplasm, some highly organized beings consist only in small part of living protoplasm but chiefly of the products formed by it.

Protoplasm Always Organized into Cells. — It will be seen in a subsequent paragraph that the physical structure of protoplasm is such that it could not exist unsupported in large mass. From this it follows that any large organism must have some method of dividing the protoplasm into smaller portions. In fact it is found to be true, that wherever the living substance increases largely in mass it is organized into distinct, very small parts called *cells*. The term cell signifies an independent bit of protoplasm.

The Discovery of Cells. — Although living organisms have been known from the earliest times, it is only within the last two hundred and fifty years that they have been known to consist of cells. The reason for this is that previous to that time there were no means of observing so small an object. Ordinary cells are too small to be seen with the naked eye or even with a small lens. They vary greatly in size, but an average cell in a growing root-tip, for instance, is about one ten-thousandth of an inch in diameter. In the human body there are probably several hundred million cells.

The discovery of cells, therefore, had to await the perfection of the microscope. In the Seventeenth Century a Hollander named van Leuwenhoek had so far progressed in grinding lenses that it became possible to see small objects. These lenses aroused a great deal of curiosity and were eagerly sought by scientific men. Among them was Robert Hook, an Englishman. In 1667 he happened to slice a piece of cork with his razor and examined it with a microscope, and discovered to his astonishment that it contained a great many tiny cavities. Because of their appearance — something like the cells of a prison — he gave them the name *cell*. This term we still use, although it is perfectly evident that it is a misnomer. The important part of the cell is not what Robert Hook saw, namely, the hard cell-wall, but the living protoplasm inside the wall, which he did not see.

THE DISCOVERY OF PROTOPLASM. — It was more than one hundred years after Hook's discovery of the cell before any observer saw and published an account of what we now know to be the living substance. The first account which one can recognize as describing protoplasm was written in 1755. A few years later, in 1773, an Italian abbot named Corti observed in the common water plant named *Chara* that the contents of the cell were, under certain conditions, in motion. Although he published an account of his observation it seems not to have attracted any particular attention until 1807 when this fact was again observed in the same plant by a German investigator named Treviranus. Still this observation did not suggest to anyone that the moving substance was alive. At that time there were many theories to account for the growth of organisms, all of which appear to us to-day to be fanciful, but it is probably due to this fact that Treviranus's observation did not suggest the connection between motion and life. It was not until fifty years later, through the labors of a great many men, that it was gradually realized that the cells in the living parts of plants and animals are always filled with a jelly-like substance, and that this is really the living substance.

In 1844 Carl Naegeli first enunciated what we recognize to-day to be the correct theory of growth: *That every living cell is derived from another living cell by division.* The full force of this statement can only be appreciated when it is realized that the fanciful theories in favor at that time supposed that cells might be produced in something like the same way that the pores in a loaf of bread are formed by the expanding gases. Thus it is seen that this was a very important discovery. It was not long until it was recognized as a correct statement of fact, both for plants and animals. At about the same time it began to be realized that the contents of the cell are of importance, and in 1846 Hugo von Mohl recognized this fact by giving the name *protoplasm* to the slimy cell contents. Within the next twenty years it became an established fact that the important part of the cell is the protoplasm and that it is the seat of all life activities.

Physical Characteristics of Protoplasm. — It might be supposed that a substance so important to all living things as protoplasm would be distinguished by easily recognizable and striking characteristics. This, however, is not true. Protoplasm from different sources appears very much the same. It is a jelly-like substance, that is to say, it is neither a solid nor a liquid, being in consistency somewhat like the white of an egg. It is either colorless or slightly yellow in appearance. It is not sufficiently fluid to run like water, nor is it sufficiently rigid to stand up like a solid jelly. Its own weight is sufficient to cause it to spread out on the surface of a glass slide. It can be pulled to one side like rubber and will retract to its original form when released, showing that it has a certain degree of elasticity. Some kinds of protoplasm are clear and transparent and homogeneous in structure, while other kinds appear to have a foamy structure, like soapsuds. Protoplasm may sometimes appear opaque because it contains considerable quantities of food.

THE CHEMISTRY OF PROTOPLASM. — Protoplasm is not a simple chemical compound, nor indeed is it simply a mixture of chemical compounds; it is, in reality, an *organized* structure, composed of many different compounds. The larger part of its bulk consists of water, two-thirds or more, in fact. The solid portion of it consists chiefly of the chemical substance known as protein, with some fats, some sugar, and various mineral salts. In addition to these substances which presumably constitute a part of the living machine, there are usually present foods or other materials formed by the protoplasm.

The actual number of elements which enter into the structure of protoplasm is small. Carbon, hydrogen, oxygen, and nitrogen are always present in the proteins and usually in addition sulphur or phosphorus, or both. The fats and sugars contain carbon, hydrogen, and oxygen; the water contains hydrogen and oxygen; the various salts present contain calcium, magnesium, potassium, sulphur, phosphorus, and iron. It is difficult to decide as to which of the elements enumerated are absolutely indispensable to the living substance. It will be shown in a subsequent chapter that living *organisms* cannot maintain life without all of the elements we have named, but it does not follow from this that each and all constitute an actual part of the living machine. It seems certain that nothing can be alive without protein, water, and certain sorts of foods. It is also certain that if the living protoplasm be deprived of the presence of some of the mineral salts mentioned it will presently cease to exhibit the living functions. This might mean that they are all a part of it; but more likely it means that some of them at least merely facilitate the work of the living machine by their presence. In a crude way, one might suppose that some of these salts enable the living machine to function in something the same way that oil enables an automobile engine to function. In the latter case, the oil does not constitute a part of the mechanism but the engine will not run long without it.

The Physiological Characteristics of Protoplasm. — It has already been mentioned that wherever protoplasm is found it always exhibits certain characteristics. Of these we may enumerate six:

1. It has the power of growth, waste, and repair.
2. It has the power to utilize foods and to liberate energy from them to do work.
3. The energy thus liberated may be used to execute forcible movements.
4. The energy liberated may be used in carrying out chemical reactions in the manufacture of other substances.
5. It has the power of response to external stimuli.
6. It has the power of automatic division and reproduction.

Growth, Waste, and Repair. — Wherever living protoplasm is found it is always in a state of change. The protoplasm of the growing parts of plants and animals is able to utilize foods to construct new protoplasm. Protoplasm wherever it exists always wastes away under its own activities. All protoplasm has the power to utilize foods to repair this wastage. These topics need little more than mention at the present time, inasmuch as they form the subject matter of a subsequent chapter.

The Power to Liberate Energy from Food. — Food is used by protoplasm not only for growth and repair but also as a source of energy. It will be shown later that in the formation of food the energy of sunlight is locked up in the chemical compounds of sugar and other similar substances. These, when used as food by protoplasm, can be decomposed and the energy liberated. This energy may be employed to change the shape and form of the protoplasm forcibly. The precise mechanism which is employed to turn the chemical energy of food into mechanical motion by the living substance is not well understood and is at best a difficult one to study.

THE POWER OF CAUSING CHEMICAL CHANGE. — The energy liberated from foods may be employed to carry out other chemical changes. The sequence of events is somewhat as follows: Energy is stored up in food substances only by the green cells of plants; but once this energy is stored in foods they may undergo further chemical changes. These changes may be of two sorts. In the first place, they may be of the sort which liberates energy. This type of change is of course necessary whenever energy is to be used for forcible movements. On the other hand, there are changes in which the resulting compound contains more energy than the one out of which it was made. Now, no change of this sort can be brought about without the application of energy from the outside. This energy must then be derived from the decomposition of foods. It will not be possible in a book of this limited scope, to discuss in detail the great variety of chemical changes brought about in living protoplasm. It will be sufficient, perhaps, merely to call attention to the fact that organic substances produced in this way vastly outnumber the inorganic ones. Such various substances as wood, the textiles, drugs, rubber, gums, and thousands of other articles of commerce, all have their origin in chemical changes which occur in living matter.

SENSITIVENESS TO STIMULI. — Protoplasm is not only capable of executing chemical reactions and forcible movements but it is also extremely sensitive to outside influences. The changes in the environment to which it responds are called *stimuli*. They may be of a variety of sorts. Mere contact, the presence of chemical substances of a particular character, electric currents, light, or other forms of energy are all capable of producing changes in protoplasm. Its power to respond to stimuli is dependent upon its physical and chemical structure. Not only does it respond at the point of contact, but the stimulus may produce the response at a distant point.

STIMULATION, CONDUCTION, AND RESPONSE. — It will be observed that these are really three separate and distinct processes. The first is the sensitiveness of the part of the protoplasm which first receives the stimulus; the second part is the conduction of the stimulus through the protoplasm, that is to say, the propagation of some sort of change; and third, there is the response in some other part of the protoplasm. The response differs from sensitiveness and conduction, ordinarily, in that it is accompanied by much greater energy changes. If the response is to be one of movement it is obvious that energy must be liberated by the decomposition of some energy-containing substance in order to accomplish it. We have an exhibition of this in our own bodies in a very specialized form, where the result is brought about, not within a single cell, but by the coöperation of many cells. If one touches his finger to a hot stove the finger will be automatically withdrawn. In order that this may happen, all of the three things which we have noted in the single cell must occur in the human body. That is to say, there must first be sensitiveness to this heat energy; then some sort of stimulus must be conducted along the nerve trunk to the nerve center and back again to the muscle; and finally, a liberation of energy must be brought about which will enable the muscle to contract and draw the finger away from the hot stove.

CELL DIVISION AND REPRODUCTION. — When cells grow they tend to reach a maximum size which is determined by the kind of plant or animal in which they occur. When they have reached this size division automatically occurs. This is a somewhat complicated process and will be described in another place. It is intended here simply to call attention to the fact that this process is necessary in order to keep the cells of their proper size to maintain the structure of the organism, and that it is an automatic, self-regulated process which is entirely characteristic of living matter.

THE STRUCTURE OF A TYPICAL CELL. — It is not possible to choose any single cell which will show all the characteristics of cells. In order to exhibit the main features of simple cells it will be necessary to choose two or more illustrations.

If a cell be chosen from the growing portion of a young root (Fig. 1) or stem of a plant, it will be found to con-

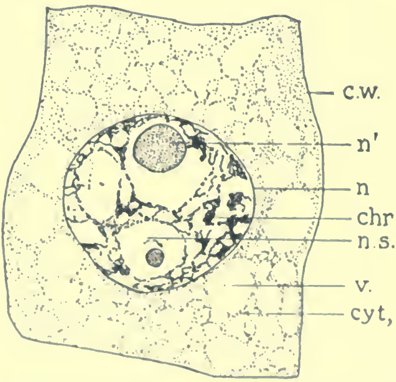


FIG. 1. — A Typical Plant Cell, from the root tip of the Spiderwort (Tradescantia virginica). *c.w.*, cell wall; *cyt*, cytoplasm; *n*, nucleus; *chr*, chromatin; *n.s.*, nuclear sap; *n'*, nucleolus; *v*, vacuole filled with water and dissolved substances.

tain or to consist of the following parts: around the outside there is a delicate wall composed of a non-living substance, cellulose; within this wall there is a solid mass of protoplasm. In the center of the protoplasm there is a rounded body, more or less spherical, called the *nucleus*. Practically all cells contain protoplasm which is differentiated into these two parts, for convenience of reference called *nucleus* and *cytoplasm*. In addition to these two structures, many cells possess other organized parts. If we examine a cell from the older part of a plant we shall find that the wall is thicker, that the cell is larger, and that the protoplasm is confined to a thin layer forming a closed sac in contact with the wall. The middle of the cell is filled by a *water vacuole* containing a variety of substances in solution. The function of this vacuole is an interesting one. It will be shown later that the materials which are dissolved in the water exert a pressure upon the protoplasmic sac to keep it in close contact with the surrounding cell-wall. This is the chief means of maintaining the rigidity of the softer parts of plants. Animal cells, on the contrary, do not usually

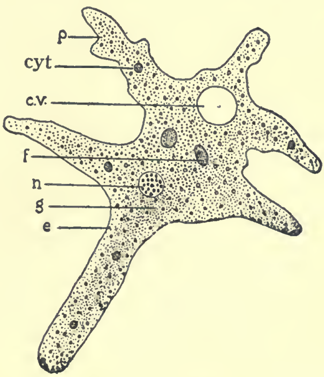


FIG. 2. — Amœba, a one-celled animal. *n*, nucleus; *cyt*, cytoplasm; *f*, food vacuole; *c.v.*, contractile or excretory vacuole; *g*, granular more fluid inner part of cytoplasm; *e*, outer solider layer of the cytoplasm, the ectoplast; *p*, pseudopodium or projection of the protoplasm.

have firm cell-walls, and do not have vacuoles of this type at all.

A single-celled animal will illustrate other cell-structures. The one called *Amœba,* shown in the accompanying illustration (Fig 2), is a very simple animal. Its body consists of nucleus and cytoplasm. There is no wall about it, nor does it exhibit any other definite cell organs. Nevertheless, if it is watched, it will be found that it is able to change its outline, that is to say, it exhibits movement. It can protrude on one side an extension of its body and enlarge that so that all the protoplasm flows into it, retracting the opposite side meanwhile. By so doing, it has changed its position. This type of movement is known as *amœboid movement*, and is probably common to nearly all protoplasm.

The one-celled green plant *Chlamydomonas* (Fig. 3) exhibits a somewhat higher degree of organization, in that it has a wall surrounding it which prevents

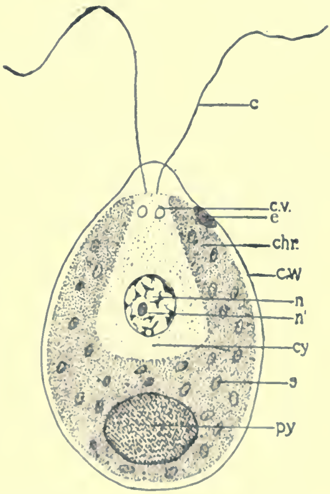


FIG. 3. — Chlamydomonas, a one-celled plant. *n*, nucleus with its chromatin network, nuclear sap, and nucleolus, *n'*; *chr*, the green chromatophore of solider protoplasm containing the green coloring matter, chlorophyll; *cyt*, cytoplasm; *py*, the pyrenoid or starch-forming organ of the chromatophore; *s*, starch grains; *e*, eye-spot, a solider mass of protoplasm containing a reddish brown pigment, supposedly an organ sensitive to light; *c.v.*, contractile vacuoles; *c.w.*, cell wall; *c*, flagella, hairlike projections of the cytoplasm by means of which the plant propels itself through the water.

the organism from changing its shape as a whole. And it has also at one end two projecting, oar-like processes which can be moved rapidly, thereby producing movement of the entire cell. It has also a green color. This green color will be found to be limited to a certain particular part of the living substance, and the presence of this green pigment, *chlorophyll,* is the chief distinction between the plant and the animal kingdoms, for it is by the action of this pigment on light that protoplasm is enabled to bring about the manufacture of sugar from carbon-dioxid and water. In the cell of Chlamydomonas we have thus two additional organs not found in Amœba, organs of locomotion and organs of food manufacture. This same plant exhibits also a special organ for the reception of stimuli. Near the end of the cell to which the locomotor organs are attached is a tiny spot of reddish-brown pigment. It has been found that organisms with a pigment spot of this sort are more perfectly adapted to react to light than those without it.

Summary. — Protoplasm is the universal living substance. It is always organized into cells or units. These exhibit a relatively uniform physical and chemical composition and are able to carry on a definite and characteristic set of physiological functions. A typical cell possesses more or less differentiated organs adapted to perform these functions. Every cell has a nucleus and cytoplasm. It may or may not have a wall of cellulose or other non-living material surrounding it. It may have a water vacuole in the center. Its protoplasm is usually able to execute movements, either by a change in the form of the cell as a whole or by the instrumentality of special organs of locomotion. All cells are sensitive to external stimuli and able to respond to them in a variety of ways, as for example, movement. Plant cells, in distinction from other cells, may possess special organs containing chlorophyll for the manufacture of sugar. Cells are able to undergo automatic division, thereby bringing about further growth or reproduction.

CHAPTER III

MULTICELLULAR ORGANISMS AND DIVISION OF LABOR

Nature of the Subject. — Since protoplasm is the only living substance, it follows from what we have learned in the foregoing chapter that living, in a biological sense, consists of sensation, movement, waste, repair, growth, and the multiplication of individuals. At the same time it is equally true that we recognize certain differences among living things that lead us to separate them into two great groups, animals and plants. We also distinguish certain peculiarities that enable us to subdivide the members of these groups into many different species or kinds of living things. We know that for some reason the squirrel is different from the oak tree up which it scampers, and the bee is unlike the clover from which it gathers honey.

Since these organisms and hundreds of thousands of other species are living, and hence are carrying on the same vital processes, it is well to ask ourselves the question, on what do these differences rest? The answer is, on structure. All of the different kinds of living things are vital engines, carrying on processes whose sum total we call life. Some are fitted to work in water, others on the surface of the earth or on the ground, while still others spend a portion of their existence in the air. The plant machines are usually stationary, while the great majority of animals move about. Furthermore, many of these machines are comparatively simple, the work they do is rather crude, and we speak of them as low forms of life. On the other hand, the oak tree or the squirrel, for example, are very complex, their functions or activities are more efficiently performed and they are designated high organisms. This fact involves the principle of the division of labor that will be better understood after we have examined a few examples illustrating simple, more complex and highly complicated types.

AMŒBA. — Among the best known examples of a primitive organism is the amœba (Fig. 4), living in the mud and slime at the bottom of ponds and gently running streams. Large individuals are barely visible to the unaided eye, but under the microscope the body is seen to

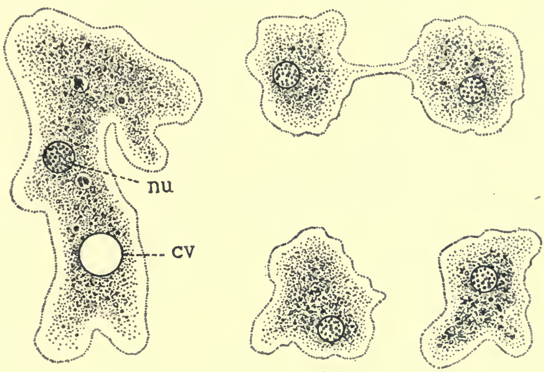


FIG. 4. — The Amœba, showing process of multiplication.

consist of a drop of semi-fluid protoplasm without an enclosing wall but surrounding a globular nucleus. This animal is thus a single cell. In moving about one part of the body is slowly pushed out in the form of a blunt process, while a corresponding part of the cell is withdrawn, the animal thus flowing along like a sheet of quicksilver moving across an unplaned, gently sloping board. Where a particle of food lies in its path the amœba pushes it into its soft interior where it is digested without the aid of any structures comparable to a mouth or digestive system. Breathing takes place through the general surface of the body. Cold, heat, and various chemical agents produce changes in the rate of locomotion or alter its direction; hence the amœba feels. There is also a definite spot where the water accumulates until it forms a droplet about the size of the nucleus, whereupon it is emptied to the outside. It is generally believed that waste products enter this *contractile vacuole,* which thus acts as a simple kidney or excreting organ.

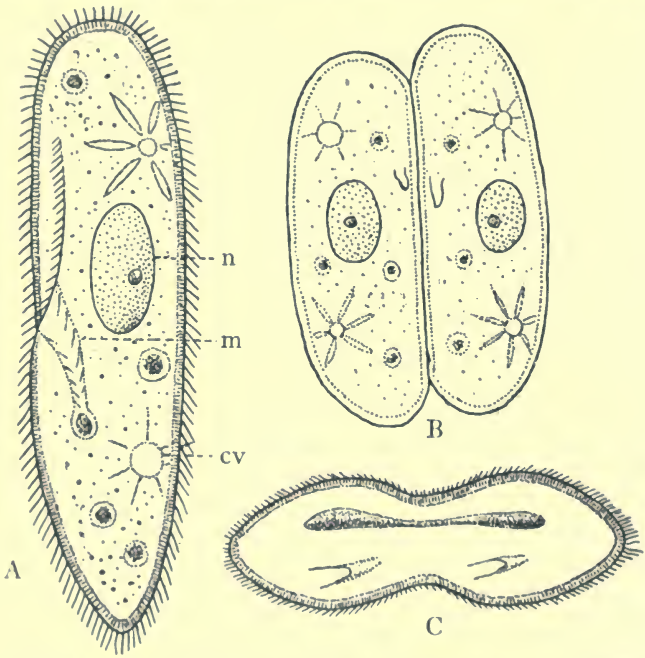


FIG. 5. — Paramœcium or slipper animalcule. *cv*, contractile vacuole or simple kidney; *m*, mouth and gullet; *n*, nucleus. *B*, two individuals conjugating, a type of fertilization. *C*, individual dividing asexually.

When the body reaches a certain size it divides into two equal halves, each of which thenceforth becomes an independent organism — a simple type of multiplication of individuals.

PARAMŒCIUM. — In the paramœcium or slipper animalcule (Fig. 5), living in the same situations as the amœba, the body is likewise of microscopic proportions, but retains a definite shape owing to a permanent cell membrane. The body is thickly covered by a coat of delicate protoplasmic hairs or cilia whose rhythmical beating drives the organism from place to place. At one point the cell-wall is perforated, and through this mouth opening food particles are driven by special cilia into the interior. In other respects the life processes resemble those of the amœba. It is to be noted, however, that the paramœcium possesses definite organs of locomotion and a mouth; and, as will appear more clearly in a succeeding paragraph, this constitutes a real advance beyond the amœba.

Importance of One-Celled Organisms. — While these two examples are insufficient to illustrate the bewildering diversity of structure of the thousands of named species of these one-celled animals and plants, they may be used to emphasize the fact that all lead successful lives. Ministering to their needs, avoiding enemies, and leaving offspring to take their place, they exist and have persisted for thousands of years, and this constitutes a successful life. Also in point of numbers of individuals they far outrank all other living things. In many regions certain aquatic forms settle to the bottom, and their skeletons of lime or flint form deposits of great extent and thickness. Chalk, tripoli earth, and other similar substances are ancient accumulations that are of high economic importance. The oil enclosed in the bodies of the minute aquatic diatom plants have formed, it is believed, the great beds of natural oil in the western part of North America. Finally, there are many species that derive their food supply from other organisms, and as parasites produce diseases that rank among the most serious scourges known to man.

Colonial Forms. — Among the greater number of one-celled organisms the division of the body results in two offspring that separate and thenceforth lead independent lives. In the higher types of simple animals and plants, however, the division products remain attached, and form colonies in the shape of threads, sheets, or solids of various form, depending upon the direction of the cleavage and the subsequent arrangement of the cells. Among the simplest of these colonial species is Gonium (Fig. 6), occurring commonly in fresh water. Here the single parental cell divides, the two products remain attached, re-divide, and in this fashion reach a sixteen-cell stage with the cells forming a plate. Every member of the colony, bearing locomotor whips, or flagella, that operate

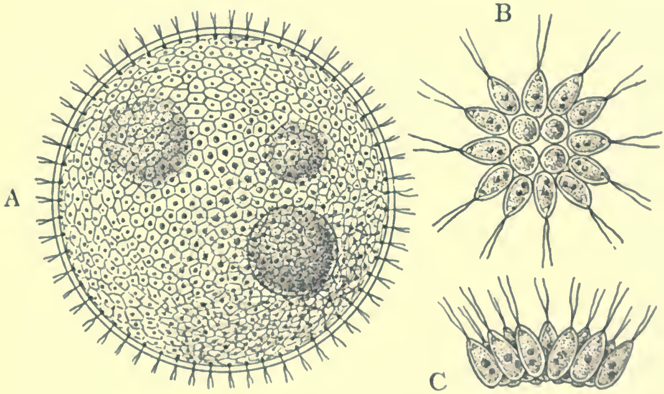


Fig. 6. — Colonial Organisms. *A*, Volvox; *B*, *C*, top and side views of Gonium.

like cilia, is precisely like its fellow in form and function. It is important to note that the colony may be broken up and each cell continue to exist. As a matter of fact the cells do become dissociated at the time of reproduction, each forming a daughter colony.

Volvox. — In Volvox (Fig. 6), a higher type of colonial organism, the body comprises many cells — in some species thousands in number — imbedded in a jelly-like substance and arranged in the form of a hollow sphere. Each cell is egg-shaped and the greater number carry flagella whose combined action rolls the association through the bodies of fresh water. When the colony has reached its full size a difference among the cells becomes apparent. A few increase in volume to a marked degree, owing to food material that they store up, and their future development occurs along one of two lines. Some divide repeatedly, and sinking into the interior form daughter colonies that escape with the rupture of the parent wall. Under other conditions certain cells divide repeatedly to form bundles of slender flagellate cells called sperms, any one of which may unite with a particular sort of large cell or egg which then enters upon essentially the same course of development as the one just described.

It is evident that Volvox lies a step ahead of Gonium in regard to complexity. In the former there are the beginnings of a division of labor among the component cells based upon structural differences. Certain cells taking no part in locomotion serve as reproductive elements, while the great majority function in locomotion, sensation, and feeding, but are wholly unable to reproduce. The importance of this fact will appear with greater clearness after we have examined another type of still greater complexity.

HYDRA. — The last example that we shall examine in its entirety is Hydra (Fig. 7), a freshwater animal related to the sea anemones, corals, and jelly-fishes of the ocean. The body, brown or green in color, presents the form of a slender hollow cylinder about one-fourth of an inch in length. One end of the body is attached by a sticky substance to some submerged leaf or stone, while the other bears the mouth surrounded by five or six slender outgrowths termed tentacles. The body wall, throughout its entire extent, is composed of two layers of closely grouped cells in which various types can be distinguished. In the outer layer there are cells that serve for protection, sensation, and motion, while special nettle or stinging cells paralyze the small organisms that serve as food. This nutritive material is conveyed by a movement of the tentacles into the hollow interior of the body, and is there dissolved by the action of a secretion from the cells of the inner layer that are thus digestive elements. Reproduction is effected by eggs and sperms formed from certain outer layer cells, or by hollow outgrowths of the body wall that, developing a mouth and tentacles, finally pinch off from the parent and become independent organisms.

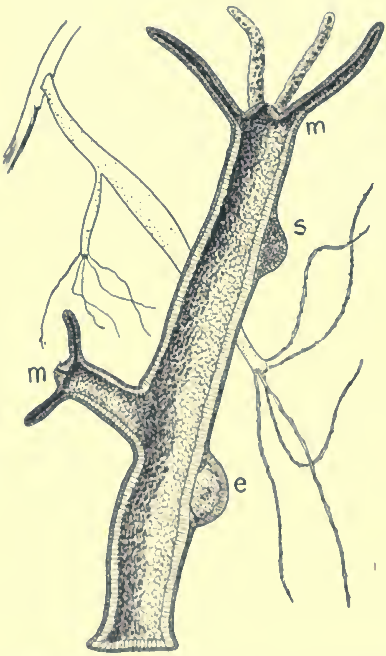


FIG. 7. — Freshwater Hydra, entire and longitudinally split individuals. *e*, egg; *m*, mouth surrounded by tentacles; *s*, sperms, considerably magnified.

DIVISION OF LABOR. — It is probable that the number of cells in many Volvox colonies is greater than in Hydra, and yet Hydra is higher in the scale of living things. The reason for this is a difference in the complexity of organization. There are more different kinds of cells in Hydra than in Volvox, and each kind is adapted to carry on a particular duty essential to the existence of the whole. And not only is each structurally fitted for a definite task, but in becoming a specialist it functions more successfully. To realize the importance of this fact let us examine it from another angle.

Let us suppose that a man makes an automobile. He constructs the essential parts and it runs, but, having to perform all of the operations involved he is not especially proficient in any one and the machine is a comparatively crude affair. This state of things is comparable to what exists in the amœba where the life processes are carried on equally well by almost any part of the body. The original automobile manufacturer may become associated with other workmen, who likewise make automobiles, and the situation is duplicated by Gonium, where the members of the community all behave in the same manner. There is here little if any real advance. In Volvox, on the other hand, we find that the cells of the colony comprise two classes, and an analogous situation in the factory appears when the workmen are divided into two groups each with distinct types of work. An increase in the number of workmen is not an essential feature. It is now obvious that to reach the level of the Hydra organization, where several types of cells are coöperating in the performance of those functions essential to the life of the colony, the workmen require to be divided into a corresponding number of groups, each with its particular tasks.

In the highest type of factories the different classes of workmen are many, and each, having but one thing to do, becomes unusually proficient, so that the result of their coöperation is a smoothly running, finished product. In precisely the same way the higher species of animals and plants occupy their position by virtue of the degree to which the various cells of the body are divided into groups that, as specialists, skillfully perform their particular functions. In such cases the individual cell loses its independence to a large degree, but in coöperating with its fellows produces an organization that is as much above Hydra, for example, as modern human society is above a savage community.

Tissues, Organs and Systems. — In Hydra the division of labor is about as complete as in the higher types

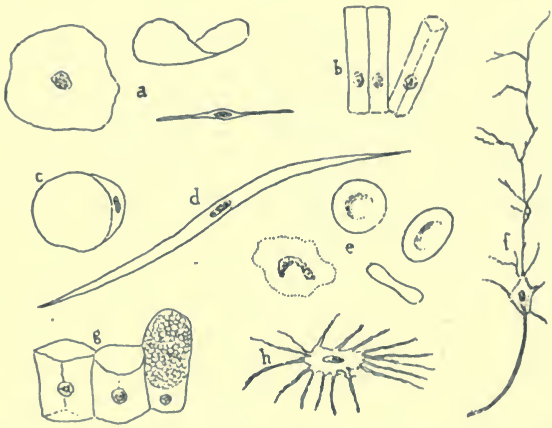


Fig. 8. — Body Cells. *a*, from skin; *b*, from lining of intestine; *c*, fat cell; *d*, muscle cell from stomach; *e*, white and red blood cells; *f*, nerve cell; *g*, cells from salivary gland; *h*, bone cell.

of plants, but above this point in the animal kingdom the great majority of species, amounting to fully half a million, are of greater complexity. In the dog or man, for example, the organization of the body involves a very great number of cells of different types (Fig. 8), each of which is usually grouped together to form a *tissue*. Thus we have the highly contractile cells, those responsible for the movements of the body, fashioned into *muscular* tissue. This is bound together by cells and fibres forming *connective* tissue, is attached in many cases to *bony* tissue, is impelled to act by impulses sent out by *nervous* tissue, and directly or indirectly is protected by *epithelial* tissue, of which the skin and lining of the mouth and digestive tract furnish good examples.

While an *organ* may be defined as any structure fitted to perform a definite function, and thus includes the nucleus, cilia, and other parts of a single cell, it involves, in higher organisms a grouping of tissues. The arm, for example, is an organ, and comprises all of the tissues just mentioned. Then again several organs may be engaged in related work and so form a *system*. The œsophagus, stomach, intestine, liver, and pancreas are all organs serving in the process of digestion, and in combination constitute the *digestive* system. Other organs combine to form the *nervous, muscular, circulatory,* and other systems that will be described in some of the succeeding chapters.

SECTION 2

THE RÔLE OF GREEN PLANTS

CHAPTER IV

THE MANUFACTURE OF FOODS AND FUELS

THE ANNUAL VALUE OF FOOD. — Since food is indispensable, its value cannot be adequately represented in definite terms. It constitutes the largest item in commerce. The food produced in California alone in 1919 was worth, in round numbers, \$500,000,000; that produced in the United States, \$15,000,000,000; and in the whole world an inconceivably large sum.

ANNUAL PRODUCTION OF FOOD NECESSARY. — There is no store of food in nature as there is of water; there is no fixed amount, for it is annually manufactured from the raw materials, in green plants. The quantity varies, both in the wild state and under cultivation, from year to year. There is rarely any considerable excess; there is frequently shortage; there is generally enough. Man and a few other animals harvest and store food for future use, but the surplus of supply over demand is generally very slight, and locally may not exist at all. The result of shortage is at times disastrous.

THE FOOD MATERIALS. — The food materials, sometimes erroneously spoken of as plant food, are carbon dioxid (CO_2), a gas, water (H_2O), a liquid, and mineral salts, solids. Carbon dioxid occurs in the air in very dilute proportions, two hundredths of one per cent (0.02%) on the average. In spite of its extraordinary dilution the total amount in the earth's atmosphere is enormous. Because of the constant contributions to the atmosphere from a variety of sources, of which perhaps ordinary combustion is the most easily understood, this amount and proportion are maintained.

Water and Mineral Salts. — Water, which also occurs as vapor in the earth's atmosphere, is taken by plants from the soil in which it is always present. It dissolves the soluble soil ingredients and covers the surface of the soil particles with films of different thickness, varying with the wetness of the soil. The composition and significance of these films will be discussed again (Chap. VI). The soil ingredients are mineral salts, the nitrates, sulphates, and phosphates of calcium, potassium, and magnesium.

The Composition of Food Materials. — The food materials are all comparatively simple compounds, stable and saturated; they do not readily change chemically. They are composed of ten chemical elements only, out of the many (about 100) known, namely, carbon (C), hydrogen (H), oxygen (O), nitrogen (N), calcium (Ca), potassium (K), magnesium (Mg), sulphur (S), phosphorus (P), and iron (Fe). The compounds in which they occur as food materials are all soluble in water, most of them freely so. Hence they are of practically universal occurrence.

The Absorption of Food Materials, to be discussed in Chapter VI, takes place through roots from soil and through leaves from air, in solution. Land plants, with roots in the soil and stems in the air, live in two sets of circumstances. Their underground parts, in darkness, in contact with hard, heavy, solid particles, take up soluble soil constituents by their roots and move them to the organs where they will be converted into food. Their leaves spread in light and air and take up from the latter such gases as will enter their cells.

The Working Over of Food Materials. — Water and salts taken up by the roots from the soil, and carbon dioxid taken by the leaves from the air, are converted from raw materials into finished products, food. The changes taking place in the manufacture of foods from raw materials involve changes in energy. Energy must be applied to the raw materials to convert them into foods. This must obviously come from outside the plant if there is to be any accumulation of food. The energy thus employed reaches the plant in the form of light.

RADIANT ENERGY. — There reaches the surface of the earth from the sun daily an almost inconceivable amount of energy. Analysis shows that this consists of rays of different wave-lengths, capable of doing different kinds of work. Thus we know that the warmth of the sun's rays raises the temperature of the air and soil and all other objects in their path. Other rays directly affect our organs of vision, and still others are used in making photographs. Sunlight can be divided by a prism as by drops of water into a spectrum (see Fig. 9) or rainbow,

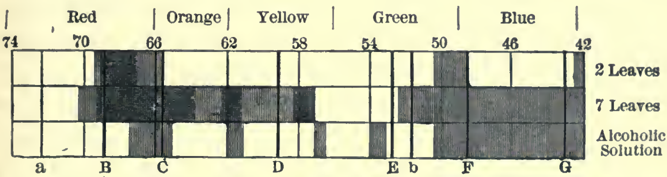


FIG. 9. — Diagrams to illustrate analysis of light by the spectroscope. *a*, spectrum of pure sunlight; *b*, spectrum of sunlight passed through chlorophyll.

made up of seven colors. A thermometer placed beyond the visible color at the red end of the spectrum will show that there are invisible heat or thermal rays in addition to the visible ones which are called light or luminous rays. Similarly a photographic plate exposed beyond the violet end of the spectrum will undergo chemical change, thereby demonstrating that invisible but chemically active rays accompany the invisible heat rays and the visible luminous ones. Thus, we see only a part of the energy which the sun's rays contain, but we know that heat also emanates from the sun, and that certain other invisible rays do chemical work.

PHOTOSYNTHESIS. — The combination of carbon dioxid

(CO_2) and water (H_2O) to form sugar ($C_6H_{12}O_6$) is accomplished only by means of light energy absorbed by the green parts of plants and is therefore called photosynthesis. It is the most important chemical reaction in nature, for it underlies the manufacture of all foods and fuels. The rays absorbed are mainly near the red and the blue in the spectrum; the absorbing agents are green pigments in cells near the surface of the bodies of plants.

CHLOROPHYLL. — The green color of leaves or other green parts of plants is due to the presence of certain substances, the chlorophyll pigments, or chlorophyll, confined in most instances to small bodies called plastids or chromatophores. Chlorophyll absorbs light of certain colors or wave-lengths only. The colors which pass through give the characteristic green to leaves and other chlorophyll-containing parts or organs. Chlorophyll, soluble in alcohol, chloroform, ether, and other fat solvents, appears to be composed of four compounds of distinct color qualities. These have been separated with great skill, and their composition determined. Two of them are green, two are yellow. They are crystalline substances, complex and unstable, though not equally so, as shown by the fact that the yellowing of leaves is due to the persistence of one or both of the yellow pigments while the green ones are undergoing withdrawal or decomposition.

OCCURRENCE OF CHLOROPHYLL. — The chlorophyll pigments do not occur in all plants, and they occur only or mainly in those parts of green plants which are exposed to light. The pigments occur only in the plastids or chromatophores of cells situated so near the surface of the plant body that an adequate supply of light will penetrate them. Chlorophyll will be formed, however, only under suitable conditions, namely, when the plant absorbs suitable and sufficient iron salts from the soil and there is enough light. Although iron is not a constituent of chlorophyll, plants will not be healthy without it, for they will not be green. Except for pine seedlings, ordinary plants will not form chlorophyll in darkness. This fact is utilized in the blanching of celery and asparagus, as well as being a matter of common observation.

WHAT LIMITS PHOTOSYNTHESIS. — Certain definite factors can be recognized as limiting and controlling photosynthesis. These are:

(1) *The amount of chlorophyll exposed to the light.* — This will vary, not only with the quantity of pigment actually contained in the chromatophores but with the number and the exposure of the chlorophyll-containing cells in leaves and stems. Plants with scanty leafage offer less chlorophyll exposed to light than those with more abundant foliage.

(2) *The amount of light that becomes effective.* — Plants or plant-parts may be shaded out of existence. This is clear in forest and chaparral, for the foliage — and often the lower branches — thus die or never develop in the shadow of branches and foliage above them. Comparatively few species of plants are able to thrive in the shadow of other plants or of opaque objects. Shaded plants usually make up for deficient light by greater exposure of chlorophyll, either by forming chlorophyll in the epidermis covering the leaves, or by larger and broader leaves.

(3) *The quality of light.* — The light reaching the forest floor may be as unsuitable in quality as it is insufficient in quantity, for it may lack the particular rays used in photosynthesis by reason of their being already absorbed by the foliage above.

(4) *The amount of warmth.* — Differences in temperature are found to affect photosynthesis in nature more than any other single factor. Photosynthesis will not take place in most plants at temperatures close to the freezing point. The rate of photosynthesis rises more rapidly than the temperature, however, up to a certain

point, and then falls rapidly if the temperature continues to rise. Excessively high temperatures are recorded in connection with experiments on desert plants; but ordinarily, out of doors, as well in the tropics as in temperate regions, the temperatures to which plants are subjected are, after all, comparatively moderate. The effect of temperature on photosynthesis must be conceived as a chemical process influenced not only by the action of heat upon the raw materials but by the action of heat upon the living cells in which "the most important chemical reaction in nature" takes place. The temperatures which are most favorable for other protoplasmic activities are fortunately also those highly favorable for photosynthesis. This is the reason for the luxuriant growth of the tropics, rather than because there is any considerably greater amount of light or any superior quality of the light in tropical regions.

(5) *Variations in carbon dioxid* are so slight and so infrequent that they are of no practical importance in agriculture; but the very great dilution of carbon dioxid in the air, in spite of its enormous volume, fixes the rate at which food can be made. This can be shown by laboratory experiment, for increasing the proportion of carbon dioxid in the air in which plants are grown will increase the yield of sugar, especially if the light is also increased; but the idea of adding to the carbon dioxid content of the air on a commercial scale, as has been suggested more than once, seems of no practical importance at present.

THE PHOTOCHEMICAL REACTIONS IN PHOTOSYNTHESIS. — The general nature of the process called photosynthesis may be expressed in the following equation:

$$\underset{\text{Carbon Dioxid}}{6\ CO_2} + \underset{\text{Water}}{6\ H_2O} = \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6\ O_2}$$

This equation expresses the fact that out of six molecules of carbon dioxid and six molecules of water, one molecule of sugar (glucose) and six molecules of oxygen are formed. The oxygen, which equals the volume of carbon dioxid taken in, is given off to the air. There is good reason to think, however, that this equation merely expresses the final result of a series of chemical reactions, the details of which are not now known. The most plausible hypothesis proposed regarding the combination is that of the eminent European chemist, von Bayer.

VON BAYER'S HYPOTHESIS OF PHOTOSYNTHESIS. — According to this hypothesis, first, one molecule of carbon dioxid may be combined with one molecule of water to produce formic acid, with the liberation of one molecule of oxygen; second, this formic acid is reduced to formic aldehyde with the liberation of more oxygen; and third, the formic aldehyde molecules may combine with one another — may polymerize — so that a molecule of sugar containing six atoms of carbon is produced. The equations concerned are as follows:

$CO_2 + H_2O = H_2CO_3$ (carbonic acid)
$H_2CO_3 = HCOOH + O$ (formic acid and oxygen)
$HCOOH = HCOH + O$ (formic aldehyde and oxygen)
$6\ HCOH = C_6H_{12}O_6$ (glucose sugar)

No chemist or physicist has thus far proved by experiment the accuracy of this very suggestive hypothesis, and the field is still open for investigation.

THE PRODUCTS OF PHOTOSYNTHESIS. *Foods.* — It is certain that a sugar containing six atoms of carbon ($C_6H_{12}O_6$), or a multiple of six ($C_{12}H_{22}O_{11}$), in the molecule is made in daylight in chlorophyll-containing plant cells, and that from this sugar sooner or later all other foods and most of the other products of plants are formed by addition of one or another of the chemical elements found in the different food materials. The food may accumulate as sugar, or it may be stored in insoluble form — temporarily or for longer times — in the form of starch or cellulose, fat, or oil. Nitrogen and phosphorus may be added, forming still more complex carbon compounds, as we shall presently see. Although the eminent plant physiologist Sachs long ago spoke of starch as the "first visible product of assimilation," we know now that his famous dictum was only approximately correct. *Sugar is the fundamental product of photosynthesis, and because of this fact* photosynthesis is "the most important chemical reaction in nature," for all food is built up from sugar.

Fuels. — The fuels no less than the foods are also of vegetable origin and are built up from the sugar made in photosynthesis. Wood, for example, is obviously so. Coal is well known to be the changed remains of wood and other parts of plants. It is supposed that oil and natural gas have also been derived from the cell-deposits of accumulated plant-remains, in some cases from the oil produced by diatoms. Alcohol is obtained (see Chap. XXIII) by the fermentation of sugar, or of sugar derivatives reconverted into sugar. The study, therefore, of photosynthesis is of the utmost importance from the economic point of view, since man's comfort as well as his nourishment are absolutely dependent upon this reaction. Everything that man uses which is not mineral comes directly or indirectly from the combination of carbon dioxid and water into sugar in the green parts of plants in warmth and light. With the exception of wind and water in motion, or the power obtained therefrom, man uses these same fuels as the sources of all the energy which he requires. Indeed, under certain market conditions it is more profitable for the farmer to burn corn than coal.

CHAPTER V

THE BUILDING OF THE LIVING MACHINE

The Living Machine, the living body of plant or animal, consists of protoplasm the organized units of which are called cells (see Chap. II).

The Composition of Protoplasm. — Microscopic analysis and the methods of the physical chemist show that protoplasm consists of some substances too coarse to pass through a porcelain filter, though going through others less fine. Such substances are called colloids, or are said to be in the colloidal condition or state. The analytical chemist shows that protoplasm is made up, in addition to water, of proteins of various sorts, and that it may enclose a great variety of substances in solution or otherwise, carbohydrates, fats, and oils, salts and other electrolytes. These simple and complex substances, water, salts, oils, and proteins, are built into a colloidal system or systems. Food is used, therefore, to build and to maintain this complex system. But the food must first be made.

Nitrogen. — This element, forming four-fifths of the earth's atmosphere, is used by most plants and by all animals only in compounds. Most plants absorb these as nitrates from the soil. In certain instances ammonium compounds and cyanamid can be used as sources of nitrogen, and a few species of carnivorous plants are known which capture or entrap small insects and devour or consume them to secure nitrogen. Nitrates of calcium and potassium are the common salts used by plants as sources of nitrogen. Nitrogen is a constituent element of protein, combined with carbon, hydrogen, and oxygen to form molecules of very considerable size and complexity. The synthesis of proteins can most naturally be conceived as constituting a series of increasingly elaborate compounds, starting from a sugar and a nitrate as the sources of the atoms to be combined.

PHYSICAL PROPERTIES OF PROTEINS. — These substances are difficult to define, both because their composition is only incompletely known, and also because they are so diverse. They have, however, certain properties, chemical and physical, in common; they are coagulated by heat and by alcohol; they are similarly soluble in water; they may be precipitated from aqueous solutions by various salts. These compounds, consisting of very large and very complex molecules containing invariably carbon, hydrogen, oxygen, and nitrogen, and many of them sulphur and phosphorus as well, either form constituent parts of that living structure called protoplasm, or are present in it as products or by-products. We may perhaps the better conceive how protoplasm is built if we attempt, through a classification of the organic nitrogenous compounds of the series leading to the proteins, to gain an idea of their relative composition and complexity. Thus the simplest compounds in this series, the amino-acids, and the nucleo-proteins, the most complex, are apparently connected by compounds of intermediate complexity and common properties.

THE AMINO-ACIDS. — These substances, characterized by consisting of one or more amino (NH_2) groups and of an organic acid radical (carboxyl group, COOH) are much better known as the products of protein decomposition than as parts of an ascending synthetic series of organic nitrogen compounds. Nevertheless, their composition and structure suggest means by which they may come into existence. Thus, it is known that, from the nitrates taken up from the soil, nitrites and ammonia may be derived; from the latter, hydrocyanic acid — common in plant tissues — is obtained. From the action of ammonia and hydrocyanic acid upon an aldehyde a simple acid might be formed, thus:

$$\underset{\text{acetaldehyde}}{CH_3COH} + HCN + \underset{\text{ammonia}}{NH_4OH} =$$

$$\underbrace{CH_3—CH—NH_2—COOH}_{\text{alanin}} + \underset{\text{ammonia}}{NH_3}$$

Such a synthesis may take place in leaves. During the hours of daylight aldehyde formation may occur as a part of the process of photosynthesis (see Chap. IV). At the same time, a part of the ammonia derived from the nitrate and nitrite may be converted into hydrocyanic acid. This may combine with the aldehyde which is being formed at the same time. While this conjecture as to the nature of the process may not prove to be correct in all its details, it suggests a very promising line for investigation.

THE SYNTHESIS OF PROTEINS FROM AMINO-ACIDS. — Proteins have actually been synthesized from amino-acids and amino-acids are always found in food solutions on their way to parts where protein is being stored or protoplasm is being constructed, yet nothing or almost nothing is known about the change which takes place in the body of the plant. The amino-acids disappear and the complex proteins appear instead. It is probable that any normal plant cell can make the proteins which it requires, if it receives suitable carbohydrates and amino-acids for construction. There is no evidence to show that protein-synthesis takes place more rapidly in one part of the plant than another. The amino-acids may be made chiefly in or near the chlorophyll-containing cells in which the carbohydrates are formed in daylight, though the formation of protein appears to be quite independent of light.

We may conceive the process of protein-synthesis from amino-acids taking place along a series which starts with glycerose ($C_3H_6O_3$), lactic acid (also $C_3H_6O_3$), and one or more amino-acids. Of these substances, *glycerose* is one of the very simplest sugars known, and *lactic acid* is a common organic acid, formed for example in the souring of milk (see Chap. XXIII). The amino-acid, *alanin* ($C_3H_7NO_2$), commonly formed in the hydrolysis of proteins, *serin* ($C_3H_7NO_3$), a somewhat less simple compound, and *cystein* ($C_3H_7NO_2S$), particularly interesting as containing sulphur, may be arranged in a series, (with glycerose and lactic acid), as proposed by Abderhalden, thus:

glycerose →	lactic acid →	alanin →	serin →	cystein →	protein
CHO	CH_3	CH_3	CH_2OH	CH_2SH	
|	|	|	|	|	
CHOH	CHOH	$CHNH_2$	$CHNH_2$	$CHNH_2$	
|	|	|	|	|	
CH_2OH	COOH	COOH	COOH	COOH	

If phosphorus is added to the protein molecule there results a nucleo-protein. The nucleo-proteins are the most complex substances known.

THE ORGANIZATION OF PROTOPLASM. — The protoplasm of the cell consists of two different parts, cytoplasm and nucleus. The latter will be discussed more fully in a later chapter (XXV) and so may be dismissed here with a bare mention. The cytoplasm exists in two different conditions, according to the relations of its various components to one another. In one condition it is fluid and capable of flowing movements; in the other it forms a more or less firm, jelly-like structure. In the liquid condition, water containing salts in true solution constitutes a continuous phase in which the colloidal particles of protein, oil, and other substances are in suspension or in colloidal solution. In the firmer condition the protein particles coalesce to form a continuous phase which encloses minute drops of water and dissolved salts as well as ultramicroscopic drops of oil and fats. Which of these two conditions will exist at any given time depends, in part at least, and perhaps wholly, on the electrical charges of the dissolved salts and the protein meshwork. Cytoplasm is thus seen to be an organized and complicated colloidal system in which powerful but imperfectly understood forces are at work at the boundaries between the protein gel and the liquid oil and water solutions.

The Functioning of Protoplasm. — We may thus conceive protoplasm to be made and maintained as a self-operating mechanism in response to the affinities of the proteins which assemble or arrange themselves with water into colloidal systems, and by means of the actions and interactions on the faces of these systems, where a great part of the energy requirements of the living organism are developed and satisfied. The operating or functioning of the system thus described constitutes living, or life. Living protoplasm is, then, a structure in which chemical processes go on in response to atomic and molecular affinities, physical as well as chemical change continually taking place, with the binding, release, and application of powerful forces which act upon the particles of matter, holding them in place as parts of systems, pushing them out or pulling them in. Thus the functioning of protoplasm, living, is continual change, physical and chemical.

The Growth of Protoplasm. — The growth of protoplasm is one of the functions of this self-operating mechanism, and consists in increasing or adding to the colloidal systems which constitute the living substance. Thus both water and colloidal substance increase as protoplasm grows. The proportions vary in different stages of the process of growth, but the systems are continued with their physico-chemical capacities and character.

The Death of Protoplasm. — When change becomes impossible, or when it becomes excessive, in those colloidal systems of water, proteins, etc., which constitute living protoplasm, death ensues. Death may be produced by almost any interruption or interference with the operation of the systems which constitute protoplasm. Thus, coagulation, produced by heat, alcohol, or other agent, stopping and preventing chemical change, is fatal. The solution of colloidal gels by acid, alkali, or electricity will cause death. Chemical changes which result in precipitation or solution of protein or other essential constituents of the system will stop operation and this constitutes death.

The Mineral Constituents. — What the botanist has called the " ash constituents " among the food materials of plants, namely, calcium, magnesium, and potassium, and the small amounts of iron, correspond to what the animal physiologist speaks of as " dietary accessories." These elements are all indispensable to health and normal activity, but they do not all appear as constituents of protoplasm. They are taken up from the soil in the form of nitrates, sulphates, phosphates. While sulphur and phosphorus are constituents of protoplasm with nitrogen, carbon, hydrogen, and oxygen, and while magnesium is a constituent of chlorophyll, calcium, potassium, and iron have never been shown by analysis to be constituents either of the living protoplasm or of any essential product. Speculation, and even assertion, have been freely indulged in; but beyond recognizing certain apparent " uses " in certain plants, and some of the physical and chemical properties of these elements wherever they occur, one cannot now go. In certain plants calcium neutralizes the oxalic acid which might otherwise accumulate in harmful quantity, bringing it down as a crystalline precipitate of calcium oxalate. That this is invariably its function is disproved, for example, by the free oxalic acid in rhubarb, in wood sorrel, etc. Nor does calcium neutralize the other acids which characteristically accumulate in the tissues of plants — citric acid in lemons, malic acid in apples, salicylic acid in cranberries, etc.

Potassium, shown to be feebly radio-active, may owe its main usefulness to this property. It is a powerful alkali, its ions are very active. Furthermore, experiment indicates that calcium and potassium ions are both needed to neutralize each other. The compounds of potassium are freely soluble and hence the more able to display their molecular activity.

Iron is equally indispensable. In some way now quite unguessed and unproved, it takes its part in the metabolic processes of the organism, being in plants as in animals intimately if not directly connected with the formation of coloring matters. Thus, iron is used in medicine to assist in the alleviation of anæmic conditions in human beings, restoration to health being indicated by heightened color; and in plants blanching may often be cured by administering iron.

CHAPTER VI

THE INCOME, MOVEMENTS, AND OUTGO OF MATERIALS IN PLANTS

CELLS ARE BAGS OF WATER. — Cells, and organisms themselves, are essentially bags of water. The physico-chemical systems, cells composed of water and colloids, arranging themselves into self-operating mechanisms, are either sac-like, the contents of the sacs or bags being aqueous solutions enclosed in walls of living protoplasm, or the protoplasm is disposed in a sponge-like mass enclosing drops of water. In either case, the behavior of living cells is that of bags of water, so far as income, movements, and outgo of materials are concerned. In plants the sacs or bags are mechanically supported and strengthened by enclosing cell walls of cellulose. Dissolved in the cell sap are many substances, so finely divided that molecular movements and chemical changes may take place which would be impossible in the solid state. Thus we find diffusion of a dissolved substance taking place throughout a volume of liquid and a perfectly uniform distribution resulting; but the movement of dissolved substances into and out of cells implies the ability of the molecules of the dissolved substance to pass through such membranes as the colloidal system which we have described possesses.

PERMEABILITY. — On the surface of contact between two different materials, as for example between protoplasm and cell wall, between nucleus and cytoplasm, an actual membrane is formed by the living cytoplasm. This membrane may be too thin to be seen under the microscope, but its existence may be otherwise proved. Thus the coloring matter in roots and other parts of red beets, and the sugar in the roots of sugar beets, are retained within the cells; they do not leak out into the soil. On the other hand, water is taken up by the roots. Hence we see that cell-membranes may be permeable to water, but not to all substances even though they may be dissolved in water. Cell-membranes are therefore spoken of as partially permeable or semi-permeable membranes.

Osmotic Pressure. — Molecules of water move with increasing freedom as water is transformed from the solid to the liquid or to the gaseous condition. Similarly, the molecules of salt, for example, move with increasing speed and amplitude as the salt dissolves in water. In consequence the movements of the molecules of substances beating upon the walls of the enclosing or dissolving medium will exert pressure. This pressure is known as osmotic pressure, and it will obviously be proportional to the concentration, temperature, and other conditions prevailing. If equal proportions of the same substance are in solution on opposite sides of a membrane, or in different parts of a solution, the osmotic pressure will be equal; but if the proportions are unequal the osmotic pressure in the more concentrated part of the solution will be greater; and if the enclosing membrane is permeable, the movements through it will result in equalizing the pressure by the entrance of more of the dissolved substance into the less concentrated and more of the water into the more concentrated parts. Osmotic pressure, therefore, determines the direction and rate of movement of dissolved substances and of the solvent itself if the intervening membranes are permeable.

Living Cells are Osmotic Systems, taking in and giving off in solution in water solids, liquids, and gases. Intake we think of as occurring principally in roots and leaves in land plants, but the outgo is not less certain. Roots absorb water, oxygen, and mineral salts from the soil; leaves absorb CO_2 and O_2 from the air.

The Structure of Roots. — The root of the ordinary land plant, serving the double purpose of absorption and of mechanical support, and living and growing in a more or less compact and resistant medium, possesses peculiarities of structure closely related to the conditions in which it lives. A root is a cylindrical organ, branched, it may be, with a conical rather than a blunt tip, which is capped or covered with cells more or less continually worn off. This thimble-shaped cap (Fig. 10) protecting the tender tissues, forming the growing point of the tip, is merely a means of meeting the mechanical wear inescapable when a point is pushed forward through abrasive material. Immediately behind the thimble-shaped cap and the point at which new cells are formed to replace those

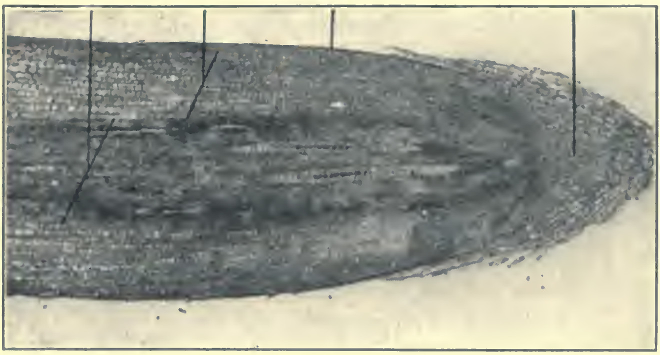


FIG. 10. — Longitudinal section of Root-tip, showing cap, enclosing and protecting the growing point, behind which is the region of growth in length. In this region the tissues differentiate.

which are worn off by abrasion, there is what is known as the growing region, only two or there millimeters in length, in which growth in length takes place. From this arrangement it is evident that only a very short segment of the root is pushed through the resistant soil. Further back from the tip, where the cells have ceased to grow in length, the epidermal cells branch out, forming absorbing hairs (Fig. 11), which apply themselves, often very closely, to the surface of the particles of soil with which they come in contact. These hairs, with thin walls lined with protoplasm and containing considerable volumes of cell-sap, bring the soil solution and the cell-sap into direct contact, thus establishing conditions upon which the intake or absorption of water and of mineral salts from the soil are absolutely dependent. Still further back from the tip of the root is the part in which growth in diameter may take place, a part which extends to the base of the stem.

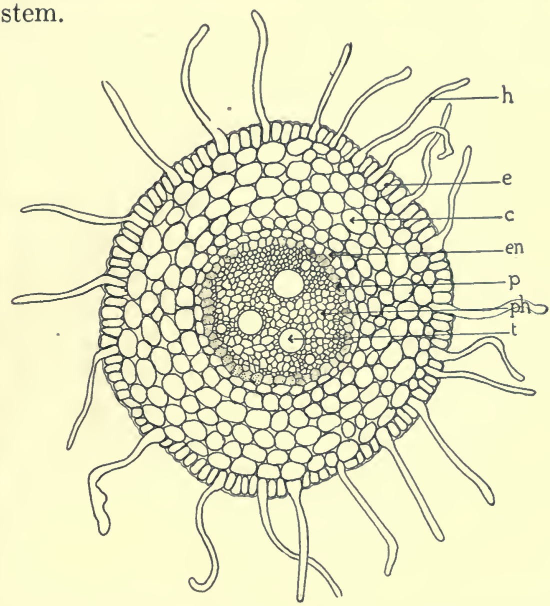


FIG. 11. — Cross-section of Young Root, in the region of root-hairs, where growth in length has ceased and absorption is most rapid. *t*, duct in the xylem or wood; *ph*, sieve tube in phloem or bast; *p*, pericycle, which bounds the vascular tissues; *en*, endodermis, which bounds cortex, *c*; *e*, epidermis, many of the cells of which put out extensions in hairs, *h*.

MECHANICAL RESULTS OF ROOT STRUCTURE. — When a part of a root grows in diameter, the root-hairs covering its surface are crushed against the surrounding soil. Increasing diameter is ordinarily accompanied by increasing strength. Thus the mechanical support which the plant requires is supplied. The position of the zone of root-hairs, only a short distance back of the tip, is almost directly under what may be called the eaves of the dome of foliage. There results from this position the contact of the absorbing root-hairs with those particles of soil most likely to hold water on their surfaces. The absorption of water and of matter dissolved in the soil water, taking place through the hairs in contact with soil particles, must be equalled by the transfer of these substances from cell to cell until they are used.

Movement of Water and Dissolved Substances. — The movement of water and of solutes from the root-hairs to and through adjacent cells finally carries them to the vascular or conducting tissues. These, with the mechanically strengthening fibrous tissues, form the core of the root. Into the cells and vessels, the so-called tracheids and ducts, of the wood the absorbed water and solutes are discharged by the adjoining cells. Through the vessels of the wood of the roots the solution is carried to the similar tissues forming the wood of stem, branches and leaves. Thus there is a conducting system for the transfer of water and raw materials which is continuous from tip to tip of the higher land plant. Through this the solution is moved by means not yet perfectly understood, but with a speed which, except in severe conditions, insures the plant against wilting.

The Structure of Stems. — The stem of the ordinary land plant gives mechanical support and furnishes the paths along which the substances absorbed by the root reach the leaves in which food manufacture is mainly carried on. Strengthening and conducting tissues, therefore, make up the bulk of the stems, branches, twigs, and even stalks of leaves, flowers, and fruits. Stems, living and growing in the air, are only feebly supported by it and hence develop mechanical tissues quite different from those of roots. The place and mode of growth of stems is also correspondingly different. Stems are formed of segments called joints, or nodes and internodes, and growth in length, which takes place only when the joints are very young, occurs in several joints and not at the tip alone, as in roots. The leaves and branches spring from the nodes. The internal structure (Fig. 12) corresponds with this external arrangement, there being growing, conducting, and mechanically strengthening tissues in the stem which persist from year to year. These are united into a cylinder surrounding the central pith and encircled by the protective tissues, epidermis, cork, etc., collectively termed the outer bark or cortex. The greater part of

Fig. 12. — Cross-section of a Tulip Tree Branch, four years old, showing the wood to consist of both conducting tissues (ducts, etc.) and mechanically supporting tissues (fibers, etc.) surrounded by the bark.

the strengthening and vascular tissues are wood, which is composed of fibers and of tubes through which water and dissolved raw materials move upwards from roots to leaves.

The Ascent of Sap. — The name sap is given to the water and raw materials carried up the stem through the wood. The mechanics of the movement are not yet completely understood, but it is evident that if water is lost by evaporation from the leaves, and is combined in the chlorophyll-containing cells to make food, and if the nitrates and other dissolved substances are also used in food manufacture, they will be pulled upwards by a certain amount of force. In the ducts and tracheids themselves, containing longer or shorter columns of water, tensions arise or exist which lift the columns of water. Water and dissolved substances may be pressed from adjoining cells into the ducts and tracheids in the roots. Thus several or many forces are combined in bringing about the lifting of great quantities of water. Under ordinary conditions of nature enough water is lifted to the top of the tallest trees to supply their topmost leaves. In the case of large trees the quantity of water may amount to several tons per year.

The Structure of Leaves. — The leaves of the usual land plant are broad, flat, thin expanses of green tissue. The structure of leaves (Fig. 13) is by no means so simple

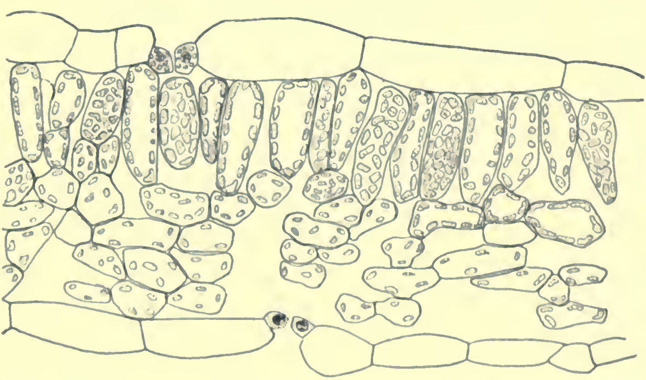


Fig. 13. — Cross-section of Leaf (castor bean) showing the upper and lower epidermis, perforated by guarded openings (stomata) and enclosing the mesophyll, consisting of a palisade layer of compact cells and the spongy portion below.

as their form. They are completely covered by a single layer of epidermal cells which are flat, rather thin, with outer walls which are water-proofed, though the inner and side walls are freely permeable to water. This single layer of cells forming the epidermis is interrupted at intervals with pores known as *stomata* which have *guard cells* that open and close. Generally speaking, there are more stomata in the epidermis that covers the under side of leaves, though pendant leaves, or vertically erect leaves, having equal exposure to light on both sides, have a more nearly equal number of stomata on the two sides. The flat, thin expanse which we call a leaf has a framework of "veins" or "nerves" which are the supporting and conducting tissues. These are the continuation and extension without interruption in the leaves of the supporting and conducting tissues of the stem, branches, and twigs.

Between the epidermis and the framework is the *mesophyll,* the cells of which contain chlorophyll. The uppermost layer of mesophyll cells may be more or less brick-shaped with relatively small spaces between them. This layer is called the palisade layer. Between it and the epidermis covering the lower surface there is a more or less spongy tissue, the cells of which contain many chlorophyll grains, and between the cells are air-spaces which are continuous throughout the mass of the leaf. Into and through and out of these spaces carbon dioxid, oxygen, and water vapor diffuse. It is from these intercellular air-spaces that carbon dioxid and oxygen enter the cell, dissolving in the water of the cell-walls and diffusing at rates varying with the difference in concentration of these gases inside and outside the cell.

LEAVES AS ABSORBING ORGANS. — Leaves, then, are thin absorbing organs spread out in the air. They absorb both light and certain gaseous constituents of the atmosphere. Because of the pigments which they contain they absorb only certain rays of light. They absorb only certain constituents of the atmosphere, namely, carbon dioxid and oxygen, because they use only these two. They absorb CO_2 only during the hours of photosynthetic activity, during the hours of warm daylight.

They absorb O_2 continuously, for it is involved in those metabolic changes of various foods which release the energy stored in them during their manufacture. The absorption of CO_2 and O_2 by cells from the intercellular spaces in the mesophyll of leaves takes place in the same manner as the absorption of water and mineral matter by root-hairs from the soil. The air of the intercellular spaces is continuous, through the open stomata, with the unconfined air outside. Throughout this continuous mass diffusion will tend to maintain uniform concentration of the constituents. Through the wet membranes bounding cells containing chlorophyll and absorbing light CO_2 will enter, dissolving in the water of the membranes, and will be combined in photosynthesis to form sugar. Thus during the hours of daylight CO_2 will always tend to be combined in chlorophyll-containing cells which, therefore, will continue to absorb it from adjacent intercellular spaces. Similarly, O_2 will be taken in as rapidly as it is used.

Leaves as Organs of Gas Exchange. — Corresponding to the intake of CO_2 and O_2 by the living cells of leaves is the discharge of O_2 and CO_2 from living cells into the intercellular spaces whenever the pressures of these dissolved gases within the cells exceed their pressures in air which fills the intercellular spaces. Thus during the hours of photosynthetic activity the volume of O_2 given off from green leaves is equal to the volume of CO_2 absorbed. But during the hours when photosynthesis is not taking place the living cells absorb O_2, using it in destructive metabolism (see Chap. VIII), and give off CO_2. Hence leaves are called organs of gas exchange.

Evaporation will take place inevitably, and its rate will depend upon the dryness of the air. The loss of water from the body of the plant has unfortunately been called *transpiration*, but there is no difference between transpiration and evaporation in plants except that plants regulate their transpiration within certain limits. They do so by various means, the chief of which are the waterproofing of the outer walls of the cells of the epidermis, and the closing of their stomata by the guard cells.

Roots as Excreting Organs. — From the foregoing, one will correctly infer that roots not only absorb but that they also get rid of whatever disssolved substances they may hold in excess, as compared with the soil solution, provided the cell membranes are permeable to these substances. The roots discharge carbon dioxid, certain organic acids, and various other substances. Some of these affect the solubility of some of the soil constituents, other excreta are poisonous and if allowed to accumulate by neglect of suitable alternation of crops, will impair the productiveness of the soil.

Secretion and Excretion. — The same physical principles apply to the secretion of sugars, the excretion of waste substances, and the discharge of liquid water from plants as underlie the absorption of dissolved substances. Thus we have glands receiving from the other parts of the plant body by diffusion and osmosis certain substances which they may so transform that they can accumulate and retain them. Thus it is conceivable that the glands on the surface of a geranium leaf receive from the leaf sugars of one or more kinds from which they make and secrete the volatile oil which gives the characteristic fragrance to the foliage of this plant. There are glandular hairs which excrete water, presumably because the permeability of their outer cell-membranes to water exceeds the permeability of adjacent membranes, so that the water will escape through the walls which are most permeable to it. Such hairs occur on the leaves of beans.

Guttation and Bleeding. — When the pressure of water in cells exceeds the ability of the cell membranes to hold it, water will be squeezed out. This pressure of water, or cell-sap, is known as *turgor*. At certain times and under certain conditions it may be very high. It tends to be so at night when evaporation from the leaves slows down or ceases, while the absorption of water by the roots continues. Thus water accumulates in the tissues of the plant. Much of what we call *dew* on the grass is a consequence of the squeezing-out of water in this way. This is termed *guttation*. Bleeding from wounds is deliberately brought about by man in his tapping of maple trees in the spring to make syrup and sugar; and of certain cacti and similar desert plants from which water and saps are collected which are used either with or without fermentation. Thus we see that the processes of absorption, secretion, and excretion are due to the kinetic energy of the molecules of dissolved substances and of their common solvent, water.

CHAPTER VII

THE STORAGE AND DIGESTION OF FOODS IN PLANTS

Storage. — We have seen that the foods made in green leaves and in other parts of the plant may be used at once for the construction and operation of the plant body, or they may be stored. This storage may occur where they are made, or it may take place in other parts of the plant body. In the latter case, the foods must be removed from the places of manufacture, and this movement, like the absorption of raw material and the secretion and excretion of elaborated compounds, can take place only in solution in water.

The Common Places of Storage. — If photosynthesis is more rapid than the diffusion of sugar from the cells in which it is made in the green leaf, the sugar will accumulate in the cells in which it is formed. It will generally be converted into starch, which is insoluble in water and occurs in the form of granules formed in the green chromatophores. Observation shows that, during the hours of daylight, such accumulation ordinarily occurs in mild or warm weather, and that during the night the cells are emptied again. Thus, while the leaves of orange trees may be very full of starch at sunset they are, generally speaking, completely emptied of it by sunrise, and the sugar which has been removed from the leaves may be stored elsewhere as starch or in other forms, or it may be used in the manufacture of more complex compounds in other parts of the plant.

The Places of More Permanent Storage vary with the length of life of the plant. Thus, we find in plants which are annuals that the food accumulated in one plant is bequeathed in more or less permanent form to its offspring, being stored in seed. In the case of plants which grow one season and seed the next, as do beets, onions, etc., the food made during the first growing season is stored in the roots and other underground parts, and is used the following year in the production of flowers and fruit. In the case of perennials the storage of food may take place in the bark, in the roots, in the seeds and fruits, in the pith, and in various other parts of the plant body. Thus we find sugar stored in sugar beets and onions. The sugar which is found in the sap of maples, grape vines, and other perennials, comes from the digested stores of starch deposited in various parts of the plant body during the preceding season. Starch accumulates in the tubers of the potato, underground, and is present in corn and in the other grains.

Starch may be conceived as a direct derivative of sugar, obtained by withdrawing a molecule of water from the molecule of sugar. Being insoluble it accumulates, or is deposited, in special cells and in special organs of the cell known as *amyloplasts,* and constitutes one of the most compact and economical forms in which non-nitrogenous food is accumulated and stored.

Other Stored Foods. — In the tubers of the dahlia the carbohydrate food accumulates in soluble form, but not as sugar, remaining in solution in the form of *inulin,* a substance of the same proportional composition as starch and cellulose. It may be precipitated by dropping pieces of dahlia tuber into strong alcohol or strong glycerine, in which case it will come down in the form of sphæro-crystals. In ivory-palm nuts, from which the buttons of men's clothes are very commonly made, the carbohydrate food of the plant is stored in the form of cellulose which is applied to the cell-walls until they become enormously thick; at the same time the cellulose is so compact and firm that it is very hard. In various other nuts, and in grains, olives, castor beans, one finds oils stored in greater or less quantities. These are non-nitrogenous foods which, however, since they are insoluble in water, are just as securely stored and are just as immovable as starch or cellulose. Similarly, proteins of various sorts insoluble in water are deposited in beans, peas, and many other seeds, and in the stems and roots, from which they may be removed only by digestion.

Means of Moving Manufactured Foods. — Foods, like the food materials, can be moved from cell to cell only in solution; but in solution the nitrogenous and non-nitrogenous foods move readily throughout the cell, and from cell to cell, through permeable membranes, in accordance with the principles discussed in the preceding chapter (VI).

The Paths of Movement. — The foods are moved (translocated) mainly along certain paths. These paths may vary from season to season, as for example in the sugar maple. In this tree the sugar moves down from the leaves to the places of storage through the inner bark throughout the summer; but in the spring it is mainly through the wood that the sugar-containing sap is moved from the places of storage upwards to the swelling buds. One may often find that the inner bark of trees or shrubs tastes sweet, whereas there is no such flavor in the wood. One may sometimes notice, on pulling apart a stalk of growing wheat, oats, or barley, in the afternoon of a warm sunny day in early summer, that the joints are both sweet and tender. In the early morning, before the leaves have made any food, and when the grain is nearly ripe, there would be no sweetness in the stalks, because there would be no sugar in transit. The inner bark, or phloëm, of the vascular bundles, is the conducting tissue through which most of the sugar is moved from places of manufacture to places of storage; whereas the wood may be the path of movement of sugar, etc., from the places of winter storage to the regions of spring growth.

DIGESTION. — The removal of solid food from the place of temporary or permanent storage, for example, the removal of accumulated starch from a potato leaf to a potato tuber, or from the tuber to the growing sprout, implies the conversion of starch, which is insoluble in water, into some other substance which, dissolving in water, thereby becomes movable. Such chemical change from insoluble to soluble material is known as digestion. In some cases digestion merely involves the conversion of one soluble substance into another.

THE MEANS OF DIGESTION. — Starch may be converted into sugar in the laboratory by treatment with dilute acid, dilute alkali, and enzyms. But the action of dilute acids and dilute alkalis, if it is to be rapid, must take place at temperatures higher than those which prevail in the living body. The process of digestion, therefore, must be carried on more rapidly than dilute acids and alkalis, acting at body temperatures, make possible. The means employed by animals and plants in digesting their food are certain substances known as *enzyms*. These are complex compounds having various common characters the most significant of which is their capacity to change the rate of chemical reactions which might otherwise go on without them. They are therefore catalyzers.

CATALYZERS. — Charcoal, platinum sponge, and various other substances have the remarkable quality of changing the rate of chemical reactions taking place in their presence. Some catalyzers are employed in industrial processes, for example, the use of platinum sponge in the treatment of ammonia in munition manufacture, and of finely divided nickel in converting oils into solid fats. But the catalyzers of most importance to man are those *enzyms* concerned in the physiological processes in living organisms. Catalyzers produce effects out of proportion to their own quantities. Often a very small quantity of a suitable enzym, diastase, for example, will convert a very large amount of starch into sugar if the temperature and other conditions are favorable and time be given for the operation. The statement may safely be made that we do not now know of any chemical change taking place, in plant cells at least, in which enzyms are not involved. The one exception to this general rule is an exception due to our own ignorance rather than to any knowledge to the contrary, namely, the series of chemical reactions taking place in photosynthesis.

Enzyms. — Generally speaking, these substances occur in such small quantities that they escape chemical analysis. It is believed, however, that they are colloidal and possibly proteins. They are soluble, and hence they are dissolved in the cells, presumably in colloidal solution. They act at ordinary temperatures, those at which cell activities are possible. Most of them are decomposable by heat.

Classification of Enzyms. — The enzyms are so numerous that classification is necessary. They are divided according to their physiological or chemical activities, thus:

I. *The hydrolyzing enzyms* (*Hydrolases*): those which accomplish the addition of water with a subsequent splitting of the molecules acted upon. Of these we may mention (*a*) *the lipases,* enzyms which act upon the fats and oils stored in castor beans, Brazil nuts, corn, hemp, etc., and split them into glycerine and fatty acids, as the seeds sprout; (*b*) *the amylases,* enzyms which convert starch into sugar; (*c*) other carbohydrases, such as *cellulase,* which digests the cellulose parts of cell walls; *pectinase,* which digests the cementing material in or between the cell walls, particularly of fruits, which forms the *jelly* made from fruits; *invertase,* which forms fermentable sugars, e.g. glucose, from cane sugar; (*d*) *emulsin* and the other enzyms which digest the glucosides found in almonds, willow bark, etc., to form glucose and various other products; (*e*) the *proteases,* which act upon protein and nucleo-proteins, converting them into amino-acids and other compounds soluble and therefore usable.

II. *The oxidizing enzyms* (*oxidases*) which are concerned in the intracellular oxidations which release the energy required for work by or in living organisms.

III. The *de-aminases,* which break down amino-acids and similar substances to ammonia and carbohydrates.

IV. *Ureases,* capable of breaking urea down into ammonia (NH_4OH) and carbon dioxid (CO_2). (See Chap. XXIV.)

V. *Coagulating enzyms,* such as cause milk to clot.

VI. *The fermentation enzyms,* which convert sugar, for example, into alcohol and carbon dioxid, which sour milk, spoil butter, raise bread, etc.

This classification includes enzyms not in any way connected with digestion either in animals (see Chap. X) or in plants, but which carry on fermentations and putrefactions (see Chap. XXIII), or are concerned in maintaining the fertility of soil (see Chap. XXIV), or are involved in the metabolic processes which supply the living cells with energy. We may mention some of these enzyms here, in addition to the descriptions in the places referred to.

The oxidases. — These are enzyms of various sorts which accelerate the oxidations going on in living cells and furnishing the cells with required energy. They are concerned in the physiological utilization, as sources of energy, of the carbohydrates, especially the sugars. They may also be concerned in fermentations, and they are undoubtedly concerned in some of the oxidations involved in maintaining soil fertility.

The de-aminases take part in breaking down amino-acids and similar complex nitrogenous compounds to the ammonia and carbohydrate out of which they were formed, making the carbohydrate available for oxidation in the cell, by which energy is released for use.

The coagulating enzyms are represented by rennet, obtainable in commerce in the form of "junket tablets," the common use of which is the clotting of milk. *Pectase* is an enzym found in plants, which has the property of causing the pectic substances which cement the cells together to coagulate and form a firm jelly-like substance. It acts in conjunction with the salts of calcium.

The fermentation enzyms, employed in raising bread dough, in making wine, beer, and cheese, etc., effect chemical changes in complex non-nitrogenous organic compounds resulting in the production of gas, alcohol, or other desired substances. It is probable that fermentation enzyms are concerned in disease due to bacteria or fungi parasitic in human beings.

Germination and Spring Growth. — The action of enzyms is illustrated in remarkable degree in the germination of seeds and in the resumption of growth which has been interrupted by cold or drought. The sprouting and growing embryo and the developing seedling are nourished by the food stored in the seed, which is digested and made available by the enzyms which work on starch, cellulose, fats and oils, and the proteins. Meantime, other enzyms, the oxidases, are active in bringing about the oxidations which supply the young and growing plant with necessary energy. Similarly, spring growth, consisting in the production of new foliage, in elongation and thickening, perhaps in blooming and fruiting as well, is made possible by the digestion and use, by means of enzyms, of food stored in insoluble form in parts of the plant often remote from the seat of growth. *Enzym action* therefore underlies the production, storage, movement, and use of food in plants and animals. Enzyms are produced by, and are always present in, the living protoplasm, which uses them in effecting and regulating chemical change.

SECTION 3

THE MAINTENANCE OF LIFE

CHAPTER VIII

THE UTILIZATION OF FOOD

Living Things Require Food for several reasons. In the first place, their own bodies, which are made up in part of living protoplasm and in part of material which the living protoplasm manufactures and lays down, must have a source of supply for making protoplasm and these other products; this source is in the food. In the second place, living things are like machines in that they use *energy,* and energy cannot come from nothing but must be developed from some source, which in this case is also the food. In respect to its energy requirement a living organism is in exactly the same situation as any familiar non-living machine which is operated through the burning of fuel. By way of illustration, recur to the automobile, to which reference was made in Chapter III. Automobiles are driven by the explosion of an air-gas mixture in the cylinders. The reason gasoline can be used as a source of power for automobiles is that it has high energy value which energy is released when the gasoline is burned. An automobile is a device for converting this chemical energy of burning into the mechanical energy of motion. Any living thing which does any kind of work must expend energy obtained from food in doing its work, being in this respect in exactly the same situation as the automobile.

For the manufacture of materials, then, and as a source of energy, foods are necessary. Whichever of these ends they may serve, they have to undergo chemical changes in the process. These changes are of various kinds, some of which will be described presently. The term *metab-*

olism is used by the biologist as a convenient general term to include all these chemical changes of foods and other substances made out of them.

METABOLISM IN GENERAL. — Chemical processes in living things involve, first, a preliminary stage, viz., the taking in of the food materials; second, the metabolism itself, or the transformations by which these are worked over into cell-substance or products on the one hand, or used up as sources of energy on the other; and third, the getting rid of such substances or products resulting from the chemical action as are not to be retained within the protoplasm. Materials to be gotten rid of are either manufactured things like enzyms, which both plant and animal cells form and secrete, or waste products, like the carbon-dioxid gas which is produced whenever food is oxidized. The chemistry of living protoplasm is exceedingly complicated, far too complicated for mankind to hope to understand it completely within any reasonably short future time. Enough is known about it, however, that the different purposes served by the metabolic processes can be set down, as is done in succeeding paragraphs.

BASIC METABOLISM. — Living protoplasm differs from dead protoplasm in that in living protoplasm there is going on continuously what we may think of as the "life process," which is made up of very complicated chemical activities whose stoppage means death. It is true that in most kinds of plants at some time in their history, and in some kinds of animals, life is tided over from season to season by a drying out of the protoplasm with a corresponding cutting down of the chemical activity going on within it; so seeds and spores manage to live over from one season to the next, or for several seasons, because the chemical processes fundamental to life are cut down to the absolute minimum and not much material is used up. But in actively living protoplasm those chemical processes which make up the basis of life go on at a fairly rapid rate, and in connection with them there is a using up of materials, and so, of necessity, there must be a replacement of this material. Living things require food, therefore, simply to enable them to go on living, even though they may not do anything else.

GROWTH METABOLISM. — Living things grow by making new protoplasm which is added to that which they already possess, and by manufacturing such non-living materials as are necessary to growth. For example, the cellulose walls of plant cells, and the hard parts of the bones in animals, are non-living materials which are made by living protoplasm in connection with growth. In plants, growth metabolism goes on more or less continuously throughout life; in many of the lower animals the same thing is true; but in all the higher animals, including man, growth metabolism (except in the skin and in the reproductive and blood-forming tissues) goes on only during the early part of life. When the animal or human being has, as we say, gotten its growth, this metabolism for the most part comes to an end.

THE MANUFACTURE OF MATERIAL. — In addition to those manufacturing processes connected with growth, which have just been spoken of, many kinds of cells, both plant and animal, make special kinds of substances, some of which serve the organisms which make them, as the saliva, made by the cells of the salivary glands, serves in the digestion of food; others, like the opium which the poppy plant makes, have no function that we know of in the life of the organisms which produce them. When one recalls the long lists of animal and plant products that are used in industry, and, as drugs, in medicine, the importance of this sort of metabolism is clear.

THE METABOLISM OF ACTIVE FUNCTION. — Practically all kinds of animals and a good many kinds of simple plants perform active motions of one kind or another.

Now, active motion, whether achieved by an automobile or by an animal, depends on chemical transformations which take place in the fuel substance or substances. In living organisms these transformations come under the head of metabolism, and to distinguish them from the chemical processes which are concerned primarily with the fundamental life processes, or with growth, they are classified as *functional* metabolism.

Nervous Activity. — In practically all animals there is still another kind of functional activity, the activity of the nervous system. When we realize that all our mental processes as well as our feelings — the things that make up the really worthwhile parts of life — depend upon processes going on in our nervous systems, we can see that this is a very important part of our bodily functioning; and, as we should expect, it depends upon transformations within protoplasm. Although of utmost importance, this metabolism consumes little fuel in comparison with the amount necessary for carrying on motion.

Metabolism as a Source of Energy can be distinguished from metabolism which gives rise to materials. For example, in growth or in the secretion of saliva or gastric juice, or in the deposition of fats or oils in the bodies of plants or animals, there are chemical transformations as the result of which food materials are worked over into special kinds of substances which may be either deposited in place, as in the hard parts of bones or in the cellulose walls of plant cells, or may be secreted, as in saliva or gastric juice. For the fundamental life process, that is, for basic metabolism, and for the making of motions on the part of animals, the purpose of metabolism is as a source of energy for keeping the machine going and doing its work. This kind of metabolism — the metabolism for energy — consists almost altogether, in plants and animals, of a particular kind of chemical process, *burning,* or as it is known to the chemist, *oxida-*

tion, since it consists of a union of the material that is being burned with oxygen. For a food substance to be useful as a source of energy, it must be of a kind that will oxidize within the protoplasm and so yield the energy which the protoplasm must have if it is to live and function. Foodstuffs, both in plants and animals, must, then, be materials that can be made over into living protoplasm, or into substances which the protoplasm manufactures for one purpose or another, or that can be burned and so yield the energy which the protoplasm needs. It is worth while to bear in mind that one important difference between plants and animals is that in plants the kind of metabolism that results in the formation of materials predominates over that which consumes them, while in animals the reverse is the case. Since most of the material that is stored in plants has high energy value, the result of this difference is that plants in general gain in weight and potential energy supply throughout their lifetime, while animals, as the adult stage is reached, carry on a metabolism that is almost entirely concerned with the consumption of energy; so that the metabolic processes of animals tend to balance those of plants, leaving nature as a whole little if any the gainer in total amount of stored-up energy.

Kinds of Food Used in Metabolism. — It has just been stated that any substance that can be oxidized within protoplasm can serve as a basis for energy-yielding metabolism. The three great classes of foodstuffs, carbohydrates, fats, and proteins, can all do this, and so are all useful as sources of energy. For the metabolism which gives rise to materials only such substances are useful as can be converted into the desired materials. Thus for the manufacture of protoplasm, in growth or in the repair of animal wastage, the protein-formers, namely, the amino-acids, are absolutely essential, so that unless they are available in sufficient amounts no protoplasm can be made, even though other kinds of foodstuffs are present in abundance. The digestive enzyms and other manufactured products of living protoplasm are for the most part of protein composition, and so require amino-acids for their production. One could, if necessary, nourish himself indefinitely on a diet consisting of proteins, as the Eskimos frequently have to do, because proteins can serve both as tissue-formers and as energy-yielders. Carbohydrates and fats are extremely valuable foods because they furnish abundant energy in readily usable form, but by themselves they are insufficient because they have no tissue-building capacity.

Metabolism in Animals is often Wasteful. — It is a curious and important fact, and one in which animals seem to differ markedly from plants, that in the former much of the metabolism that occurs consumes a great deal more material than is theoretically necessary. For example, we can calculate the energy necessary for doing a certain amount of work, one of the simplest calculations the engineer has to make. We can measure very accurately the energy yielded by the burning of a given amount of food material. But when that food material is burned in the body in connection with the doing of a given amount of work, we find that much more food is burned than is necessary to account for the work that is done. It is a familiar principle of engineering that the energy consumed in doing a particular job is greater than the energy that can be recovered in the doing of the work. Since we have the law known to physics as the law of the conservation of energy, by which we mean that the *total amount* of energy neither increases or decreases — although it may be changed from one form into another — this energy which fails to appear in the doing of the work must appear in some other form; and the form in which it appears is always heat. This law applies as well to the energy transformations of living things as to the energy transformations going on in dead machines. Since we find that we do not get as much energy out in the form of work as is consumed in the way of foodstuffs, we should expect to find the balance putting in an appearance in the form of heat, and that is exactly what happens; wherever metabolism goes on which is at all wasteful, heat is produced. Sometimes this heat serves a useful purpose, as it does in the warm-blooded animals.

Warm-Blooded Animals make up the two highest animal groups, birds and mammals. These differ from all other living things in that their bodies are maintained at substantially the same temperature day in and day out, through summer and through winter. Since this means that their bodies during most of this time are warmer than their surroundings, they must produce a great deal of heat. The animal that is warmer than the air around it will tend to cool off just as would a stove or any other inanimate object in the same situation. This cooling off which is going on nearly all the time is counterbalanced by the production of large amounts of heat, which from the standpoint of efficient metabolism would be considered wasteful since it represents a large consumption of food for which no useful work — in the engineering sense — is accomplished. Warm-blooded animals profit by this large heat-production, because it enables their bodies to stay at a favorable temperature for activity at all times. On the coldest days of winter as well as on the pleasantest days of summer, the temperature within their bodies is favorable to metabolic activity.

Cold-Blooded Animals, on the other hand, produce much less heat, and in consequence their bodies are at all times very nearly at the temperature of the surroundings. It follows that whenever the surrounding temperature falls to a point unfavorable for metabolism, the cold-blooded animal must suffer a great diminution or an almost complete suspension of activity. During a large part of the year, in cold climates, the cold-blooded animals are hibernating, living over to the next season by virtue of a very small amount of metabolism which suffices to keep the protoplasm alive but does not permit it any real activity. The active life of a warm-blooded animal is longer than the effective life of the cold-blooded animal whose chronological age is the same, by just the number of days that the cold-blooded animal has been in hibernation.

WASTE MATERIALS ARE PRODUCED IN CONNECTION WITH METABOLISM. — This is more striking in animals than in plants, although the greater ease with which we recognize the production of wastes in animals may be due to the higher key on which all the metabolism of animals is pitched. At any rate, we realize that in animals waste products are produced which must be gotten rid of. It is a curious fact about the metabolism of rest, or basic metabolism, as it occurs in animals, that it is accompanied by steady waste of the very complex substances of which living protoplasm itself is largely composed. Thus proteins, which have been described in an earlier chapter as the most important constituents of living protoplasm, are being continually lost from the protoplasm and have to be as continually replaced. Although we do not understand precisely why this happens, the fact that it does happen is of a good deal of importance. For one thing, it means that all animals, including ourselves, must acquire in the diet the necessary materials by which the protein that is lost in basic metabolism can be replaced. Since animals are so constituted that they can only replace proteins with proteins, this means that the diet must always include proteins or there will be a wasting away of the life substance, with its ultimate death if the loss is allowed to go too far.

WASTE IN GROWTH METABOLISM is less noticeable. In fact, it would seem as though animals should be able to put together the constituents of which protoplasm is composed without much waste. It is true, however, that if — as usually happens — the substances which they get in the food do not correspond exactly with the substances of which they are to make their protoplasm, they will have to pick and choose the things which they can use and reject the balance. This gives rise to an accumulation of unused materials in connection with growth. Some of these may be serviceable in connection with basic or functional metabolism, others may be wholly wasted. Growing boys often eat as much as twenty-five pounds of food a week, although during that time they may not gain more than a pound in weight, and their combined basic and functional metabolism will not nearly account for the other twenty-four pounds. The best way to explain the great surplus of food which growing children regularly eat is by supposing that the growth metabolism is wasteful, so that in putting together a pound of body substance a good deal more than a pound of food is required.

Waste in Functional Metabolism. — As we have already tried to make clear, the essential difference between functional metabolism and growth metabolism is that in the former the liberation of energy is the important feature, a feature which is secured by the burning of fuel. We are all familiar with the fact that wherever fuel is burned waste products are formed. Since burning is really the chemical process of oxidation, namely, the combining of oxygen with food, there are bound to be produced as a result of this combination substances of which the energy value has been exhausted and which are, therefore, from the standpoint of the tissues, waste products. Chief among these is carbon-dioxid, one of the materials which, as we saw in an earlier chapter, serves as the raw material for the manufacture of sugar. Besides carbon dioxid, water, and various other less well-known waste products are formed in connection with functional metabolism.

Waste Must Be Gotten Rid of if Metabolism is to Continue. — The furnace fire cannot be kept going if the products of combustion are not removed. There must be sufficient draught to carry the flue-gases up the chimney, and the ashes must be cleared out from time to time. This necessity of getting rid of the products of chemical activity applies to bodily metabolism. It follows that unless the waste products are carried off as they are formed the metabolism itself is certain to be hampered. Some means of getting rid of waste products then is a necessary part of the equipment of living tissues.

Metabolism Goes on in Every Cell. — A point that must be kept in mind is that all living protoplasm has these various chemical activities going on within it. This means that every living cell must have access to food. Furthermore, since a large part of metabolism is oxidation, supplies of oxygen must be available to every cell, and every cell must have some means of ridding itself of waste products.

The Services of Supply. — In the higher animal forms, including man, most of the cells of the body are so situated that they cannot possibly have direct access to the source of supply of their food or oxygen or to any outside region into which they can discharge their waste. This means that in all higher forms some special means must be provided for insuring to every cell the necessary food and oxygen and the means of getting rid of its waste products. These we may call the *services of supply.* They are four in number: (1) a general transportation system; (2) a service for the preparing and delivery of food; (3) a service for the delivery of oxygen; (4) a service for the removal of wastes.

CHAPTER IX

THE TRANSPORTATION SYSTEM IN ANIMALS

Conditions Favoring Cell Activity. — Every living cell resembles a tiny laboratory whose structure determines the nature of the processes it carries on. The work done by a nerve cell is different from that performed by a muscle fiber and both differ from the operations of an amœba. Yet, however great their structural differences and their modes of operation, all cells agree in requiring certain conditions for their perfect operation. In the first place the temperature must be above freezing and below 120° F. in most instances. And, what is of the utmost importance, in connection with the subject matter of the present chapter, every active cell must be bathed to a greater or less extent by a liquid. This water frontage serves two purposes. It maintains the proper degree of fluidity of the protoplasm, and, containing as it does, food substances, it acts as a storehouse from which the cell draws its supply and into which it discharges its wastes.

Need of Transportation. — Not only must every cell have this water frontage from which it withdraws its necessary food, but it is evident that this fluid must be renewed or shifted in order to provide for new supplies. Among the smaller aquatic animals, which consist of a single cell or of many cells located at or near the surface of the body, the movement of the water or of the body in the water is all that is necessary in this respect. Among the higher animals on the other hand, many of the cells are buried far beneath the body surface and are thus remote from the immediate source of supplies. This handicap is overcome by small fluid-containing spaces among the tissues upon which every cell has a frontage. Moreover, these spaces usually form a continuous system that is supplied at definite points with food materials and kept in action by a definite pump, the heart, so that the wants of every cell are adequately provided for.

Cell Diffusion. — The dissolved food materials pass into the cell by the process of diffusion, as described in a previous chapter. Hence it follows that the cell membrane must not only be thin and permeable to permit of a rapid movement, but it must be of relatively great extent when compared to the enclosed protoplasmic mass. This state of affairs exists only when the mass is small, as will be seen from the following illustration:

Cell Surface and Body Surface. — If we take a cubic foot block of wood and saw it into cubic inch blocks the external surface of these smaller masses is twelve times greater than that of the original one. If we reduce it all to sawdust the resultant surface is increased to a much greater degree. The finer the subdivision the greater the entire surface.

Applying this principle to the body of a man, for example, we find that the outer surface measures approximately sixteen square feet, a relatively small amount when compared to the mass weighing 150 pounds. But in reality this body, excluding much of the bones, body fluids and certain other structures, is subdivided into an inconceivably great number of cells. In the blood alone it is estimated that there are 25,000,000,000,000 cells, and it is safe to say that the entire body comprises at least five times this number. If, therefore, the surface of the blood cells has a superficial area of 3,800 square yards, as has been estimated, it follows that the surfaces of all the cells of the body measure not less than 170,000 square feet, or more than 10,000 times greater than the body surface.

WATER FRONTAGE IN LOWER ANIMALS. — Among the one-celled animals no special transportation system exists, for reasons already described. In somewhat higher animals, such as hydra, it will be remembered, the component cells are arranged to form an outer protective and an inner digestive layer surrounding the central digestive cavity. Food material, entering the sac, is circulated by means of flagella borne on some of the cells, and is thus brought into intimate relation with the entire inner layer, by which it is taken up. The excess of nutritive material diffuses to the outer cells. No special transportation system exists, and in this respect hydra resembles its relatives, the sea anemones, jelly-fishes and the more distantly related sponges where the diffusion stream also supplies the needs of scattered cells between the outer and inner body layers.

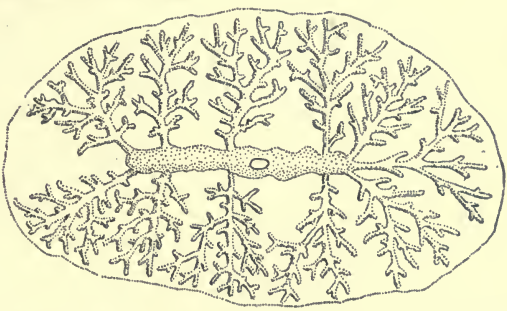


FIG. 14. — Diagram of the Digestive System of a Flatworm. Mouth in center of figure.

THE FLATWORM TRANSPORTATION SYSTEM. — The flatworms are small animals, usually not over an inch in length, frequently beautifully colored and abundantly represented among the rocks along the seacoast and to a less extent in fresh water. The body is flat and leaf-like, as their name suggests, and on its under surface bears the mouth opening. This leads into a central cavity from which intestinal branches extend through the animal to its outer margins where each ends blindly (Fig. 14).

Within this system the food is not only digested, but is circulated throughout its entire extent by means of muscular contractions of the enclosing wall, thus enabling every cell of the digestive tract to secure a portion of the food supply. The excess diffuses through the intestinal walls, supplies the cells of the immediate neighborhood and still farther on enters numerous liquid-filled cavities between the outlying body cells, that are thus supplied. In these animals, therefore, the transport of food materials falls upon the digestive tract and to a less extent upon the body fluid that is kept in motion merely by the movements of the body.

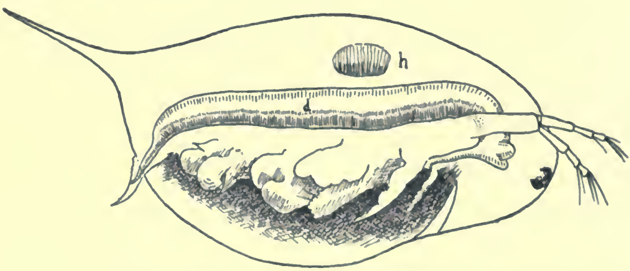


Fig. 15. — Common Water Flea (Daphnia) showing heart (*h*) in the midst of a large blood space traversed by the intestine (*d*).

Moderately Complex Transportation Systems. — Above this point there are several interesting types of transportation systems, and of these we shall examine one representing a halfway stage between the flatworms and the higher classes of animals (Fig. 15). It exists in the crabs, insects, spiders and their allies, and accordingly is characteristic of two-thirds of all the known species of animals. In these creatures there is an external body wall, enclosing a cavity spanned by the digestive tract and penetrated by numerous muscles that nevertheless leave a continuous though irregular space of relatively greater volume than in the flatworms. It likewise holds a fluid, but as special cells or corpuscles exist in it, and since it has a fairly definite chemical composition, this fluid is now known as blood. Furthermore the body wall is rigidly held in position by a firm heavy shell or case, and thus mere bodily movements are no longer sufficient to shift the body fluid; hence a muscular pump, the heart, is present to drive it along a fairly definite route. In many of the larger species there are vessels leading from the heart to various parts of the body, which are thus more directly supplied with materials from the digestive tract and respiratory organs, but sooner or later the blood pours through the open ends of these arteries into the main body cavity and is thus brought into direct contact with the various tissue cells.

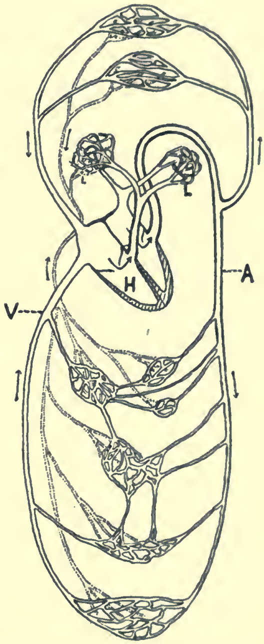


FIG. 16. — Diagram of circulatory system of higher animals. *A* artery, *H* heart, *L* lung, *V* veins. Lymphatics in stippled outline.

CIRCULATORY SYSTEM OF HIGHER ANIMALS. — In the highest group of animals, the vertebrates or those with backbones, the transportation or circulatory system is an extensive and complicated set of vessels communicating with a compact and powerful pump, the heart (Fig. 16). The exact course of the blood through these channels is not an important matter in this connection, but it may be said that the one, or two, great vessels or arteries leaving the heart branch repeatedly as they make their way into the tissues and finally communicate with the capillaries. These are exceedingly slender and delicately walled vessels, which, it is important to note, are so numerous and widely distributed that they are in the vicinity of practically every cell of the body. On the other hand, the capillaries unite with larger vessels, the veins, whose union finally results in one, or two, main vessels entering the heart.

It will be seen from this brief description of the circulation that the blood never leaves these vessels, and accordingly at no point does it come in direct contact with the cells of the body excepting those of the blood itself and those lining the circulatory system. It is a closed system and the transfer of nutritive materials to the tissues and the removal of wastes to the blood stream is provided for by a special process that will be more clearly understood after we have examined some of the peculiarities of blood.

THE BLOOD. — The familiar red fluid known as blood, when examined under the microscope, is seen to consist of a fluid, the plasma, in which there are floating cells of two types, the red and white corpuscles. The plasma consists largely of water in which food and waste substances are dissolved, together with certain other materials some of which aid in the destruction of disease-carrying germs, while others regulate various activities of the body cells. That it is more than water is also indicated by its ability to coagulate or form a clot in an injured vessel that, thus plugged up, is incapable of further bleeding. The white corpuscles are likewise active agents in engulfing and digesting germs in the blood stream. In some instances they may even carry on this work outside of the capillaries through whose walls they have bored a way; or they may carry off and digest fragments of injured cells whose removal paves the way for repair processes. The red corpuscles owe their name to the presence of a pigment, the hemoglobin, carried in their substance. As this material is of the utmost importance in the process of respiration, its general characteristics will be considered in that connection.

LYMPH. — The blood capillaries are not only widely distributed, but throughout the greater part of their extent they are surrounded by slit-like spaces, so that practically every body cell, being in the neighborhood of a capillary, borders upon one of these cavities (Fig. 17). Furthermore, the walls of the capillaries are very thin and permit small quantities of liquid from the blood continually to diffuse into these spaces, and thus bathe the tissue cells. This fluid, known as lymph, is of the highest importance to the existence of the cells of higher animals. Very much as a fish lives in water a cell lives in lymph. It is the source from which it derives the food that has been brought from the digestive tract, and the oxygen that has come from the gills or lungs, and is the medium into which it discharges its carbon dioxid, salts, and other waste products. Lymph, therefore, acts in the nature of

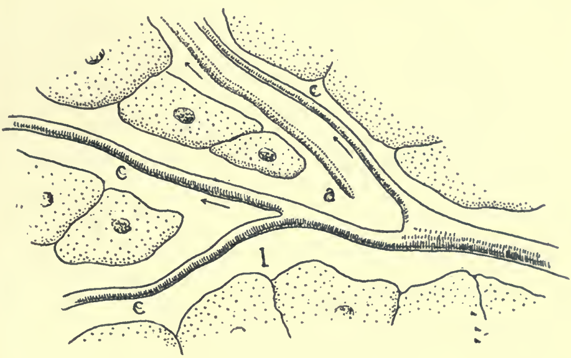


Fig. 17. — Diagram Illustrating Blood Capillaries (*c*) surrounded by a lymph space (*l*) which is drained by an absorbent or lymphatic capillary (*a*).

a retail station intermediate between the wholesale supply in the blood, and the consumer, or the cell.

Lymphatic or Absorbent Vessels. — Lymph is continually diffusing through the capillary walls, as has been described, and the excess usually escapes by way of a special system known as the lymphatic or absorbent vessels. This comprises a vast number of lymph capillaries, each of which ends in one of the circum-capillary tissue spaces, and on the other hand unites with similar branches whose subsequent union finally results in one or two large vessels opening directly into a large vein in the region of the shoulder. The lymph stream, diffusing from the blood and flowing past the cells, enters these lymph capillaries and is finally returned to the blood.

SUMMARY. — A transportation system, in the form of vessels or extensive blood spaces, carries nutritive materials to and removes waste products from every body cell in all but the simplest species of animals. In the higher types the blood does not come into direct contact with the tissues, but a constant stream of fluid, the lymph, diffuses from the capillaries into adjoining spaces from which the cells absorb their food materials and into which they discharge their wastes. Beyond this point the stream enters communicating lymph capillaries, and slowly journeys through these into larger vessels that finally pour their contents into the blood stream. We shall now consider the method whereby food substances are introduced into the transportation system and the wastes are removed.

CHAPTER X

THE FOOD-PREPARING SYSTEM

Digestion. — In an earlier chapter (VII) we saw that the complicated materials which are built up by plants and stored within them have to undergo a breaking-down into simpler compounds in order that they may be moved about from place to place, or in order to make them useful for the purposes of the plant. This breaking-down of the complicated into the simpler substances we have learned to call *digestion.* The food of animals consists either of the protoplasmic body substance of animals or plants or of the materials which they have manufactured and stored away within themselves. Most of these materials are too complicated to be used by the cells of the animal body in precisely the form in which they are taken in, and so must undergo digestion before they can be utilized.

Classes of Foods. — As we have already learned, the many kinds of substances called foods can be grouped into a few classes. In the first place, we set off the *foods proper,* which can yield energy or be built into protoplasm, from those which cannot; the former are often called *nutrients,* while the foods which are of use for other purposes are called *food accessories.* In the class of food accessories fall inorganic materials like ordinary table salt and the lime salts, which have to be taken by young children in order that their bones may be properly formed, and the series of organic substances whose importance we have only lately commenced to realize, the vitamins. These are complex organic substances which are not nutritious in the sense that they furnish us with any energy, nor, so far as we know, are built into living protoplasm; yet, if they are left out of the diet we do not thrive. It is evident that some essential bodily processes cannot go on well unless these vitamins are present, but just what the nature of these processes may be is not at present at all clear.

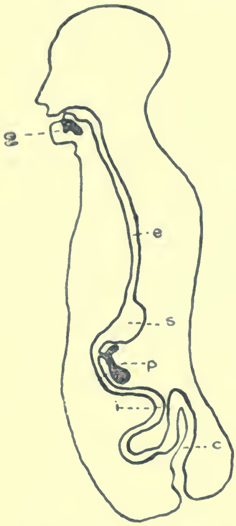


FIG. 18. — Diagram of Alimentary Canal in a Higher Vertebrate (man). *e*, esophagus; *s*, stomach; *i*, small intestine; *c*, large intestine; *g*, salivary gland; *p*, pancreas. For the sake of simplicity the liver and the passages opening from the alimentary canal (nostrils and windpipe) are omitted.

THE FOODS PROPER fall into three classes: carbohydrates (sugars and starches), fats, and proteins. The accessories do not have to be digested, they are utilized by the body in the form in which they are taken in. All of the nutrients except some of the simpler sugars have to be digested, either because in the form in which they are taken in they are insoluble in water and so can not be taken up by the body fluids, or because they are not in such chemical form that the cells can use them.

THE ALIMENTARY TRACT in the higher animals consists, first, of a tube, into which is inserted at one end the mixtures of complicated materials which the animal eats and within which the process of preparing the food for the use of the cells goes on, and second, of cell-masses called glands, which manufacture the various digestive secretions and pour them out into the alimentary tube. The three food classes, the carbohydrates, fats, and proteins, have to be treated individually; that is to say, the processes by which carbohydrates are digested do not serve for fats, nor is the digestion of fats exactly like the digestion of proteins. So we find the alimentary tract organized to deal properly with each class of food.

THE MANUFACTURE OF ENZYMS. — The method of digestion, as stated previously (see Chap. VII), is to bring in contact with the food a particular kind of substance known as an *enzym,* which has the special property of hastening the decomposition of the complex food material into the simpler substances which we call the *digestion products.* Different kinds of enzyms must be provided for the different food constituents. In the higher animals the enzyms are manufactured, as previously stated, by groups of living cells which have that as their special function and which we call *secreting*

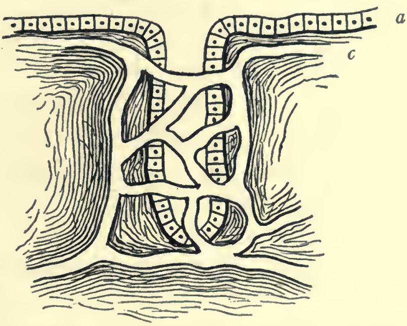


FIG. 19. — Diagram of a Simple Gland. The secreting cells (*a*) make up a tube, closed at the bottom, opening at the top into the alimentary canal. Surrounding this tube is a network of fine blood-vessels (*c*). In the spaces between the blood vessels and the gland there is tissue fluid.

glands (Fig. 19). These glands withdraw from the tissue fluid which surrounds them various food constituents; their functional metabolism consists in manufacturing out of this material the special substances which serve as enzyms. These latter are poured out along with a stream of water from the gland into the alimentary tract, where the enzym becomes mixed with the food. The most familiar example of this is the saliva, which is manufactured by the salivary glands, poured out into the mouth, and there mixed with the food as it is being chewed.

SALIVA. — The first of the digestive enzyms is that in saliva. It is called *ptyalin,* a sort of amylase, and its action is to decompose starch into a form of sugar which is familiar to the chemist but not especially familiar in ordinary life. It is the so-called malt-sugar, being exactly the same sort of sugar that is produced in germinating barley in connection with the manufacture of malt. This malt-sugar has to undergo further digestion in the small intestine before it is ready to serve as fuel for living cells.

GASTRIC JUICE. — After the food is swallowed it enters the stomach where it comes in contact with the second enzym of the series, *pepsin,* a part of the gastric juice. This proteolytic (i.e., protein-splitting) enzym begins the decomposition of the proteins, reducing them from the highly complex form in which they are eaten to simpler forms known as proteoses and peptones. The action of pepsin is like the action of ptyalin in that it is not final but preparatory. Further action must take place to complete the digestion that is started by pepsin, as well as by ptyalin.

PANCREATIC JUICE. — After the partly digested food passes from the stomach into the small intestine it comes in contact with the secretion of the pancreas to which we give the name of pancreatic juice. It contains three enzyms. The first is an enzym which has exactly the same action as the ptyalin of saliva, i.e., can cause starch to take up water and split into maltose or malt sugar, and as far as we know is the same enzym. The second is *lipase,* which digests fats. The third is *trypsin,* which digests proteins. Trypsin is a more effective enzym than pepsin, in that it carries the digestion, i.e., hydrolytic splitting, of proteins much further. In fact, the result of digestion by trypsin is to break the proteins up into the amino-acids of which their molecules are composed.

THE COMPOSITION OF PROTEINS. — As has already been stated (Chap. VII), the very complex protein molecules are built up by combining the molecules of certain nitrogen-containing organic acids to which are given the name of amino-acids. There are twenty different amino-acids now known as constituents of proteins. One protein may differ from another in the actual amino-acids which are present, or in the relative proportions of the different amino-acids, or in the way in which the amino-acids are put together in its molecules. A simple mathematical calculation will show that by starting with as many as twenty different amino-acids and granting that they may be put together in different ways or in different proportions, or that one or more may be left out, a great variety of proteins can exist. Since we are naturally inclined to believe that the differences which occur among animals and plants are, in many cases at least, bound up with chemical differences in their proteins, we can thus conceive how the differences are possible. In fact, it is hard for us to imagine how living protoplasm, which has many features in common wherever it is found and yet which can take this infinite variety of forms, could exist were it not that its chief constituent is a substance having the peculiar complexity of protein. The reason why protein must be digested into its constituent amino-acids becomes clear from the facts which have just been set down; for, while in one or all of the three respects outlined above the *protein* of the food is always certain to differ from the protein within the body of the organism which eats it, the *amino-acids* in the food protein are exactly the same as the amino-acids in the body protein. Hence, it follows that if the food proteins are broken up into their constituent amino-acids, these can then be recombined in proper proportion to form the body proteins.

The Intestinal Juice. — The food which has been acted upon by the pancreatic juice will have all its starch converted into malt-sugar, all or most of its proteins decomposed into amino-acids, and its fats digested by the lipase of the pancreatic juice. Further along in the wall of the intestine are tiny glands which secrete what is called *intestinal juice*. This juice contains several enzyms. Among them, one supplements the action of trypsin, so that if any proteins escape digestion in the upper part of the small intestine they are sure to be acted upon as the food reaches the region where the intestinal juice is secreted. The other enzyms of the intestinal juice are those which convert cane sugar (ordinary table sugar), milk sugar (one of the constituents of milk), and the malt sugar which is produced from starch by the action of ptyalin, into the simple sugar, glucose, which is the actual carbohydrate that is made use of by the cells.

Movements of the Alimentary Tract. — For the digestive process to go on properly the food must be mixed thoroughly with the digestive juices, and it must be propelled slowly along the alimentary tract from region to region as well. The process begins in the mouth, where, by the act of chewing, every particle of food is, or should be, brought into contact with the saliva. Then comes the process of swallowing, whereby the well-moistened food is passed from the mouth into the stomach. In the stomach the food mass is subjected to a churning by the muscular action of the stomach walls, which serves to mix it well with gastric juice, and is then expelled little by little into the small intestine. This process is a gradual one and is usually not completed for two hours or more after the meal is eaten. The food that enters the small intestine from the stomach is again churned by muscular movements of the intestine to insure that the pancreatic juice has access to every particle and is propelled slowly along by other muscular movements. Then, after the digested material has been absorbed according to the description in the next paragraph, the residue, which is of no further value, is passed into the large intestine, whence it is discharged from the body.

Absorption. — The digested food within the alimentary tract is ready for use by the living cells. But in order to reach them it must pass from the alimentary tract into the blood, to be carried by the blood to all parts of the body. The process by which it gets from the alimentary tract into the blood is called *absorption.* It consists in the passage of the material through the very thin membrane, consisting of one layer of cells, which lines the alimentary tract, and through a second thin membrane which makes up the wall of the capillary. This process of absorption takes place almost wholly in the small intestine. In essence, it is the same process described in Chapter VI as the means by which substances pass through plant membranes. Whenever the intestine contains digested food in any quantity the concentration of these foodstuffs within it is higher than in the blood, and consequently foodstuffs diffuse from the intestine into the blood. The materials which enter the blood in the intestinal capillaries leave it shortly in the capillaries of the tissues which require nourishment, so the blood does not have a chance to become loaded with foodstuffs to an extent which would interfere with absorption.

CHAPTER XI

RESPIRATION AND THE DISPOSAL OF WASTES

Respiration. — For the same reason that an engine requires fuel whose oxidation or burning supplies the driving power or energy, so the vital machine depends upon foods and a steady supply of oxygen to oxidize them. The higher animals when deprived of oxygen die in a few minutes; lower forms, like the amœba, may live for twenty-four hours, but sooner or later protoplasm forever ends its activities when deprived of a supply of this substance. Oxygen, therefore, is as essential to the life of an animal or plant as water, salts of various kinds, sugar, and higher compounds usually classed as foods.

One of the results of the oxidation of cell substances is the formation of carbon dioxid and water that as waste products escape to the exterior. This process, embracing the introduction of oxygen into the cell and the giving off of carbon dioxid gas, is known as *respiration.* In higher forms, however, where vast numbers of cells are packed together, accessory respiratory structures to carry oxygen to the cells and to remove the carbon dioxid from them are usually present. They comprise such organs as gills or lungs, fitted to absorb the oxygen from the surrounding medium and deliver it to the blood, that in turn transfers it to the cells. Hence, in addition to the cell or internal respiration, there is this accessory, or external, respiration.

Diffusion of Gases. — In every liter of air there are 210 cubic centimeters of oxygen, 790 cubic centimeters of nitrogen, and 0.03 cubic centimeters of carbon dioxid gas. In fresh water, every liter contains dissolved in it about 7 cubic centimeters of oxygen, 15 cubic centimeters of nitrogen, and varying small quantities of carbon dioxid. In sea-water these substances are slightly less in amount.

In respiration the passage of oxygen from the air or water into the blood or through the surface of a cell is not a peculiarity of living things but follows the law of the diffusion of gases that is essentially the same as the diffusion of liquids. If we take a closed jar divided by a thin moist membrane, such as a sheet of parchment, into two equal compartments in one of which there is twice as much gas as in the other, the molecules will pass through the membrane until the pressure on each side is the same. The net result is a passage of gas from the compartment of higher pressure or greater amount into that with less, until the density in both compartments is equal.

In the cell where oxygen is continually being used and the pressure is accordingly less than in the surrounding air or water, or in the lungs where the amount per unit volume of this gas in the blood is less than in the air outside the thin moist lung-wall, diffusion brings a fresh supply. In the same way the abundance of carbon dioxid in a cell leads to its diffusion into the water or blood where the amount is less.

Respiratory Organs. — In unicellular organisms where the body surface is relatively large and comes in immediate contact with the surrounding medium (air or water), no special respiratory organs exist. Even in higher types, such as the hydra, jelly-fish, sponges, and many worms living in moist places, respiration takes place through the general body surface, and the needs of the underlying cells are ministered to by diffusion, with or without the aid of a circulatory system. Even in animals of large size, where respiratory organs are present, the skin may continue to take an active part in the process. In the frog, for example, the skin is always active in this regard and during hibernation, or the winter sleep, is the sole organ of respiration. On the other hand, there are many animals enclosed in shells or horny cases or scales, feathers, or hair, as in the higher types, that are either too thick or too dry to permit of the diffusion of gases through the skin, and accessory respiratory organs, constructed on various plans, perform the duty of gas exchange.

Gills. — The conditions surrounding an animal that spends its life in the water are very evidently different from those of a land-dweller; hence it is not surprising to find that the special respiratory organs of aquatic forms are constructed on a different plan from those breathing atmospheric air. They usually take the form of delicate expansions or outgrowths of the skin known as *gills.* In many of the worms they appear as great plume-like structures borne on the head, or as feathery or broad plate-like organs along the side of the body. In some of the snails the gill resembles a many-petaled flower carried on the back, or exists in the form of delicate and slender outgrowths widely distributed over the body. In the fishes they are comb-like organs situated along the sides of the throat. In every instance these organs are penetrated by an extensive capillary network or system of blood spaces that are thus most favorably situated for receiving oxygen and discharging carbon dioxid. Even more favorable conditions are present where the water is kept in motion by movements of the gills, as happens in many species of worms, shrimps, and some of the salamanders, for example.

Respiratory Organs of Land Animals. — In most terrestrial animals the surface of the body is more or less enclosed in a protective coat or outer skeleton that reduces the chances of injury by enemies, heat, or light, and at the same time prevents excessive evaporation of water from the body. Furthermore, this investing sheath is not only relatively thick but in most instances it is far too dry to permit the ready exchange of gases through the skin. The respiratory organs of land animals, therefore, are built on a different plan from those of aquatic species, and generally speaking are ingrowths of the body wall, communicating with the outside by narrow passages, and, buried deep among the tissues of the body, are kept sufficiently moist to meet the requirements. Breathing organs of this type comprise two classes: the tracheal system of insects and related forms, and lungs, chiefly a characteristic of higher animals.

THE TRACHEAL SYSTEM OF INSECTS. — In all but a few small insects respiration is carried on by a unique mechanism known as the tracheal system (Fig. 20). If the body

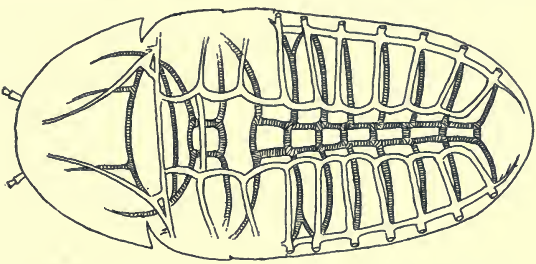


FIG. 20. — The Tracheal System of the Cockroach.

of a grasshopper, for example, is carefully examined, several small openings can be seen along the sides of the body, and further investigation shows that each of these leads into a delicate horny tube that penetrates the tissues and breaks up into a large number of exceedingly fine branches. A swelling movement of the body-wall like that of the human chest in breathing, draws air into these canals and distributes it to the cells. The oxygen is then absorbed by the cells and carbon dioxid is liberated by them and is then discharged by a reverse contraction.

In some of the water bugs and beetles that hunt their food in ponds and gently running streams, periodical visits are made to the surface where a small quantity of air is imprisoned under the wing-covers or among hairs on the body and is breathed in during the time of submergence. The young of many flies and beetles are also aquatic, and in the intervals of feeding come to the surface and breathe in a supply of air. Where such species are a pest, as in the case of the mosquito, a thin layer of oil spread over the surface of the water cuts off the air supply and destroys the insect.

Lungs. — Lungs are ingrowths of the body surface or of the digestive tract, which amounts to the same thing, that communicate with the outside by comparatively narrow openings and on the interior expand to form a sac of varying degrees of complexity. In some of the salamanders, lizard-like scaleless animals related to the frog, the lung is merely a smooth-walled bag. In the frog and toad its inner surface is increased by the development of a few folds. In still higher species these folds become extraordinarily numerous and of complicated arrangement, exposing a large amount of surface to the air. In man, for example, the surface of the lung measures about 2000 square feet, or 125 times that of the general surface of the body. When it is remembered that the lungs are exceedingly thin-walled, are kept continually moist, and are penetrated by a very extensive capillary net-work, it will be seen that the high absorption of oxygen meets with a ready explanation.

Lung or pulmonary respiration is associated with rhythmical movements of the chest or thorax. During inspiration the thoracic cavity, in which the lungs are located, is enlarged, the lungs expand to fill the increased space, and a supply of oxygen-containing air is thus breathed in. In expiration the chest cavity decreases in volume and presses the air to the outside. Such movements, as has been noted, are purely accessory and do not constitute respiration.

Respiratory Pigments. — Blood plasma is capable of absorbing about as much oxygen as water, and its capacity in this regard is far less than that of hemoglobin, a complex reddish compound containing iron and carried in the red corpuscles. Under ordinary atmospheric pressure this substance forms with oxygen a feeble compound that under reduced pressure, as in an air pump, again breaks up into hemoglobin and free oxygen. In the lungs therefore, oxygen combines with the hemoglobin and in this combined state is transported to the tissue capillaries. Here the surrounding lymph is practically without oxygen, the pressure or tension is nearly zero, and as in the air-pump the oxygen separates from the hemoglobin, diffuses through the capillary wall into the lymph and from thence into the cells.

In some of the lower animals, such as the clams, snails, crabs and their relatives, compounds of copper act like hemoglobin in the respiratory process. There is also some evidence that substances carrying zinc and manganese may perform a similar function in certain species, but the subject is one of great complexity and is very imperfectly understood.

In the removal of carbon dioxid from the body the case is quite similar to that of oxygen. Upon diffusing from the cell this gas enters the lymph, diffuses through the capillary wall, always travelling into regions of low tension, and in the blood forms a loose union with the plasma that releases it under the diminished carbon dioxid pressure of the lungs through whose walls it makes its escape.

Excretion. — The oxidation of cell materials results, as has been described, in the formation of worthless products known as excretions. In addition to carbon dioxid gas, these include mineral salts, water, and a considerable number of simple nitrogen compounds. In the amœba, paramœcium, and many related unicellular animals, these substances are believed to accumulate in one or two definite spots in the body along with water absorbed from the outside. At frequent intervals this contractile vacuole, as it is termed, empties the droplet to the exterior and thus functions as a simple excretory organ. In other unicellular animals, and even in the hydra-like animals and the sponges, the excretions are removed from the body without the aid of any special organs. Elsewhere in the animal kingdom there usually are definite excretory organs called kidneys, that in many special cases coöperate with organs having other functions as well. The digestive tract of worms, the liver of numerous snails, clams, and vertebrates, the walls of the heart and neighboring blood vessels all play a minor though often a very important part in the excretory process.

In a few groups of animals a portion of the waste products are not removed from the body, but in the form of variously colored pigments are deposited in the skin. The wings of many butterflies owe their color to such compounds, and the silvery sheen of a fish's body is likewise due to an otherwise useless substance embedded in the scales.

Excretory Organs of Lower Animals. — The different types of excretory organs among the lower animals are many, and their modes of operation are equally diverse. In the flatworms they take the form of many widely scattered cells which in form appear much like highly branched amœbae. The branches extend into the spaces between the tissue cells, collect their wastes into a droplet that is periodically discharged into a delicate tube with which each cell is in contact. A flagellum at the junction of cell and tube drives the wastes along into larger vessels that finally open through the body-wall by one or more pores.

In the segmented worms, such as the earthworm, in the snails, clams, and their allies, the kidneys (one or more in number) present the form of more or less voluminous tubes, one end of which communicates with the exterior while the opposite extremity opens into the body cavity. The main portion of this organ is either directly bathed with blood or is supplied with capillaries from which the wastes are extracted by the kidney cells and are thereupon emptied into the central cavity. In most instances the inner end of the kidney tube is provided with heavy cilia whose continued beating drives a steady current of body cavity fluid through the canal and thus washes the wastes to the exterior.

KIDNEYS OF HIGHER ANIMALS. — The kidneys in the vertebrates are relatively large paired organs attached within the body cavity on each side of the backbone. A tube, passing from each organ, leads to the bladder or to the exterior, and on the other hand communicates with a relatively small cavity within the kidney itself (Fig. 21).

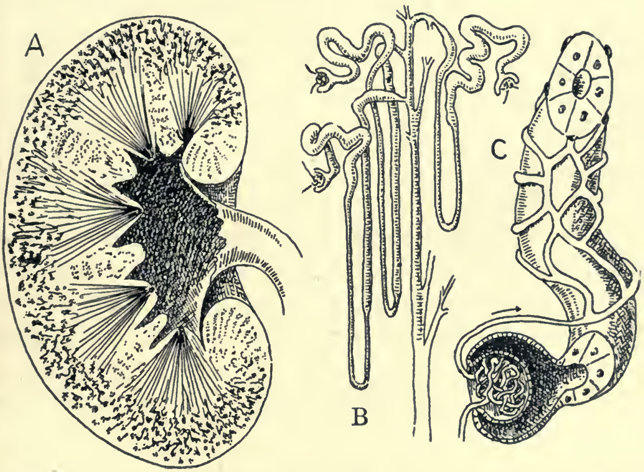


FIG. 21. — *A*, longitudinal section through human kidney, showing radiating tubes opening into the main cavity communicating with the bladder. *B*, kidney tubes enlarged. *C*, terminal section of tube to show cup-like depression filled with a capillary loop which extends as a network over the adjacent section.

Into this space the wastes are poured from the main kidney mass through small openings each of which communicates with a canal, that, as it makes its way into the interior, breaks up into a large number of very small subdivisions. The kidney is thus made up of many tree-like though hollow branches, opening on the one hand into the main kidney cavity and on the other terminating blindly near the outer surface of the organ. The terminal section of each tube thus developed is the active agent in removing excretions and calls for a brief description.

Each of the thousands of kidney tubes ends in an enlargement, resembling the rubber tube and terminal bulb of a camera with one side of the bulb pushed in to form a cup-like depression. In the kidney this cup is filled with a twisted capillary loop, and the tubular section for a considerable distance is covered with a network of capillaries.

Mode of Operation. — Not only does each terminal cup with its included capillary loop differ widely in structure from the adjacent tubular section, but the processes carried on in each are equally unlike. In the cup a stream, consisting essentially of lymph, is continually filtering from the capillary into the cavity of the tube down which it flows to the exterior. This is a purely physical process.

At the same time the cells of the tubular section are absorbing from the blood of the capillary network certain waste substances, chiefly nitrogenous, that are unable to filter through the terminal cup. These are passed through the cells of the tube to the central cavity where they dissolve in the before-mentioned lymph stream and are washed away in it.

SECTION 4

ADJUSTMENT OF ORGANISMS

CHAPTER XII

HOW PLANTS ARE ADJUSTED TO THEIR ENVIRONMENT

THE ENVIRONMENT. — No plant or animal can live its life entirely to itself. The sum total of all the external influences acting on any organism constitute its environment. No organism can escape the influence of temperature and moisture. The duration and intensity of light is very important to any green plant. The amount and distribution of rainfall and the fertility of the soil are vital factors. The competition of other plants or the abundance of plant-eating animals may determine whether a species can occupy a particular habitat or not.

Animals are somewhat less directly dependent on the physical factors of their surroundings than plants but are nevertheless subject to them indirectly. Temperature usually proves an important factor limiting the spread of animals. The kind of plants occupying any region determines the food supply and the nature of shelter available to animals. A very important part of an animal's environment is its relation to other animals. It must compete with some of them for food and avoid becoming food for others.

THE NECESSITY FOR ADJUSTMENT. — With so many elements of the environment playing important rôles in the life of plants and animals it is obvious that adjusting mechanisms are required to enable them to secure or maintain favorable relations with their surroundings. Plants need to be able to adjust the growth of roots, stems, and leaves so as to place these organs in a favorable position to perform their several functions, for if these adjustments are not promptly and properly made the plant perishes.

All animals require food. In a few instances they can remain stationary and have a supply brought to them by currents of water, but in far the majority of cases they must have organs of locomotion to go in search of it and organs of special sense to recognize it when they are in its neighborhood. They need these also to avoid being eaten by other animals.

Plants and Animals Contrasted. — In conformity with these differences between animals and plants in their relation to the environment there have come in the course of evolution to be great and striking structural and functional differences between them. In general animals are highly motile and plants are not. Plants have strong rigid bodies and animals do not. The higher animals have developed highly specialized sense organs by means of which they are acutely aware of many elements of the environment which make little or no impression on the plant. Moreover, they have developed complicated and efficient nervous systems and brains through which the stimuli affecting the sense organs bring about immediate and effective response by the motor organs.

The Adjustment of Roots to the Soil. — A plant whose roots failed to assume a suitable relation to the soil would very shortly perish. This danger is, however, effectively guarded against in several ways.

Geotropism. — The force of gravity is one of the chief directive stimuli for roots. This does not mean that roots merely hang down on account of their weight. It really means that some roots take a position pointing in the line of gravity, while others take a position at right angles to it. In both cases gravity is the effective stimulus. No matter in what position a germinating seed is placed, its root will turn down. Two things are to be noted in respect to this turning of a root in reference to gravity. First, it is the direction and not the force which is the effective stimulus. Second, the turning is brought about by growth and not by contraction, as in the muscles of animals. Such turnings by growth in response to the direction of gravity are technically known as *geotropism* (Fig. 22).

CHEMOTROPISM. — Next to directing roots into the soil is the need to direct them to that part of it where water and the necessary soil nutrients are to be found in the most suitable quantity. It is a familiar fact that roots are likely to find sewers in a dry soil and clog them

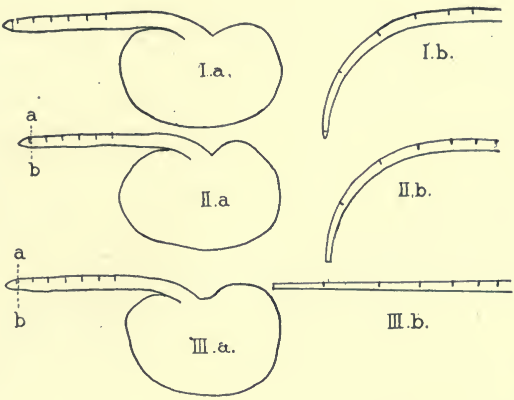


FIG. 22. — Geotropism of Roots. Fig. I.*a*, shows a bean with a young root marked into lengths of 2 mm. each and then placed in a horizontal position. I.*b*, shows the same root a day later. A comparison of the two figures shows that the greatest amount of elongation has taken place in the 6 mm. region immediately behind the root cap. In Fig. II.*a*, the tip was cut off along the line *ab* about 30 minutes after the root was placed in position. II.*b*, shows that the root nevertheless elongated and bent down toward the earth. Fig. III.*a*, shows a root from which the tip was removed before being placed in position. It elongated, Fig. III.*b*, but it did not bend. The three experiments together show that the stimulus of gravity is *received at the tip* but that the *response* by growth occurs in the slightly *older* part.

with a great mass of rootlets. That they are sensitive to water and dissolved salts can also be readily shown by experiment in the laboratory. If seeds are planted in a vessel so that the young roots grow out through the bottom into dry air, they turn back, in spite of the stimulus of gravity, toward the wet soil in the exposed bottom of the vessel. Though the experiment is less easy, it can nevertheless be shown that roots will turn away from a poor soil toward a fertile one. This sort of response is known as *Chemotropism.*

THERMOTROPISM is the response to differences of temperature. To some sorts of plants this is important. For example, in the cacti of arid regions it keeps the roots near the surface of the soil where they can best take advantage of the scanty rainfall when it does come. Under experimental conditions their roots may be induced to turn down and penetrate deeply into the soil if it is heated from below.

OTHER TROPISMS OF ROOTS. — Roots are also sensitive to the direction of light. This is useful in some cases, particularly in roots which originate on parts of a plant exposed to light. Thus, on the English ivy, roots originate on the dark side of stems next the wall (Fig. 23) on which it is growing, where they can secure a hold and fasten the shoot securely in place.

It can be shown experimentally that roots are sensitive to the direction of a current of water. They will also respond to an electric current and to still other sorts of stimuli. It seems probable, however, that most of these are of little or no consequence in nature. They are mentioned here merely to call attention to the fact that protoplasm often has unutilized possibilities but which might conceivably sometime be of use to it under new conditions. This fact should be borne in mind when reading the chapter on Evolution in reference to the question whether the environment really produces the characteristics of organisms or whether the characteristics they already have determine whether and where they can live.

THE ADJUSTMENT OF STEMS is primarily controlled by responses to light and gravity (Figs. 24, 25). Unlike roots, they grow away from the earth and toward the light. In a very young seedling, even where the stem and root are scarcely a millimeter apart, they respond oppositely. Since the cells of both have been only recently derived from the same single cell there must be a very early differentiation of cells in this respect. Likewise, a lateral branch originates within a minute fraction of an inch from a stem-tip and yet shows a response to light and gravity which is different from that of the main stem, since the former grows horizontally and the latter vertically. The response to light is called *phototropism.* It serves to bring stems into the most

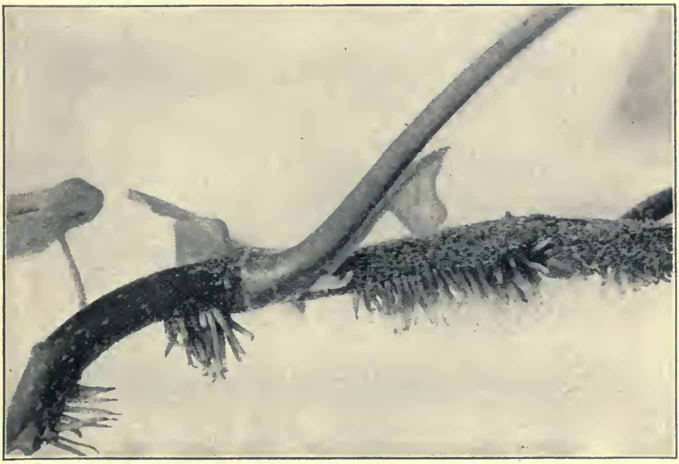


FIG. 23. — Roots on the Stem of English Ivy, which originated on the dark side next the chimney on which the plant grew. Note that these roots grow away from the light and toward the moist brick chimney.

favorable position for exposing the leaves to light and air.

TENDRILS AND TWINING STEMS are guided in part by light and gravity, but their special characteristics are chiefly due to their reaction to contact, i.e., *thigmotropism.* A twining stem in the course of its growth causes the tip portion to swing around in a circle. Contact with a suitable support stimulates growth in such a manner that the coils of the stem are wound about it.

Tendrils behave somewhat similarly. When a tendril comes in contact with a support it may react, according to its nature, by twining about it or pressing its end into firm contact and forming a sucker-like attachment. In some cases, grape for example, as soon as a firm attachment has been made this itself acts as a stimulus to cause a coiling of the intermediate part of the tendril so as to

FIG. 24. — Geotropism of Stems. These bean plants were grown in a pot which was kept right-side up until they were about 3 in. high and then placed on its side. Note that the stems have promptly bent upward to bring themselves in the line of gravity.

draw the main stem into closer relation with the support.

ADJUSTMENT OF LEAVES is chiefly accomplished by light stimuli. It is easy to demonstrate this experimentally. If a potted plant is placed a few feet away from a lighted window and shielded from light from other sources, all its leaves will presently be found facing the window

(Fig. 25). If the pot is turned so as to face them away from the light, the leaves will in a short time grow around to face it again. Everyone is somewhat familiar with this fact out of doors. The leaves of the ivy on the wall are all faced out and arranged like a mosaic so as to shade one another as little as possible. The leaves of small plants like the plantain or dandelion spread out in a rosette, facing upward to the light. It is less easy to observe the leaves on trees because one is rarely in a

FIG. 25. — These plants were grown in a pot placed near a window in an otherwise darkened room. It will be noted that they have grown in a direction which is somewhat of a compromise between the position which they would have taken in response to the stimulus of gravity alone (i.e. if they had been equally lighted on all sides) and that which they would take if influenced by the direction of the light from one side only.

position to see them from the direction of the incident light, but when he is so situated it will be seen that the leaves do face the light.

ADJUSTMENT OF REPRODUCTION. — This sort of adjustment is not so obvious to casual inspection, but it is nevertheless vitally necessary. Trees which produce flowers in winter, as they occasionally do, have small chance of maturing seed. From considerations of this sort it is plain that the tree does react to climatic conditions in such a way that the reproductive processes are properly regulated. When plants are taken from one region to another it not infrequently happens that they grow vigorously but fail to flower or to set seed. Some of the necessary stimuli are wanting. The climate may

Fig. 26. — A Rosette of Leaves so arranged as to expose each leaf as fully as possible to light. Although not so obvious, the leaves of most plants are accurately placed to take the best advantage of the available light.

be too wet or too dry, too hot or too cold, the light too intense or too weak, or some characteristic of the soil may be unsuitable.

Lack of water stimulates reproduction in many kinds of plants. Among the Algae are many which have two methods of reproduction, a sexual and a non-sexual one (Chap. XXVI). When water is fresh and abundant they grow rapidly and set free multitudes of non-sexual single motile reproductive cells called swimming spores capable of immediate growth into new plants. On the contrary, when water becomes scarce or unsuitable for growth, they form by sexual processes a kind of resting spore which is not motile and is surrounded by a hard thick wall that protects it when the pond dries up. This spore produces a new plant the next season.

INTERNAL CORRELATIONS IN PLANTS are as necessary as their adjustment to the environment. A great many things which are ordinarily taken for granted are in reality the result of accurate correlation. Trees form myriads of leaf buds every year, but only a fraction of them unfold in the spring. If, however, the first crop of leaves is destroyed then another lot of buds unfolds to replace them. Clearly, either the unfolding of the first buds must have acted as a restraining influence on the others, or their absence acts as a stimulus, for the correlation is an evident fact.

It is a commonplace that roots develop at the lower end of cuttings and leaves at the top. Nor does it alter the result if the originally upper part of the cutting be the one stuck in the soil. This is, no doubt, due in large part to the fact that the two ends are subject to different stimuli, but not entirely so, since roots do not develop at all parts which are in contact with the soil and so receive the same stimuli.

THE MECHANISM OF TROPISMS. — The reception of an external stimulus depends on the sensitiveness or irritability of the protoplasm. Whether a response will follow depends on the conduction of this stimulus to some part of the same cell or to other cells at a distance where some other activity of protoplasm can be excited. In the tropism of roots and stems the stimulus is received by cells near the tip and some sort of change is propagated through several cells to a region further back where there are induced growth changes which cause the root to bend.

The bending is due to the fact that the cells on one side grow faster than those on the other.

The nature of the change is still somewhat uncertain. There is some evidence to show that it is an impulse of some sort comparable to an electric current but certainly not identical with it. Certain other facts seem to point to a wave of chemical change. In still other cases there is indication of the actual movement of a definite and peculiar substance from the stimulated to the reacting region. In animals, substances of this nature are becoming fairly well known and are called hormones.

The Mechanism of Correlation in Plants is even less well understood than that of tropism. There is gradually accumulating a considerable body of facts which seem to point to the movement of hormone substances from one part of the plant to another, which are concerned in correlation (compare Chap. XVI).

CHAPTER XIII

MOVEMENT IN ANIMALS

Movement in Protozoa. — The Protozoa, as we name the one-celled animals, live in water where they either move about freely or are attached by some part of their protoplasm to some solid object. As we stated in an earlier chapter (III), there are very many different kinds of Protozoa which differ greatly in appearance as well as habits. We can distinguish among all of them four types of movement which serve the entire cell, as distinguished from movements of protoplasm within the cell.

Amœboid Motion. — The first of these is the characteristic form of motion of the very simple organism known as the amœba (Fig. 2), and this kind of motion is, therefore, called amœboid movement. The motion consists of a thrusting out of the protoplasm in some direction with an equivalent drawing in of other parts, so that the volume of the cell is not changed, although the outline of the cell is continually changing. The movement is not rapid. An amœba usually has to be watched carefully under the microscope to make out whether it is moving or not. These amœboid movements appear to be purely random, yet if an amœba is observed for a period of time it is usually seen that it makes progress in one direction, so that out-thrustings in that direction must have been on the whole more frequent than in any other. We apply the expression amœboid movement to any cell motions in which the protoplasm is thrust out bodily.

Ciliary Motion. — The second kind of motion is known as ciliary. It receives this name from the fact that the motion is accomplished by the whipping of very tiny threads of protoplasm which project from the main surface of the cell. These protoplasmic threads are called cilia (singular, cilium) from their resemblance to tiny hairs (Fig. 27). They whip rapidly back and forth,

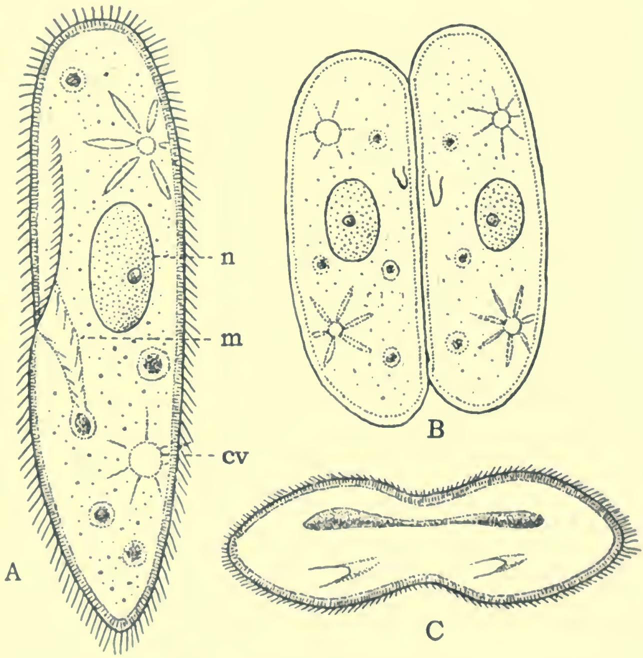


Fig. 27. — Paramœcium or slipper animalcule, showing cilia.

either in unison or in regular succession, the motion being always more powerful in one direction than in the other. Thus the organism, if a free form, is propelled through the water. In Protozoa that are fixed to some object, the cilia set up currents in the water whose effect is to sweep the food particles into contact with the protoplasm where they can be taken in.

Flagellate Motion. — The third type of movement is called flagellate motion. In this form the organism has at some point on its surface one or two protoplasmic projections which are larger and stronger than cilia and which are called flagella — singular, flagellum — (Fig. 28). These flagella sweep back and forth propelling the organism forward very much as a fish propels itself by strokes of its tail.

Contraction of Protoplasmic Strands. — The fourth type of movement is found in Protozoa that are attached, and serves to save them from threatened harm. In this type of motion there can be seen in the protoplasm one or more thickened strands which reach from the spot where the organism is attached out toward the free end (Fig. 29). It is by the shortening of the protoplasmic strand or strands that the body is pulled down out of harm's way. This form of motion is interesting because the strand of protoplasm which has the power of shortening represents the beginnings of the method by which motion is carried on in all the higher animals, namely, through muscular contraction.

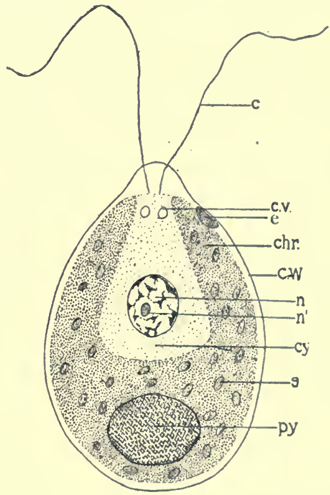


Fig. 28. — Chlamydomonas, a one-celled plant showing flagella.

Motion in Many-Celled Animals. — In the higher animals both amœboid and ciliary motions occur to some extent, and in many instances accomplish very important effects. For example, in our own bodies the windpipe and bronchial tubes are lined with cells which have cilia on the surface fronting on the tubes. These cilia whip constantly in such a way as to sweep up toward the throat any mucous or dust particles that may lodge on the moist surface of the respiratory passages. One can readily appreciate the importance of this continuous clearing out of the channels by which air enters the lungs. The most important instance of amœboid movement in the human body is in connection with the wandering of the white blood corpuscles, which help to protect the body against infection by seeking out and engulfing disease-producing organisms. The way in which these corpuscles get from place to place among the cells of the body is through amœboid movement. The chief organs of movement, however, are:

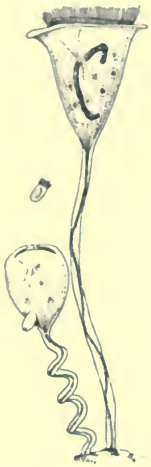


Fig. 29. — Diagram of the Protozoan, Vorticella, shown in the normal extended position, and also partially contracted. The protoplasmic strand by which contraction is produced is shown extending down the stem.

Muscles. — All the large movements of the higher animals are carried on by specialized *muscle* cells. These will be described below. Here we wish only to say that they represent a marked example of the division of labor which was discussed in Chapter III. Muscle cells are composed of living protoplasm which has the contractile property highly developed and the other properties correspondingly reduced. The functional metabolism of muscle cells consists in the performing of these contractions, in other words, in the conversion of chemical energy into the energy of motion.

The Biological Importance of Motion. — Before going on to a further description of muscular action, let us take a moment to inquire into the utility to animals of the power to move.

(1) *Primarily Motion in Animals is a Means of Securing Food.* — All animals require for their food complex substances which result either directly or indirectly from

the activities of the green cells of plants. Animals either move to places where these products are or else cause the products to come to them. As an example of the first type may be mentioned any grazing animal which goes where grass is and then eats it. As an example of the second take the oyster which is anchored firmly to the rock, and by movements of cilia on certain of its surfaces within the shell causes a current of water to sweep through its gill cavities in such a way that minute food particles which the water may contain can be sifted out and consumed.

(2) *Motion in the Struggle for Existence.* — Where animals are at all numerous competition enters, introducing the element of struggle, either of two animals for the same plant food or of some animals to use other animals for food. Here we find a second biological necessity for motion, namely, the avoidance of injury. Motions for this purpose may take the form either of flight or combat. Closely related to these are motions required for making adjustments to climatic conditions. A search for shelter from the elements or for warm quarters in which to sleep are examples.

(3) *Motion and Perpetuation of the Race.* — Next in order comes a series of motions which are related, immediately or remotely, to the perpetuation of the race. The pursuit of a mate, strife with competitive suitors, the care of the young, all involve many motions and all have immediate bearing on racial perpetuation. Of more remote connection, yet undoubtedly belonging here, are the motions by which the young of both sexes strive to make themselves attractive. Among civilized men there are many activities which have to do with racial perpetuation, although the relation is often not obvious. For example, the sacrifices of parents in order that their children may be properly educated come under the head of care of the young, just as truly as does the toil of a mother for her infant's welfare.

(4) *The Motions of Play.* — Finally, we must not omit to make mention of the motions which are made in play. These are particularly characteristic of the young, but are by no means missing in adults, either among the higher animals or man. A fact that is worthy of consideration is that while the motions of the first three groups are practically universal among animals, it is extremely difficult to detect with certainty any motions of play except in the higher and more intelligent forms. Most kinds of mammals play, but it would be hard to say certainly whether fish ever play, and one would certainly be justified in doubting the occurrence of play among either worms or starfishes.

THE REGULATION OF MOTION. (*a.*) *Receptors.* — It is quite evident that the mere power to make motions has very little biological importance. In order that motions shall be effective they must be adjusted to the requirements of the situation. This means that the organism must have knowledge of its environment. Motions cannot be directed toward securing food unless the position of the food can in some way impress itself as a guide for the motion. In general terms, the situation or environment must have a means of influencing the organism. This consists in all animals, except the lowest, of special organs of one kind or another which are known as the sense organs. As a convenient single word, applied to all the various kinds of sense organs that exist, the term *receptor* has been adopted.

(*b.*) *Adjustors.* The reception of impressions from the surroundings will not by itself bring about effective muscular motion. An additional step is necessary, namely, the establishment of connections between the receptors and the organs that are to carry out the movements. In other words there must be a means of controlling the motions in such a way as to produce a suitable and effective muscular response as a result of the impression made upon the receptors. The apparatus for exercising this control is known technically as the *adjustor* mechanism, which in all the higher animals consists of the nervous system.

(*c.*) *Effectors.* — Finally we have the apparatus which makes the motions, to which is given the general name of *effectors.* The advantage of the word "effector" rather than the word "muscles" is that we have, even in some of the higher animals, movements carried on by means of cilia, and a broad term like effectors covers such movements while the word muscle would fail to do so.

TYPES OF EFFECTORS. — From the preceding paragraph it is clear that cilia must be included in a complete listing of the kinds of effectors found in the higher animals. For our present purpose, however, it is desired to concentrate the attention on the more highly specialized and more familiar kinds of effectors, the muscles.

In the higher animals there are three distinct kinds of muscle tissue which will be mentioned briefly here and described in more detail further on.

SKELETAL MUSCLES. — Under this designation are included muscles which move the bones of the skeleton, hence the name. These muscles make up the great bulk of our muscle substance. They are quick-acting and powerful, and are responsible for our main bodily movements.

SMOOTH MUSCLES. — The second type of muscle, known as smooth muscle, carries on most of the internal movements of the body. This kind of muscle is much more sluggish than skeletal muscle, and is also comparatively feeble. In most of the lower animals this is the only type of muscle that is present. In the higher animals it is found in the walls of the alimentary tract, in the walls of the blood vessels, and in a few other places which need not be listed here.

HEART MUSCLE. — In all of the higher animals the heart muscle differs from any other kind of muscle, and must therefore be given a separate classification. It is like the skeletal muscle in being quick-acting and powerful; it differs from all other kinds of muscle in its property of contracting and relaxing automatically. In a paragraph above was emphasized the importance of the control of muscular movement. This control requires that the muscles in general shall be inactive except when activity is especially called for. The heart presents quite a different case, since its proper functioning as an organ for pumping blood requires that its muscle shall contract and relax in regular sequence. Corresponding to this difference in requirement we find the difference in behavior already mentioned, namely, that the heart muscle works automatically, while the other types of muscle are under control and work only when called upon to do so.

Muscle Fibers. — All muscles are composed of living cells, the shape of the cells being in general cylindrical, that is, they are comparatively long and slender. For this reason they are commonly referred to as muscle fibers. The size varies. Single cells, or fibers, of skeletal muscle may range in length from 1 mm. to 35 mm. (1/25 inch to 1 2/5 inch); and in diameter, from .034 mm. to .055 mm. (1/750 inch to 1/450 inch).

In the higher animals smooth muscle fibers are much smaller, averaging not more than .042 mm. (1/600 inch) in length, but in the lower animals, in which they constitute the chief type of muscle substance, they may attain to larger sizes.

Make-up of Skeletal Muscle. — The fibers are bound together in bundles or sheets of various kinds to form the muscle as a whole. A good idea of the structure of the skeletal muscles can be obtained from an examination of raw lean meat, where it can be made out that individual fibers are held together in bundles by means of a binding tissue known as connective tissue. These small bundles are bound together into still larger bundles, and these again into still larger, the connective tissue becoming coarser as the bundles that are to be bound together are larger and larger (Fig. 30). The arrangement of the bundles with reference to one another and to the muscle as a whole will be described in more detail in a subsequent paragraph. Here we may say that the shape of the muscle is determined by the arrangement of the bundles; that is, they may be placed end to end, making a long and slender muscle; or side by side, giving a short, thick muscle. Examples of these various shapes are numerous and familiar to most of us in our own bodies.

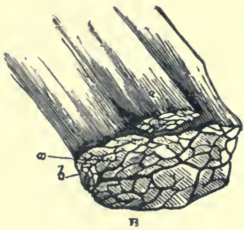


FIG. 30. — A Piece of Muscle Showing Five Coarse Bundles, each composed of a number of fine bundles. The latter, in turn, are made up of microscopic muscle fibers.

MAKE-UP OF SMOOTH MUSCLE AND HEART MUSCLE. — In some of the lower animals the smooth muscle fibers are bound together in fairly definite muscles. In others, they form rather large masses, for example, the foot of a clam is a mass composed of smooth muscle fibers. But in the higher animals the fibers of smooth muscle are usually bound together in the form of sheets, and so do not make up individual muscles which can be dissected out as can particular skeletal muscles. Thus the muscular part of the lining of the stomach consists of two layers which can be separated from each other but which can not be distinguished as made up of individual muscles.

The fibers of heart muscle are bound together to make up a muscular bag in which it is difficult to distinguish individual muscles.

THE STRUCTURE OF SKELETAL MUSCLE FIBER. —A single fiber of skeletal muscle presents under the microscope a very interesting appearance, since it shows a regular sequence of cross-markings or striations (Fig. 31). But apparently these cross-markings do not have much significance. Careful examination of the fiber shows that its protoplasm is of two general sorts. There is a series of dense protoplasmic strands running the length of the fiber but not occupying its entire bulk; the spaces between and among these fibers are filled with very thin watery protoplasm which is probably not much firmer (i.e. viscous) than the body fluid or lymph which bathes the fiber on the outside. Enclosing the entire fiber and holding its parts in place is a delicate membrane or sheath. It is probable that the individual contractile strands within the muscle fiber are comparable with the protoplasmic strands which were described at the beginning of the chapter as occurring in many of the fixed protozoa. Just as these strands have the power of contracting forcibly, so have these in the muscle fiber, and it is their combined action that makes up the contraction of the fiber as a whole.

Fig. 31. — A Small Piece of a Single Muscle Fiber. At (*a*) the fiber has been crushed and twisted to show the outer sheath separated from the protoplasm beneath. At (*b*) the dense and closely packed longitudinal strands are suggested, together with the characteristic cross-markings.

Smooth Muscle Fiber. — The fiber of smooth muscles is much simpler in structure than is that of the skeletal muscle. In fact, on account of its simplicity of construction it may be compared directly with the protoplasmic contracting strand in the Protozoa, although as an apparatus for doing work it is probably a great deal more efficient than is the contracting strand in the one-celled organism.

Heart Muscle Fiber is intermediate in structure between smooth and skeletal muscle. The individual cells contain protoplasmic strands similar to those in skeletal muscle; but the fibers, instead of being enclosed each in its own sheath, merge together into a continuous protoplasmic network, so that it is difficult to say where one fiber leaves off and the next begins.

Attachment of Muscles. — Nearly all muscles that bring about bodily movements as distinguished from internal movements, as of the stomach or intestines, make their contractions effective through pulling upon hard parts (bones in higher animals, shell-structures in lower). The effect is to bring about the bending of joints. Muscles are attached either directly or by means of tendons; these are tough and inelastic extensions of the connective tissue which encloses the muscle fibers and binds the bundles together. Good examples of tendon action are found in the hand (Fig. 32). The muscles which move the hand are so bulky that if they were located in the hand itself it would be too clumsy to be of service. The arrangement which is actually present is that the muscles are out of the way in the forearm, whence they connect with their point of attachment by long tendons which can be seen and felt readily in the back of the hand and at the wrist.

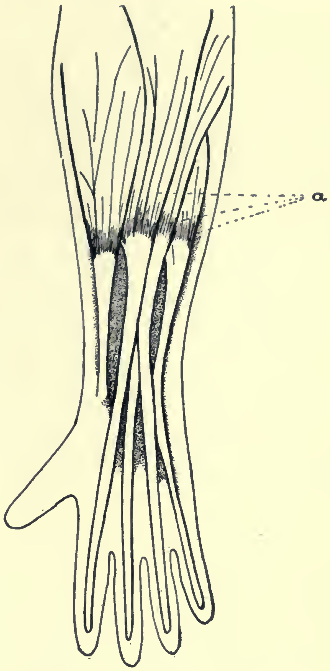


Fig. 32. — Human Forearm and Hand; to show how muscles in the forearm are attached by long tendons to the wrist and fingers. (*a*) group of muscles that bend the wrist and fingers.

Joint Motions. — Skeletal muscles usually operate, as was said above, by causing joints to bend. Joints are of many kinds, the most familiar being the hinge joint such as we have at elbow and knee (Fig. 33). This is a common type of joint not only in the higher animals, but also in all of the groups of lower animals that have jointed limbs. Crayfish and lobsters (Fig. 34), for instance, have limbs with several hinge joints in them, these joints being set in different planes so that by contracting one or the other the limb can be bent now one way and now another. In our own bodies freedom to move in more than one direction is obtained either by a ball-and-socket joint as at the shoulder and hip, or by the kind of joint we have at the wrist where a number of small bones can slide over one another in various directions, and so permit flexibility of motion. Muscles are arranged about the joints in opposing pairs. The number of such pairs depends on the variety of motions of which the joint is capable. What is meant by opposing pairs is

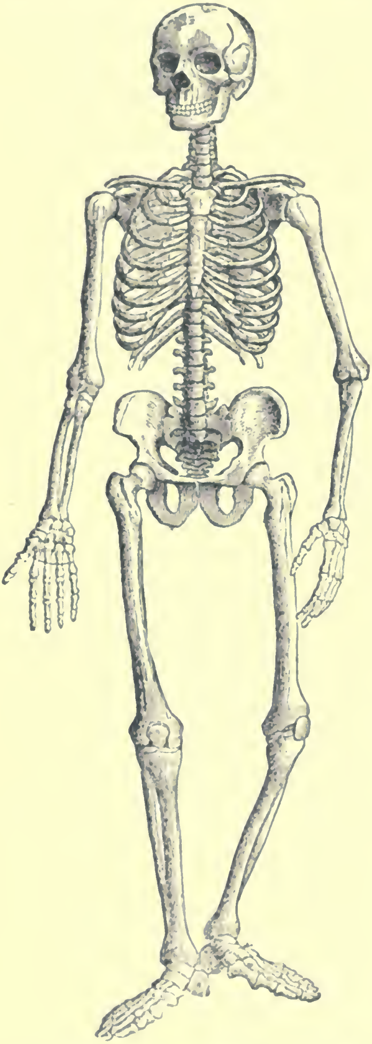


FIG. 33. — Human Skeleton, showing simple hinge joints at elbow and knee; ball and socket joints at shoulder and hip; joints made up of small bones at wrist and ankle

that one muscle of the pair bends the joint and the opposing muscle straightens it again. In the case of the elbow, the muscle that bends the joint is the biceps and the opposing muscle that straightens it is the triceps. The hip joint which is capable of movement in several directions has more than one such pair of opposing muscles.

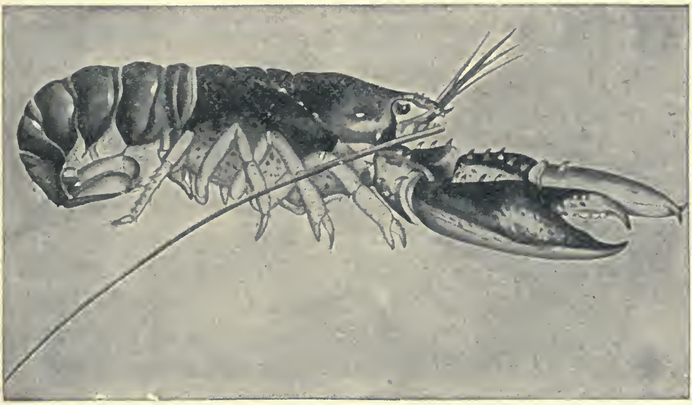


FIG. 34 — Lobster, showing limbs, each with several joints.

MUSCLE FORM IN RELATION TO MUSCLE DUTY. — The force which can be exerted by any muscle is simply the combined pull of its individual fibers. Since any single fiber is of microscopic size and of considerable fragility, it is only by there being great numbers of them together that muscles of such power as our bodies possess can be obtained. The arrangement of fibers in a muscle depends on whether the muscle is one in which strength is the chief need or one in which amplitude of motion is required. Strong muscles must have many fibers side by side, and so are thick. Long muscles have many fibers placed end to end and so are capable of great decrease in length, thus producing large motions of the parts to which they are attached.

THE STRENGTH OF MANY OF THE MUSCLES is remarkable, particularly when we consider the mechanical disadvantage under which they work. The strongest muscle-group in the body is that by which one rises on tiptoe; it is located in the calf of the leg. Direct tests show that the pressure that can be applied on the ball of the foot by the contraction of the calf muscles may amount to as much as 400 pounds in an adult of average strength. So strong a muscle as this must have a great many fibers joined in the pull. If the number which are necessary to exert this force were placed side by side in such fashion that they all pulled directly upon the tendon the calf would be at least twice as bulky as it is. Compactness, together with the necessary strength, is secured in this muscle by having the tendon by which the muscle is attached to the upper leg extend down through the muscle nearly to its tip and having the fibers inserted on the slant (see Fig. 35). This makes possible the presence in the muscle of a great many more fibers than could otherwise be accommodated in the same bulk.

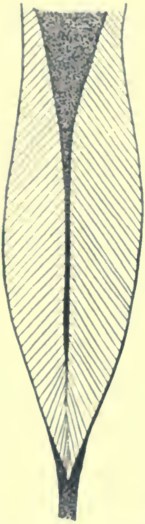


FIG. 35. — Diagram showing how a Muscle may be composed of many Fibers without being unduly bulky. The upper tendon extends well down through the muscle. The fibers extend slantwise downward to the surface of the muscle where they are attached to a surface tendon which merges below into the Achilles tendon of the heel.

LONG MUSCLES. — There are some instances in the body where movement must be exerted through a considerable distance but need not be especially powerful. A muscle which makes this kind of movement must be long because a single fiber can shorten by only a very small fraction of an inch, hence to get a total shortening of several inches a great many fibers must be placed end to end. The best example of this sort is the so-called tailor's muscle which is the muscle by which the leg is drawn into the cross-legged position. To place the leg in this position requires an extensive motion, and therefore a long muscle. The tailor's muscle is in fact the longest muscle in the body, starting as it does in the trunk above the hip joint and extending across the front of the thigh and over the knee to an insertion on the inner side of the leg just below the knee.

Classes of Movements. — Although the movements of any animal are both numerous and varied, those that are visible from the outside fall into six classes as follows: (*a*) *Posture.* This is more significant in two-legged forms like man and birds than in the four-legged animals which have a steadier base. A man who is standing erect, even though he be a soldier at attention, makes balancing movements almost continuously. They are usually so slight as to be observed only by careful watching. (*b*) *Locomotion.* Under this head we include all bodily motions whose effect is to transport the body from one point to another. (*c*) *Grasping,* which includes all movements by which materials are seized or handled. These movements are of first importance in the securing and taking in of food. So closely related to the grasping movements that they cannot well be separated, are the forcible outward movements of the arms which take place in striking. (*d*) *Chewing and swallowing.* These are again motions which are primarily concerned with the taking of food, although in many of the lower animals the motions of biting enter also as a part of combat. (*e*) *Sense perception.* Under this head are included movements of the eyes, of the external ears in such animals as have movable ears, of the nose in sniffing, and perhaps a few others. (*f*) *Voice production and breathing.* All the higher animals make movements of breathing and in those among them that have voice the movements of breathing and of voice production fall under a single head. There are not many motions which cannot be assigned to one or another of these classes. An interesting fact is that the specialized activities of civilized men, the activities in which they differ most strikingly from their uncivilized fellows, fall mostly either into class (*c*), grasping, or class (*f*), voice production. We realize the truth of this when we consider that all use of tools and instruments, including pens, comes under the head of grasping, and that it is by voice production that all ideas which are not committed to writing are communicated.

CHAPTER XIV

ANIMAL SENSE ORGANS

Adjustments in Lower Animals. — In Chapter XII the general fact of the sensitiveness or irritability of protoplasm was stated, and the reaction of plants to stimulation discussed. In that chapter the point was made that in respect to fundamentals plant protoplasm and animal protoplasm act similarly, the differences that exist depending mainly on differences in the relation of the organisms to their food supply. Thus it comes about that in plants the responses to stimulation take the form of slow changes, *due usually to growth,* while in animals the responses are rapid, and are *carried out by contractions of protoplasm.* The very simple animals, those that do not have highly specialized tissues, react to such features in the environment as light, temperature, substances in solution, gravity, and one or two others, in definite fashions which demonstrate clearly their sensitiveness. For example, the protozoan, Paramœcium, will travel from highly illuminated regions to others less brilliantly lighted. If a number are placed in a small trough of water which at one end has a temperature of 25° C. (72° F.) and at the other a temperature either higher or lower by several degrees, all the Paramœcia will presently be found gathered at the end where the temperature is 25° C. The adjustments thus made are on the whole favorable to the organisms making them, either through bringing them into the presence of abundant food or by rendering them safe from harm. The property of irritability is thus seen to serve a highly useful purpose, even in the lowliest types.

Receptors or Sense Organs are made up in the higher animals of groups of cells in which specialization has taken the form of intensifying the property of irritability at the expense of other fundamental properties of protoplasm. The cells of the sense organs carry on, of course, regular basic metabolism, but have no functional metabolism so far as we know except such as is involved in that alteration in the state of the protoplasm which results from the stimulus, and after the disturbance has passed on to other parts of the body the activity of the sense organ comes to an end until it is stimulated again.

Classes of Sense Organs. — The common method of classifying the sense organs is in accordance with the kinds of impressions to which they are particularly susceptible. In accordance with this scheme, we find that in all the animals except the very simplest we have two main classes: (*a*) internal; (*b*) external. As the names imply, the internal sense organs are located inside the body and are acted upon by stimuli arising within the body; the external receptors, on the other hand, lie on or near the surface and are acted upon by stimuli which are exterior to the body. These external stimuli may be of various kinds. In the main, they consist either of changes in the environment immediately in contact with the body or in changes in the environment at a distance which in some way are able to impress the sense organs. Those receptors which respond to immediately adjacent changes are called contact receptors. For example, the organs of touch are affected only by agents which come against the body. Those receptors which are affected by disturbances at a distance are called distance sense organs. The organs of sight and hearing are illustrations of these.

Internal Sense Organs. — We recognize in the higher animals at least five kinds of internal sense organs. Some of these are known to be present also in many of the lower animals; with regard to others we are not quite so sure.

The five will be listed, and each considered briefly. They are the organs of hunger, thirst, pain, muscle sense, and equilibrium.

Hunger. — This is a sense whose biological importance is manifest, since without it animals would not be driven to the search for and consumption of food, and so would starve to death. When one realizes that of all animals man only has learned the connection between the taking of food and the avoidance of death by starvation, he can appreciate the importance of the mechanism which impels animals to eat. The organ for hunger in man and in the higher animals is located in the wall of the stomach, and is stimulated by a particular kind of muscular contraction in the stomach wall which gives rise to what is known as a pang of hunger. The sense of hunger is complicated by the thing we call appetite, which is not a true sense, as is hunger, but is rather a memory of the enjoyment of food. We do not know much about the relation of appetite to hunger in any of the lower animals, but in ourselves we recognize that appetite has a good deal to do with arousing genuine hunger. In thinking of hunger, and of appetite, one has to remember that civilized man has gone a long way in his habits from his savage progenitors, and the conditions for arousing the sense of hunger are correspondingly altered. We know that all kinds of animals which have to rove about in search of food are impelled urgently to that search by some means. At present it is not known whether that means consists, in such lower forms as insects, for example, of an organ of hunger in the stomach, though such an organ is present in mammals and probably in birds.

Thirst. — This is the sense which impels land animals to take water from time to time for the purpose of replacing that which is lost from their bodies by evaporation and through the channels of excretion. In man, and probably also in the higher animals, the organ of thirst is located in the mucous lining of the throat, and the sense is roused by insufficient moisture in that region. This insufficiency of moisture may be due to the drying out of the exposed surface, as when one sleeps with his mouth open; or may be due to a lowering of the percentage of water in the throat in consequence of loss of water from the whole body. Thirst due to the first cause can be allayed by swallowing saliva, but thirst caused by insufficient water in the body can be relieved only by taking in water from outside. It is interesting to note that human beings may through accident or disease lose all their other senses, but very few cases have ever been observed in which the sense of thirst is lost.

Pain. — There are organs for pain, both within the body and on its surface, so that pain is in a manner both an internal and an external sense. It is ordinarily classed with the internal senses because in the experience of human beings it is recognized as a change in bodily state, and not as an environmental change. For instance, if the edge of a knife is pressed against the skin, we think of the knife; but as soon as it penetrates to the point of stimulating the pain organs it is no longer the knife that we think of but the body that is hurt. Pain is a warning sense, it is aroused only under conditions which imply harm. The adjustments to pain are obviously adjustments whose purpose is the avoidance of injury.

Muscle Sense. — This is a sense about which most of us know very little, but which is of the very greatest importance in the activities of mankind and animals. Its organs are located in the muscles and about the joints and they furnish information as to the degree of contraction of the muscles, and the position of the joints. This information is important in that it is the basis of successful locomotion. Any animal that moves from place to place by muscular effort must contract its muscles in correct sequence and with the proper degree of force, with reference to one another. Otherwise the activities which constitute locomotion will not be properly coördinated.

The muscle sense is the means by which the motions are thus adjusted. In ourselves little attention is paid to it because the sense works so perfectly that we do not find it necessary to attend to it. In case of injury to the sense, as for example, in the disease known as locomotor ataxia (Chap. XVI), the impairment of locomotion is very striking.

Equilibrium. — This is a sense found in all animals that have a special position, to which they will return if disturbed. For example, so lowly an animal as a starfish, if turned on its back, will with considerable labor right itself. Insects, crustacea, and all vertebrate animals, have this equilibrium sense, and in all higher animals there is found a special equilibrium organ. In man and in all vertebrates this organ is located in the ear, the semi-circular canals making up the chief portion of it. It is an organ which is affected by shifts in the position of the body with relation to gravity, and the animal in which the shifts occur makes righting motions until it is back in its accustomed position.

The Contact Senses. — These are the senses which are aroused by environmental conditions at the surface of the body. They include touch, temperature, and the chemical sense, so-called, as well as pain. The contact senses have an interesting relationship to the activities of animals in that they make up the original basis of the relations of animals to their environment. All animals are subject to those influences which come into direct contact with them. It is only by secondary development that means for coming under the influence of conditions at a distance come into play. Further reference to this interesting fact will be made later.

Touch. — The sense of touch has a vast number of organs consisting of tiny structures embedded in the skin and distributed over nearly all parts of it. These organs are much more abundantly present in some parts than in others, but about the only surface of any size from which they are entirely absent is the front of the eyeball, which has the sense of pain but no sense of touch. The total number of touch organs in man probably mounts into the millions. Touch is obviously a basis for information in connection with nearly all kinds of animal activity. The suitability of objects for food, or their possibility as sources of injury are determined largely through this sense.

The Temperature Sense is the means by which an animal perceives differences of temperature between its skin and objects with which it is in contact. From the standpoint of the organs involved, there are really two temperature senses, since we have a set of organs for the perception of warmth and another for the perception of cold. The temperature sense is undoubtedly present in all warm-blooded animals, viz., the mammals and birds; whether it exists in the cold-blooded animals is uncertain.

The significance of the temperature sense is obviously to stimulate the animal to adjust itself to the most favorable possible temperature. The stimulus of cold leads to activities which either will make the animal warm by reason of increasing the amount of functional metabolism, and so the production of heat (see Chap. VIII), or will bring the animal into an environment in which it is protected from the cold. Warmth, on the other hand, influences the animal to remain comparatively quiet, and, if extreme, to seek a cool spot.

The Chemical Senses are the means whereby animals are affected through chemical substances in the environment. Only substances dissolved in water can act as stimuli to protoplasm, and so the chemical sense reacts only to dissolved material. The sense is limited in scope in that not all dissolved substances affect it, although the number of substances which do not arouse the sense is small indeed in comparison with the enormous number by which the sense is aroused.

In aquatic animals the organ for the chemical sense consists of cells located conveniently on the surface of the body where the dissolved materials will come in contact with them. The cells which make up the organ are always exposed directly to the outside, with no protective skin between (Fig. 36). To lessen the likelihood of injury they are often located in little pockets or hollows of some sort. In land animals the chemical sense can be aroused both by substances in solution in water and

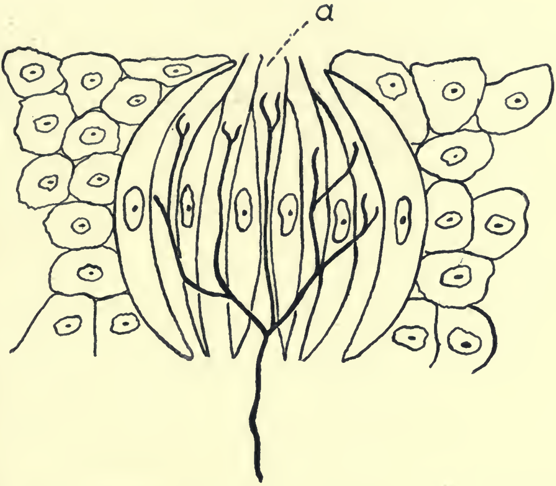


FIG. 36. — Diagram of an organ of chemical sense. (*a*) the place where the sensitive cells are directly exposed to the exterior.

by materials which are present in the air in the form of gas. It is quite true that these latter substances dissolve in the moisture which overlies the cells of the sense organ before acting upon it, so that, strictly speaking, the chemical sense in land animals operates as in aquatic animals through substances in solution.

TASTE. — In the higher animals the organs for chemical sense are of two kinds to fit them for reacting to chemical substances which reach the body by the two different channels suggested above, i.e., in the food or drink which is taken into the mouth, or in the air which is breathed in through the nose. In the higher animals, then, we find one organ located in the mouth and the other in the nose; the former is called the organ of taste, the latter the organ of smell. The taste organ is affected only by materials which are actually present in the mouth. Contrary to common belief it has a very limited range of perception, there being only four true tastes, namely, sweet, sour, salty and bitter. Flavor, which is usually confused with taste, is really part of the sense of smell (see below).

The significance of taste is obviously to aid in forming a final judgment as to the desirability of food that has been captured or grasped, before swallowing it. It is widely but by no means invariably true, that materials which are of agreeable taste are fit for food, while materials that do not taste good are unfit for food.

The Distance Receptors. — Under this head we include the three senses of smell, hearing, and sight. The advantage which they confer on the organism possessing them is obvious in connection with all or nearly all of its activities. For example, to learn of the presence of food at a distance, or of the threat of harm at a distance, greatly facilitates the response of the organism.

Smell. — The organ for smell, as stated above, is stimulated by materials that are present in air in gaseous form. It is located in the mucous lining of the nose, where the air that is breathed in and out passes over it, and the gaseous constituents of the air are thus able to stimulate it. One or two points about this sense may be mentioned. The first is its extraordinary delicacy. When we think of the amazingly minute amounts of odorous material which suffice to arouse the sense of smell in a good dog, for example, we realize the extraordinary sensitiveness of the organ. A second point is the ease with which the sense is fatigued. The continued presence of any odorous substance in the air that is being breathed quickly fails to be perceived. It is this which enables persons to remain in places where the air is seriously vitiated, without knowing it. It also explains why foul breath is not smelled by the person having it.

When air that is breathed *in* contains odorous material it is recognized as coming from outside and the sensation is called smell. When the odorous material is in the mouth, as when food is being eaten, and air containing some of it is breathed *out* over the organ of smell the sensation is called flavor. It is easy to show that flavor is really smell and not taste, for when one has a cold in the head his food, as he says, loses its taste, whereas what it really loses is its flavor. The true tastes, sweet, sour, salty, and bitter, are perceived readily no matter how severe one's cold may be.

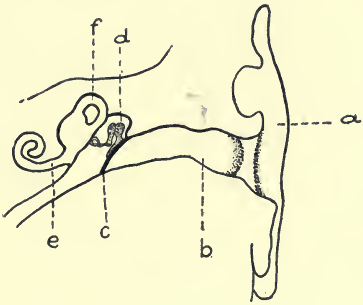


Fig. 37. — Diagram of human ear. (*a*) External ear; (*b*) ear canal; (*c*) eardrum which is set in vibration by sound waves; (*d*) chain of bones by which vibrations of eardrum are transmitted to sensitive part of ear; (*e*) cavity filled with liquid, within which are protoplasmic receptors which are affected by vibrations; (*f*) one of the semicircular canals, part of the organ of equilibrium, not directly concerned in hearing. The entire structure, except the external ear, is imbedded in solid bone.

The Organ of Hearing is the Ear (Fig. 37). — It consists of an apparatus whereby sounds stimulate protoplasm. Sounds are due to vibrations either of solids, liquids, or gases. The majority of the sounds which reach our ear are caused by vibrations in the air. These vibrations strike upon a drum-head — the ear-drum — and set it into exactly synchronous vibration. The vibrations of the ear-drum are transmitted to a liquid that is within the sensitive part of the ear, setting the liquid in turn into vibration, and the vibrations of the liquid affect protoplasmic receptors which are directly exposed to them.

SIGHT. — This sense is an extension, amplification, and modification of the response of protoplasm to light, described in Chapter XII. In its simplest form in animals it consists, as stated in the beginning of the present chapter, of an effect upon the protoplasm of such sort that the animal is impelled to move either toward or away from the light. This implies both reaction to the presence of light and some kind of recognition of the direction from which it comes. There are very few kinds of animals that are devoid of this type of sensation. The sense of sight, as commonly thought of, includes, along with the perception of light, recognition of the *form* of objects. As soon as perception of form is achieved a great advance is made in the utility of the sense, because there is now the possibility of gaining accurate information as to the nature, size, direction, and distance of the objects that make up the environment. This important knowledge cannot be obtained with anything like the same degree of accuracy by all the other senses working together.

THE PERCEPTION OF FORM requires that the object shall reflect light upon a sensitive protoplasmic surface, and that the light so reflected shall make upon this surface a pattern or image of the object from which the light comes. In a strict sense, any specialized receptor which reacts to light is an eye, but in all the higher animals and in many of the lower as well the eye is an apparatus for forming images.

IMAGE FORMATION is accomplished in the eyes of animals in at least two different ways; the compound eyes of insects do it in one way, while the eyes of vertebrate animals — including man — do it in another (Fig. 38).

The latter is the only way that will be considered here. The principle is familiar, since it is made use of in ordinary photographic cameras. It consists in focusing beams of light by means of a lens. In all the higher animals the front part of the eye acts as a lens through which light reflected from the object is focused in such a way that the image of the object is formed upon the

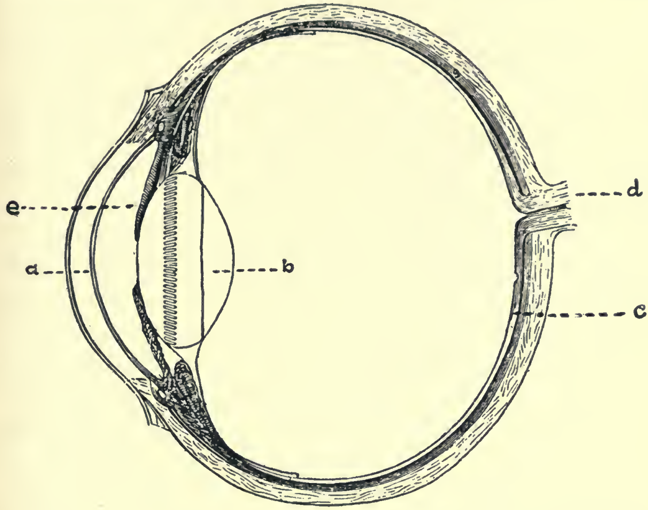


FIG. 38.— Diagram of vertebrate eye. (*a*) cornea; (*b*) crystalline lens; these together make up the focussing apparatus; the lens serves also in *accommodation;* (*c*) the retina or sensitive surface upon which images are formed; (*d*) the beginning of the optic nerve; (*e*) the iris.

sensitive surface known as the *retina,* which is at the back of the eye in line with the lens.

ACCESSORY EYE STRUCTURES. — In the eyes of the higher animals there are one or two additional parts which call for brief description. First is the arrangement for changing the focus, or for *accommodation* as it is called. This is necessary in order that objects at different distances from the eye may be seen with equal clearness. Everyone knows that an adjustment takes place in his own eyes when he turns from looking at distant objects to look at a book in his hand. The change of focus is brought about by a thickening of the crystalline lens, and this, in turn, results from the contraction of tiny muscles within the eye-ball. Second, is the adjustment of the diaphragm, known as the *iris,* to regulate the amount of light entering the eye. That the pupil is small in bright light and large in dim has been noticed by nearly everyone. The change in size of the pupil is the result of adjustments in the iris, whereby light is either largely excluded or allowed to enter freely.

THE PERCEPTION OF COLOR. — A feature of sight not yet touched upon is the recognition of color. The ability to perceive color contributes greatly to the utility of sight in man, as well as to the enjoyment he derives from it. The presence of bright colors in birds, fish, insects, and other forms which have eyes, has led to the general belief that they share with man the ability to perceive color. Whether these lower forms actually do possess color vision or not is not easy to prove, and at the present time we must admit that we know very little as to how widespread among animals color vision is. In ourselves, color vision is evidently due to special properties possessed by the sensitive retinal cells. These properties are not present in equal degree in the eyes of all people. Color blindness is a condition in which some colors, usually red and green, appear as neutral tints instead of as definite colors. Color blindness is fairly common, particularly among males, of whom four out of every hundred, on the average, are color blind.

THE PERCEPTION OF DISTANCE is accurate only within a comparatively limited range. This is because it depends upon the combined use of the two eyes. Whenever one looks at a near object his eyes are turned in to some extent in order to bring both of them to bear directly. The " turning in " is accomplished by the muscles which move the eye-balls, and the judgment of how far the eyes have been converged is made through the muscle sense (page 138) in the eye muscles. Whenever an object is so far away that the eyes are not sensibly converged in looking straight at it, this method of judging distance fails, and such estimations as are made are consequently less accurate. They depend, in fact, upon a judgment as to how far away the object must be in order to appear as small as it does. In other words, judgment of distance is based on knowledge of size. If the object is of known size, as a man, the distance can be estimated quite accurately; but if the size must be guessed at, the distance is likely to be seriously mis-estimated.

THE RELATION OF SIGHT TO TOUCH. — A fact of interest in connection with the conclusions human beings draw from the sense impressions they receive is that sensations of sight are generally interpreted in terms of touch. That is to say, the idea one really forms when he looks at any object is how it would feel if he could get his hands on it. We are told that this is because touch is a primitive sense while sight is of much later development. Hence, the tendency to form judgments in terms of the sense which has functioned longer. Whatever the history of the relationship may be, the fact is undeniable that no comprehensive idea of any object is to be had except as the mind deals with it from the standpoint of how it would reveal itself if it were handled.

CHAPTER XV

NERVOUS CORRELATION

Origin of the Nervous System. — In Chapter XIII the fact was pointed out that in order for the motions of animals to be correlated in accordance with the situations existing in the environment the stimulation of the receptors must be conducted to the effectors, as we name the muscular tissue, by means of an apparatus which is called the *adjustor mechanism.* Early in the book (Chap. II) it was stated that one of the fundamental properties of protoplasm is *sensitiveness* or *irritability,* a property by virtue of which the organism responds to stimulation. A feature of this property is that the disturbance set up by the stimulus spreads through the protoplasm, so that parts at a distance share in the response. The adjustor mechanism evidently depends on this tendency of disturbances to spread through protoplasm to points more or less distant from the stimulated point. In introducing the general topic of nervous correlation, which concerns itself with the action of the adjustor mechanism, the various stages between the simplest possible arrangement and the highly complex structure of the higher animals will be outlined as briefly as possible.

Correlation in Protozoa. — That even so simple an organism as a protozoan shows definite adjustment to its environment is shown by the passage of disturbances from the surface of the protoplasm throughout the mass and so to those special parts of it which are capable of motion. Thus, in Paramœcium, which swims by means of cilia, the vigor of stroke, or often its direction, can be seen to vary according as the organism comes into contact with one thing or another as it swims along. The cilia whose motions are affected need not actually come into contact with the object that causes the change in their stroke. Usually it is the very tip of the Paramœcium's body which makes the contact and the disturbance is transmitted from this point through the body to the cilia. Here we have in simplest form a mechanism for adjustment.

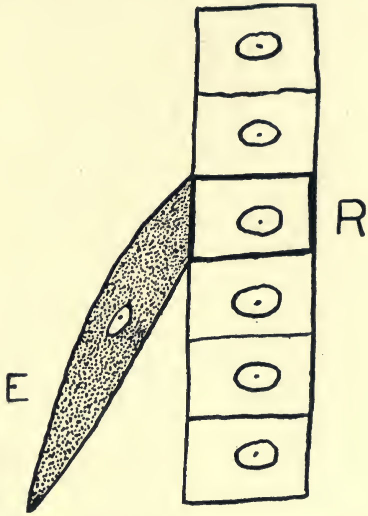


FIG. 39. — Diagram to illustrate how a sensitive cell, *R*, on the surface, may lie in direct contact with a contractile cell, *E*, underneath, a disturbance of *R* being transmitted directly to *E*.

CORRELATION IN PRIMITIVE METAZOA (*i.e., Many-Celled Animals*). — Among the very simplest of the many-celled animals are to be found forms in which the specialization of function has proceeded to such a point that the cells which are sensitive to external influences are not themselves capable of motion but lie in immediate contact with other cells which have the property of motion highly developed and which represent the primitive form of smooth muscle cells (see Chap. XIII). The relation of the sensitive cells to those which can achieve motion is illustrated in the diagram (Fig. 39).

It will be seen that the contact of one with the other is so close that a disturbance of the sensitive cell, to which we may now give the name of *receptor* since it is specialized for receiving stimuli, can be transmitted directly to the *effector* (muscle) cell so as to excite it to activity. The next step in the development is seen in Fig. 40, where the receptor at the surface is separated by a short distance from the muscle cell; the gap is bridged by

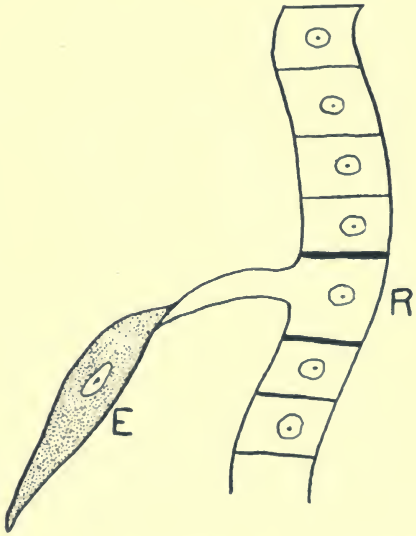


Fig. 40. — Diagram illustrating how a projection of sensitive cell, *R*, may bridge a small gap to contractile cell, *E*, enabling a disturbance of *R* to be transmitted across the gap to *E*.

an outgrowth of the receptor cell which enables it to establish contact with the effector. The next step, which is illustrated in Fig. 41, is one in which the distance between the receptor and the effector is too great to be bridged by a simple extension of the receptor, and so we find another cell making the connection. This cell which comes between the receptor and the effector cells, and serves to carry messages across from the receptor to the effector, constitutes the beginning of a definite adjustor mechanism.

Correlation in Higher Forms. — As one goes up the animal scale beyond the most primitive multicellular types increased complexity of structure is shown in various directions. Only two are to be stressed here. They are (1) increased number of receptors and effectors, and (2) a device for permitting flexibility of connection be-

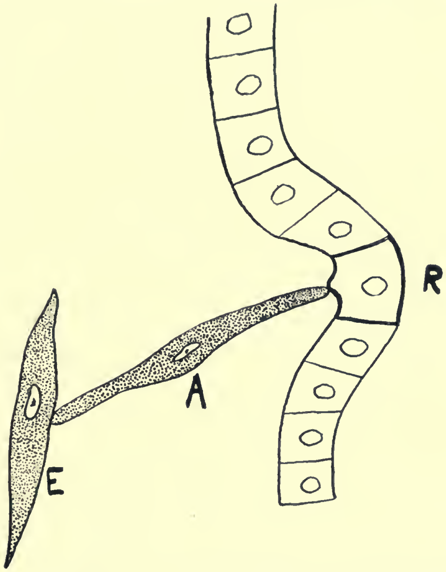


Fig. 41. — Diagram to show how when the distance from *R* to *E* is too great to be bridged by a simple outgrowth of *R* an additional cell, *A*, establishes the connection. Such an intermediary cell, specialized for conduction, represents the beginning of a definite adjustor mechanism.

tween the receptors and effectors. In the last paragraph the organism was pictured as though it had only one receptor and one effector, so that the only nervous system required was a single cell connecting the receptor to the effector. As a matter of fact, one does not have to go very far up the animal scale before encountering forms which have many receptors and likewise a goodly number of effectors. One who studies carefully the activities of an organism of this kind will perceive that the adjustor mechanism must be more complicated than anything that has been pictured thus far. For it can be shown that a single effector may be played upon now by one receptor and now by another. Also, that any given receptor may influence sometimes one and sometimes another of the effectors. Evidently the adjustor system in such an animal consists of something more than nerve cells extending directly from individual receptors to individual effectors, since that arrangement offers no means by which any receptor could establish connection with any effector other than the particular one with which its adjustor nerve-cell connects.

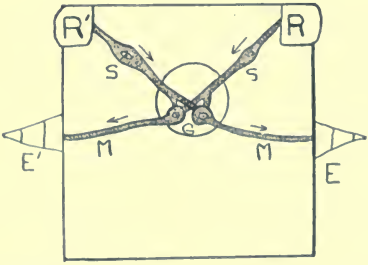


Fig. 42. — Diagram to suggest the organization of a simple nervous system. From the receptors, *R* and *R'*, sensory nerve cells, *S*, lead to the ganglion, *G*. Thence motor nerve cells, *M*, lead to the effectors, *E* and *E'*. It is seen that within the ganglion each of the sensory nerve cells has contact with both motor nerve cells.

The Structure of the Nervous System. — The method by which flexibility of connection between receptors and effectors is established in animals is by means of an arrangement comparable to a telephone installation. Every receptor has nerve-cells leading from it to a region in the body which we may call a nerve center, or, to use the technical name, a *ganglion* (see Fig. 42). The disturbances aroused in the receptors will be conducted from them to this center instead of directly to an effector. Each effector in turn has nerve-cells leading to it which come directly from the ganglion instead of from a receptor. Thus it is possible for nervous disturbances to pass from receptor to effector, but only by way of the center or ganglion, and only by passing through two nerve-cells. It is customary to call the nerve-cell which extends between the receptor and the ganglion a *sensory* nerve-cell, and the one which extends from the ganglion to the effector a *motor* nerve-cell. The arrangement which is described is easily understood because, as stated above, it is comparable to a telephone installation. Just as in the latter messages coming in over one line can be directed out over another and their course can be directed from the center, so that the outgoing line is now one and now another, the nerve impulses coming into the ganglion from the receptors are passed through it and out into pathways leading to one or another effector.

SIMPLE REFLEX ACTION. — A fact of the behavior of animals which can be clearly demonstrated by careful study is that the stimulation of a given *contact* receptor nearly always results in the action of a particular effector, the response of the effector coming with no more delay after the stimulation of the receptor than is necessary for the nervous impulse to pass from the receptor up to the center and from the center out to the effector. So far as the majority of actions of the simple animal go, one might dispense with the ganglia and suppose the receptor and effector to be directly connected, as they are in the very primitive forms described in a former paragraph. Evidently there are within the center or ganglion preferred or usual connections between sensory and motor nerve-cells so that under ordinary circumstances the nervous disturbance arriving from any particular sensory cell is passed on at once to a particular motor cell and arouses a particular effector to activity. A case of this sort, in which a given action follows the stimulus of a given receptor with regularity, is called *reflex action*, and the particular sequence of nerve-cells between the receptor which is stimulated and the effector which ordinarily comes into action as a result of its stimulation is known as a *reflex path.* We can imagine an animal which has anywhere from twenty to one hundred receptors, and from half-a-dozen to forty effectors, exhibiting a great variety of simple reflex actions, as one receptor or another is stimulated and so one or another effector is thrown into operation.

Nervous Organization in Jointed Animals. — In the paragraph above a situation is pictured as existing in a fairly simple metazoan whose nervous system consists of a single ganglion with outlying nerve-cells connecting it with the receptors on the one hand, and with the effectors on the other. Complexity of bodily structure comes about in the animal kingdom in various ways, but the one which is characteristic of most of the higher animals is the device of jointing, that is, of having the body made up of a sequence of joints or segments. In its simplest form such a jointed body has each division exactly like every other, and such a body can be represented as in Fig. 43, which is simply Fig. 42 repeated over and over. In an animal so constructed each joint has all the organs necessary for the maintenance of life, and such a mechanism could be thought of as a colony of relatively independent organisms. Needless to say, practically all of the jointed animals go beyond this simplicity, and there is specialization among the joints (in respect to most organs) so that some joints carry on one bodily function and some another. So far as the nervous organization is concerned, however, the specialization is in many cases not very marked. As Fig. 43 shows, the structure in such organisms consists essentially of a reduplication of the arrangements already described for a simple organism, that is to say, each segment has its receptors, its effectors, its ganglion, with sensory nerves passing from the receptors to the ganglion and motor nerves from the ganglion to the effectors. In order for a jointed animal to function with any degree of success all of the segments must work in harmony. Hence the machinery of nervous correlation in these must be so organized as to extend from joint to joint. As Fig. 43 shows, the arrangement is to connect each ganglion with its neighbors on either side by nerve-cells which extend directly from ganglion to ganglion. Since these are neither sensory cells nor motor cells but connections, we give them the name of *connecting cells.* The presence

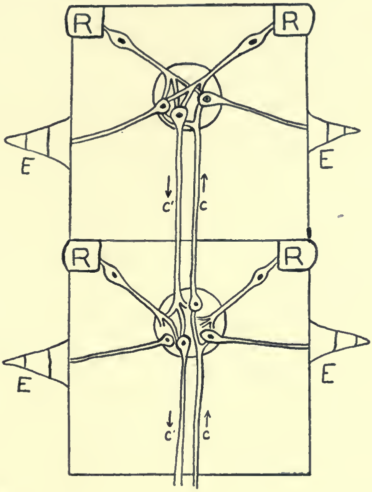


Fig. 43. — Diagram illustrating the nervous system in a jointed animal. In addition to the structures shown in figure 42 the connecting nerve cells (*c*) and (*c′*) are shown, by which nervous disturbances can pass from joint to joint. For the sake of simplicity part of the possible nerve connections in the second ganglion are omitted.

of these connecting cells opens up additional possibilities of complexity in the movements of nerve impulses, for now a disturbance originating in any receptor and passing from it to the ganglion is not confined in its outward path to the motor nerves leading directly from that ganglion to the effector, but may pass over the connecting nerve-cells to an adjoining ganglion and so to an effector in the adjoining joint, or may pass from the ganglion along the whole length of the body, arousing the most distant effectors to action.

Complex Reflex Action. — It will be clear that in a jointed animal with its multiplicity of receptors and effectors and its numerous ganglia there is much more scope for complexity of nervous action than in the simple unjointed forms. An additional feature of the situation also contributes to the complexity, namely, that there is nothing to prevent more than one receptor from being stimulated simultaneously. In fact, the usual thing is for a number of receptors to be stimulated at once. This means that several streams of nerve impulses are pouring into the same ganglion if the animal be of the simple type with only one joint, or into various ganglia if the animal is composed of several joints. In either case proper adjustment requires that the streams of incoming impulses be so correlated that the outgoing impulses to which they give rise shall throw the effectors into action in a way that is orderly and adjusted to the requirements of the situation. Part of the function of the ganglia is thus to correlate the streams of incoming nerve impulses into properly organized outgoing streams to the effectors. Between the simple and direct passage of a nervous impulse from a given receptor to a particular effector, and this organization of streams of impulses to bring about the complicated yet orderly activities of many effectors is a long step, and we must confess at once that we do not know how the process of correlation is actually carried out. It is not at all difficult to prove that there is such a process and that it functions very efficiently, but much beyond that the investigations of biologists have not yet enabled them to go.

Importance of the Front End of the Body. — If the activities of a jointed animal be considered as it moves from place to place, it will be realized that its front end is ordinarily the part that comes first into a new environment and is therefore the first to be affected by whatever is new in that environment. Obviously, the receptors at the front end will be most frequently stimulated and their stimulation will be of greatest significance to the organism. It is in accordance with this principle that we find the most important receptors at the front end; and particularly is it true of nearly all animals that such *distance receptors* as they possess are in that part of the body. An important consequence of this grouping of the distance receptors in one region is the corresponding increase in size and complexity of the front ganglia. The distance receptors are complicated organs composed of numerous parts and requiring many sensory nerve-cells to connect them with the central ganglia; the result is that the ganglia at the front end of the body are usually the largest of all that the animal possesses, and on account of their connection with the distance receptors they are also the most important. Here we have the beginning of the brain, namely, a group of ganglia with an especially large number of sensory nerves leading in, and of course an equivalent supply of outgoing nerves, either motor, leading directly to effectors, or connecting, leading to other ganglia, and so, indirectly, to more distant effectors. Moreover, it is of predominating importance because it is the ganglion-group with which all the *distance receptors* communicate and into which, therefore, are poured the nervous impulses bringing information of facts in the environment at a distance from the body surface. These factors of numbers of nerve connections and of relation with the distance receptors, in combination, make the brain at once the dominant part of the nervous system.

THE ADVANTAGE OF THE DISTANCE RECEPTORS. — When the contact receptors are stimulated, the response is as prompt as the working of the mechanism will permit. Obviously, this promptness is an essential part of adjustment to contact stimuli, since if the source of the stimulation is in immediate contact with the body immediate activity is likely to be the only kind that will serve the animal. When the distance receptors are stimulated, on the other hand, the adjustment need not be immediate. If the stimulus is indicative of danger the reaction may be delayed somewhat and yet the organism may survive. This introduction of a possibility of delay in response to stimulation permits a great extension of nervous action in that it opens the way for the making of a choice as to what the response is to be. In simple reflex actions, as has been repeatedly said, no choice enters, the response follows immediately and automatically upon the stimulation. The possibility of choice implies, on the other hand, that the response need not be immediate and automatic but may be delayed somewhat and may be subject to regulation. We can think of only one basis for this regulation which would be of any value whatever to the organism, namely, what has happened to it before; so that choice, to be worth anything, must be founded on past experience. A very little reflection will show clearly how vast is the extension of an animal's range of adjustment if it can call previous experience into play as a part of the mechanism for guiding its present behavior.

Machinery for Using Past Experience. — In an earlier paragraph the fact was brought out that distance receptors communicate directly with the front ganglion of the nervous system, the brain. Some of the nerve-cells of this front ganglion have a peculiar property not found in the other nerve-cells in the body, namely, that when nerve impulses come into them they are not passed out immediately as is the case with the other nerve-cells, but are stopped and held. The result of this property is to interrupt reflex action and prevent its completion. These nerve-cells have the additional peculiarity that the nervous disturbances that are thus held within them make some kind of permanent impression upon them, so that under suitable conditions impulses previously received can be passed on again. Thus a reflex action that is started at one time may be completed later. This ability of brain cells to store nerve impulses is called *memory,* and is the basis for the use of past experience.

It should be remembered that all experience is based upon the stimulation of receptors, and the machinery of memory is a machinery for storing the impressions which these stimuli impart, for use at some future time. An impression once stored in the form of memory may serve as the starting point for activity not once but repeatedly, thus making a single memory able to bring about many actions and so contributing greatly to the utility of memory.

Contact Receptors Participate in Memory. — In practically all animals which have a brain the contact receptors and probably the internal receptors as well have indirect communication by means of connecting nerve-cells with the brain (Fig. 44), so that when any of the sense organs are stimulated it is probable that nervous impulses will pass into the brain. In the case of most contact receptors this connection with the brain would be called a secondary connection, the primary connection being with the motor nerve-cells. When receptors having this kind of connection are stimulated the ordinary reflex response follows at once, automatically, and at the same time there is a flow of nervous impulses into the brain. Those which pass to the brain register there as memories, just as do the impulses coming more directly from the distance receptors. Thus all the channels of experience become available for the future guidance of the animal.

Association. — Memories are made serviceable by a further property of the brain-cells to which we give the name of association. This is the grouping together of memories that are related so as to form other and more complex memories. The best way to show the significance of association is by illustration. It is customary to use for the purpose of illustration the case of a baby that starts life without any background of experience and therefore without memories. Suppose that before the eyes of the baby an ordinary bell is held. The

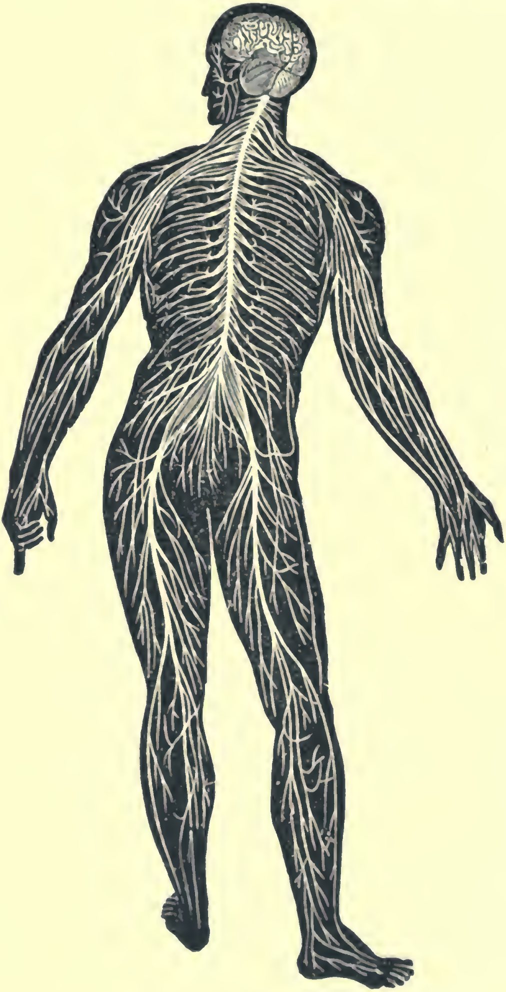


Fig. 44. — The Human Nervous System, showing the main nerve trunks communicating with the spinal cord, which extends downward from the brain into the body. Within the spinal cord the sensory nerves from contact or internal receptors may make direct connections with motor nerves to effectors, and also, by means of connecting nerves, may make indirect connection with the brain. Martin, *Human Body*.

baby sees the bell, or in other words, the image of the bell is formed upon the sensitive surface of the baby's eyes. This image stimulates sensory nerves by which in turn nervous impulses are conveyed to the brain where the sensory impression is registered and stored as a memory. This is pure memory of the appearance of a certain object, and can have no meaning in the child's mind. At another time the bell is rung, the child hears it and another receptor is stimulated, another set of nervous impulses is aroused, and in an entirely different part of the brain a memory is registered, this being a memory of a certain sound. Still later the child gets its hands upon the bell and receives a series of sensations of touch which are registered as memories in a still different part of the brain. Thus the child has three separate and distinct memories, all relating to the same object. By some process within the brain which we do not at all understand, these three related memories are associated. In other words, the child perceives that they all belong together. Thus it forms what we call an idea, which is a memory of the bell as a whole. We must remember that the beginning of this process in a baby is on a very small scale and is probably not carried on very efficiently, so that it may take the child some time to form satisfactory associations. We all know from our own observation, however, that at a very early age the normal infant is found to be equipped with a considerable range of very useful associated memories.

THE CONTROL OF ACTIVITY IN THE HIGHER ANIMALS. (*a*) *Reflex.* — From what has been said in the paragraphs above it should be clear that the activities of any animal whose brain has the properties of memory and association may be governed in at least two distinct ways. In the first place, much of the activity may be purely reflex. By this is meant that sensory stimulation may lead at once and automatically to certain definite movements. More of our own motions than we realize are of this character. For example, the act of walking, although very complex, is in a technical sense a pure reflex. This means that the muscular contractions which make up the act are initiated and regulated by immediate sensory stimulation. The sensory stimulation which operates in this particular reflex has a number of sources, the pressure of the soles of the feet upon the ground, the muscle sense aroused from the contractions of the muscles and the bending of the joints, the sense of equilibrium brought into play as the head swings with the motions of the body, the sense of sight if one happens to be walking with the eyes open, all contribute stimuli which are correlated within a part of the central nervous system set aside for that purpose and caused to discharge an accurately timed and properly graded series of stimuli to cause the muscles to perform in sequence and to the degree that is necessary for successful walking.

(*b*) *Volitional.* — Contrasted with an act of this sort, which is purely reflex, are many activities which are spoken of as *voluntary*, namely, as carried out by the will. When a volitional act is analyzed it is found to be guided by a combination of the immediate environment with such associated memories as apply to the case in hand. It is conceivable that a volitional act might be the result wholly of memory, no immediate stimulus having anything to do with starting it off. Yet, study of the activities of animals as well as our own activities shows that in a vast majority of cases the acts that we call volitional depend upon a combination of immediate sensory stimulation with associated memory. Since all associations are built originally upon sense impressions it is possible to trace the origin of all activities back to receptors. Thus, strictly speaking, the brain does not originate activity but merely causes to go on to completion chains of events which have their origin in sense organs.

Instinct. — In many of the lower animals, but most strikingly exemplified in insects, are to be seen numerous complicated activities which are described as instincts to distinguish them from acts of volition. The complexity, orderliness, and utility of these instinctive actions are often astounding, and to one who has not looked into them it might seem that they cannot indicate anything less than the exercise of a very high degree of intelligence. As a matter of fact, careful study demonstrates conclusively that these so-called instinctive actions, no matter how complicated and orderly, are purely reflex in origin and control. The animals which carry them out do so on the basis of immediate sensory stimulation, the action follows immediately upon and is determined by the sum total of the sensory stimuli which the animal experiences. It must be admitted that many facts about instinct are not at all understood at present. For example, we may take the instinct of migration in birds. It is clear that the stimulus for migration is an immediate stimulus, based in part probably on chemical changes that go on in the body of the bird itself and in part on features of the environment. But the actual execution of the migration, particularly such feats as the flight of birds from Alaska to a tiny outlying island of the Hawaiian group, and there hitting upon the island with unerring accuracy at the end of hundreds of miles of flight with no single landmark in view, is entirely unexplainable at the present time.

Behavior Determined by Nervous Organization. — The question of whether in any given species of animal associated memory (volition) shall dominate over pure reflexes (instinct), or whether the reverse shall be the case, is determined by the make-up of the nervous system from birth. Certain kinds of animals inherit from their ancestors a nervous organization in which associated memory plays an important part; others inherit a nervous system in which complicated reflexes determine their behavior. Human beings belong in the first of these categories, insects in the second. Many forms, particularly the lower vertebrates, represent combinations of the two kinds of organization. It is worth noting that when we ascend to the very top of the scale, to man himself, we find instincts, in the sense in which we usually speak of them, almost wholly wanting, volitional acts taking their place.

Habit Formation. — It has been shown how, in animals that possess the property of associative memory, any given act may be based upon the combined effect of immediate sensory stimulation and such associated memories as are relevant. Assuming that the activity thus set into motion proves useful, the recurrence of the same combination of stimuli will naturally bring about the same response. If the situation is one which recurs frequently, there will be successive repetitions of the same kind of activity. The result is to establish within the nervous system exceptionally ready connections between the sensory, association, and motor regions involved, so that with the recurrence of the sensory stimulation the performance of the particular act follows more and more certainly. This is what we call *habit formation.* It will be seen that it amounts to a suppression of the volitional part of the control, thus making the process approach the status of a pure reflex. No better illustration of habit formation could be given than the driving of an automobile. The beginner receives first a series of sensory impressions in the form of instructions and observations of other drivers; from these he forms a series of associated memories; and when he begins to drive, his equipment for performing the act successfully consists of these memories, together with the sensory stimuli which come to him as the car moves along. The correlation of these into correct muscular acts is at first extremely difficult; all the memories that have been acquired must be called into the mind every time a new movement on the part of the driver becomes necessary. With the passage of time this necessity for recalling definitely one's instructions diminishes, and ultimately the proper driving motions follow the receipt of the sensory stimuli as promptly and as automatically as in any pure reflex. Once this situation is realized we say the habit is fully formed. There are, of course, all possible stages in habit formation, depending on the complexity of the memories involved and on the frequency of the repetition of the stimuli.

Consciousness or Awareness. — It should be clear that the process of associating memories makes up what we call thought, or intellectual activity. Does it follow that every animal which is able to form associations has the power of thought? In answering this question a feature of intellectual activity or thought must be taken into account which human beings and probably most of the higher animals possess but concerning which we are extremely doubtful when it comes to the lower animals — this is the property familiarly known as *consciousness*, and to which psychologists give the name *awareness*. The mental processes of human beings are accompanied very largely by a knowledge of what is being thought. Thus we are in the habit of assuming that the process of association always involves consciousness or awareness. This, however, is by no means the case; there is good proof that the process of associating memories can and does go on without consciousness being at all involved. Thus the fact that lower animals can associate memories does not prove that they are aware of their associative processes.

The Feelings or Emotions. — There is a type of nervous activity to which we give the name of feeling, or emotion, which is not the same as the nervous activity of the intellectual processes although the two kinds are closely interwoven. The emotions are of the utmost importance to human beings, because both the joys and the sorrows of life are largely wrapped up in them. We know by observation that many of the animals lower than man experience emotions of one kind or another. One naturally inquires, therefore, what is the biological significance of emotion. In attempting to answer this question it is necessary to note that the emotions fall naturally into two opposing groups, (*a*) the agreeable, (*b*) the disagreeable. If these two classes are analyzed it is found that those of the first class are associated either with conditions favorable to bodily well-being, or with racial perpetuation; the second class of feelings are, on the other hand, seen to be associated with conditions which are inimical to bodily well-being. This is clearly seen if we list the most important of the emotions of this class. They are: fright, anger, emotions connected with pain, emotions connected with hunger, emotions of worry or anxiety. This does not exhaust the list of the disagreeable emotions but covers those which are of primary biological importance. In the next paragraph will be shown how these emotions actually relate themselves to self-preservation.

Bodily Changes in Emotion. — For a long time it has been known that every genuine emotion is accompanied by some sort of bodily change. Familiar illustrations are the shedding of tears in time of sorrow, the blush of embarrassment, the smile of pleasure. If the emotions have any biological significance it would be expected to be in connection with these bodily changes which accompany them. To get at the meaning of the emotions, the chief bodily changes accompanying the five disagreeable emotions listed above are set down and their significance briefly considered. Taking them in order they are as follows:

1. The hair stands on end.
2. The pupils are dilated.
3. The face is pale.
4. The mouth is dry on account of suspension of the action of the salivary glands.

5. The heart beat is greatly quickened.
6. The digestive function is completely suspended, both the secretion of the digestive juices and the muscular movements of the alimentary tract being suppressed.

All these bodily changes are recognized at once as characteristic of such emotions as fright or anger. The analysis of them reveals that without exception they are associated with the preservation of the body in time of immediate emergency.

The erection of the hair, although of no importance in man with his scanty equipment of hair, will be easily recognized as a definite aid to self-preservation in such animals as dogs or cats, in which their usual appearance of mild friendliness is transformed into malignant ferocity by the simple process of causing the hair to stand on end.

The dilation of the pupils probably contributes to the acuteness of vision out of the corners of the eyes, and thus is of assistance to fighting animals. The four other bodily changes in the list all contribute to one end, namely, the favoring of metabolism in the brain and in the skeletal muscles at the expense of other parts of the body. When the face turns pale it means that the blood to which it owes its color has been diverted from the skin to the brain and muscles. The suspension of the action of the salivary glands and of the other digestive organs enables the blood which would ordinarily be required for their nourishment to be shifted to the brain and muscles. The quickening of the heart-beat means greatly improved circulation of the blood, which again benefits the brain and muscles. When one recalls that in time of emergency an alert brain and active muscles are vitally important to self-preservation, whereas digestive activity or the ruddiness of the skin may be dispensed with for the moment without harm, it is clear how these bodily changes aid in self-preservation.

The Reproductive Instinct. — In nearly all kinds of animals reproduction, and therefore racial perpetuation, depends on the fusion of two special sex cells, an egg produced in the ovary of the female, and a sperm produced in the testis of the male (see Chap. XXVI). In order to insure racial perpetuation there must be a definite guaranty that this fusion will occur. The mechanism for accomplishing it involves correlated muscular movements, which are set in motion and guided, just as are all such movements, through the operation of the nervous system. The correlated movements make up a complex reflex action, which resembles other reflex actions in being based on sensory stimulation. This stimulation is in part external and in part internal, the latter part rising from the organs of reproduction themselves. Chemical regulation (see next chapter) is probably a factor also. The combined effect of these influences is to arouse an exceedingly powerful emotion fully as strong as any connected either with securing food or with escaping harm. By this emotion the stimuli are vigorously reinforced and the organisms are impelled to reproduce. When one recalls that it is inconceivable that any of the lower animals can or does appreciate the connection between mating and the subsequent appearance of young, the vital biological importance of the reproductive instinct is clearly seen. Moreover, should the effect of civilization be to weaken the effects of this instinct seriously in the human race, there would be no effective motivation to prevent the disappearance of mankind from the earth.

CHAPTER XVI

CHEMICAL CORRELATION

THE NECESSITY FOR GRADUAL ADJUSTMENTS. — In the chapter just finished the means whereby animals adapt themselves promptly and efficiently to the varied requirements of an ever-changing environment have been outlined. The general topic of the adjustment of organisms has, however, not been completely considered until account has been taken of the many *gradual* adjustments which organisms have to make. Numerous examples of these gradual adjustments will be considered in the paragraphs below. Here, by way of illustration, need be mentioned only two: in plants, the ripening of the fruit is an adjustment which serves the biological requirements of the plant, and it is an adjustment which goes on gradually. It is not only gradual but it is a genuine adjustment, that is to say, the chemical changes which constitute ripening occur at a definite time in relation to the development of the seed, as well as to the general growth activities of the plant. A gradual adjustment in animals is the adjustment of symmetrical growth. If one stops to think about it he may well inquire how it happens that the two ears, which are separated from each other by the width of the head, manage to grow at a uniform rate and to stop their growth at the same time, so that in the majority of people the two ears are of the same size. Here is just one of the numerous adjustments that occur in animal growth and without which misshapen and distorted bodies would inevitably result. It is clear that a mechanism like the nervous system is not well adapted for making adjustments of this character. To maintain an unceasing flow of nervous impulses to every growing part throughout the period of growth, and for no other purpose than the regulation of that growth, would seem to involve an excessive amount of nervous activity if any simpler means of accomplishing the same result could be found.

CHEMICAL ADJUSTORS. — As a matter of fact, experiment has shown that gradual adjustments in organisms are made through the agency of chemical substances. The great advantage of this method is that a chemical regulator can be constantly present as a constituent of the protoplasm, and so can exercise its influence continuously and uniformly. That protoplasm is susceptible of chemical stimulation has been pointed out repeatedly.

BASIC AND GROWTH METABOLISM CHIEFLY AFFECTED. — It is perhaps worth while to note that while chemical regulation may affect all the kinds of metabolism of which organisms are capable, basic metabolism and the metabolism of growth appear to be most definitely subject to this kind of influence. Functional metabolism, in contrast, is typically under the control of the nervous system. When one considers that the utility of functional metabolism is the immediate adaptation of the organism to its environment, it becomes clear that nervous regulation, which brings about prompt reactions to environmental changes, is on the whole better suited to the control of active function than is the slower acting chemical regulator.

CHEMICAL CORRELATION IN PLANTS. — Reference was made to this phenomenon at the close of Chapter XII. Here only a few familiar illustrations will be cited. A chrysanthemum plant if left to itself will produce many buds, each of which will develop into a moderate-sized chrysanthemum blossom. By destroying all these buds but one a single large blossom can be obtained. Evidently there is here in the plant some type of correlation which, so far as we know, must be chemical. If the growing tip of a branch is injured, some bud along the stem, which may have been long dormant and which would ordinarily continue dormant, will start into activity and carry on the growth of the stem as a whole. If a cutting of geranium is thrust into suitable soil, roots will develop on it at spots which ordinarily would never produce such structures. All these are examples of chemical regulation. Nothing is known as to the nature or source of the chemical substances which actually serve as stimuli for bringing about the changes.

Chemical Correlation in Animals. — In animals all the machinery of adjustment is more highly organized than in plants, and so we find in them a definite mechanism for chemical correlation. This mechanism consists of the production of special chemical substances which are poured out into the tissue fluids and which exert definite effects on metabolism. These substances have come into prominence in recent years and bid fair to assume even greater importance in the public eye as the years go on. It is worth while, therefore, to become familiar with the technical name which has been applied to them. They are known as *hormones,* from a Greek word meaning literally " to excite " and referring to their property of functioning as chemical stimuli.

Hormone-manufacturing Glands.—All of the higher animals have in their bodies cell masses whose functional metabolism consists in the manufacture of particular hormones. These cell masses are similar to the glands already described, by which digestive juices are manufactured; the only important difference between them and the more familiar glands is that the materials which they produce are poured out directly into the blood stream to be circulated about the body, whereas the secretions of the glands of the other type, such as the salivary glands, are passed by means of special tubes or ducts into the digestive tract, or in the case of the sweat glands, on to the surface of the skin. Because the glands that are now being described have no ducts they are often referred to as *the ductless glands.*

HORMONES WHICH AFFECT BASIC METABOLISM. — A fact of great importance is that in normal animals so long as the temperature continues constant the basic metabolism goes on at a very uniform rate. The temperature here referred to is the *cell* temperature and not the external temperature. So in warm-blooded animals, whose cells live in a uniform temperature, basic metabolism proceeds without much alteration in rate, day in and day out. Evidence has been obtained of recent years to prove that the actual rate of basic metabolism is determined by the influence of a group of hormones, and the reason that it holds at a fairly uniform level is because these hormones are manufactured and poured out by their glands at a uniform rate. Should the glands become disordered so that their output is either increased or diminished, the rate of the basic metabolism is altered to correspond.

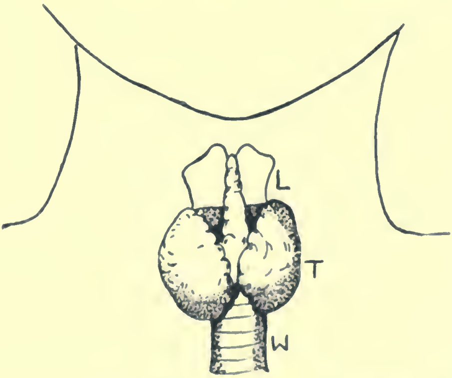


FIG. 45. — The Thyroid Gland, *T*, shown in relation to the larynx, *L*, and the trachea (windpipe) *W*.

THE THYROID HORMONE. — To illustrate the effect of hormones on basic metabolism a single example, the best known of all, will be cited. The thyroid gland lies at the front and sides of the windpipe (Fig. 45) where it ordinarily fits into the contour of the neck and so is not noticed; but sometimes it becomes enlarged — a condition known as *goitre* — in which case the change in size of the neck is readily perceived. The thyroid gland manufactures a hormone which has been identified chemically and has been given the name of *thyroxin*. The rate of the basic metabolism of the body cells is determined by the amount of this substance in the blood stream. When the thyroid departs from its normal production of thyroxin, so that the blood contains too little or too much of the hormone, the metabolism is affected one way or the other and the individual in whom this happens is no longer normal. A description of the bodily changes thus caused is given in the next chapter, where the effects of disturbances in correlation are taken up.

Hormones Affecting Growth Metabolism. — Reference was made at the beginning of the chapter to the fact that growth is a kind of process which lends itself particularly to chemical regulation. Our knowledge of the various hormones which control growth is very incomplete, but two illustrations will be cited to show something of the method of action of the growth-regulating agencies.

The Hormones of the Pituitary Body. — In the space between the roof of the mouth and the base of the brain and behind the nasal passages is a hormone-manufacturing gland known as the *pituitary body*. This is a complex structure and probably secretes several hormones. We are interested here only in the one which is known to influence growth. The manner in which this particular influence is exerted is through an effect upon the size of the skeleton. It is a fact that on the whole the size of an animal is determined by the size of his skeleton, the soft parts adapting themselves of necessity to the growth of the bones. Giants and dwarfs have always been more or less common, but the cause of over- or under-growth has only recently come to light. It is now believed that a considerable percentage of the giants that are exhibited in shows owe their exceptional size to over-activity of this gland during the normal growth period of childhood. The contrary condition of dwarfishness is thought to be the result of under-activity of the gland.

THE INTERSTITIAL HORMONE. — Intermingled with the strictly reproductive parts of the organs of reproduction are cells which are glandular in function and to which have been given the name of interstitial gland cells. The hormone which they secrete is of particular importance in growth, particularly in that stage which is concerned with the change from youthfulness to maturity. There are certain bodily changes characteristic of this period consisting in the development of the so-called " secondary sexual characters." Among them are included such changes as the alteration of the vocal cords which causes the voice to break, and the development of hair on the face. The hormone of the interstitial gland is of special interest because observation of its effects first suggested the idea of chemical correlation. Although castration of domestic animals and caponization of fowls had been practiced for centuries and their effects upon the development of the secondary sexual characters had become a matter of everyday knowledge, it remained for the biologist, about the middle of the last century, to explain the connection. From the studies thus initiated came others which have given us all that is now known about the hormone mechanism.

HORMONES AFFECTING FUNCTIONAL METABOLISM. — Although, as already pointed out, functional metabolism in animals is for the most part under nervous rather than chemical control, there are some instances in which the functional metabolism is affected by hormones, so this type of regulation cannot be altogether neglected.

THE PANCREATIC HORMONE. — The pancreas is primarily an organ for the manufacture of a digestive secretion which is poured out into the intestine through a duct;

but here and there among the cells of the pancreas proper are cells of a different type that are now known to manufacture a hormone which they pour out into the blood. This hormone has to do with the utilization of fuel by the muscles, and thus plays an important rôle in the functional metabolism by which motion is produced. It is found that when this hormone is deficient the ability of the muscles to make use of sugar is seriously impaired. Under ordinary circumstances, probably from eighty to one hundred per cent of the fuel which the muscles burn in making their movements is sugar. It is evident, then, that an impairment of their ability to utilize sugar is a serious matter. In the next chapter an account is given of the disease known as *diabetes,* which results from deficiency in the pancreatic hormone.

Hormones Affecting both Basic and Functional Metabolism. — Although for purposes of description a fairly definite distinction has been drawn between the different kinds of metabolism, it is clear that they are more or less closely inter-related, so that whatever affects one can scarcely avoid affecting the other in some manner. It would be expected that hormones which influence any type of metabolism would bring about modifications in other types as well. There is, however, at least one specific hormone which is known to exert a particular kind of influence on basic metabolism and another influence on definite kinds of functional metabolism. For this reason it deserves special mention.

The Hormone of the Adrenals. — In close contact with each kidney is a small glandular structure known as the *adrenal body.* This body produces and pours out into the blood a hormone to which various names have been given, the most familiar of which is *adrenalin.* This substance first came into prominence when it was discovered that a little of it dropped on a wound would draw together the edges of the injured blood-vessels and so stop the bleeding. If a small quantity of the substance is injected into a vein and distributed throughout the body, it draws together the walls of the tiny blood-vessels and so causes a marked rise in blood-pressure. At first this action on the blood-vessels was thought to be the special function of adrenalin, but it was very soon shown that what adrenalin really does is to stimulate the tiny nerves which terminate in the smooth muscles in the walls of the blood-vessels, and so cause these smooth muscles to contract. The action of adrenalin in closing small wounds and in raising blood-pressure is thus incidental to its real function of rousing smooth muscles to activity. An important fact about this action is that the amount of adrenalin normally present in the blood is not enough to bring this about. There must be an increase above that which is ordinarily present if the blood-pressure is to be raised.

The Regulation of Adrenalin Secretion. — The fact just mentioned has caused the question to be asked, whether there is any condition in which the adrenal glands become more active than usual and pour out into the blood large enough amounts of adrenalin to cause the smooth muscles of the blood-vessels to be excited. Such a situation has been shown to arise in connection with the unfavorable emotions described in the last chapter, where it was seen that in time of stress the body rallies its powers to meet an emergency. The possible connection of adrenalin with this emergency reaction came to light when it was found that not only are the smooth muscles of the blood-vessels stimulated, but all the other effects listed on page 166 are brought to pass through the action of adrenalin in the body. Thus, supposing that the adrenal glands pour out increased quantities of adrenalin in times of emergency, there is a chemical reinforcement of the effects produced by the nervous system, with the presumable advantage of increasing one's ability to cope with the situation. There is a great deal of evidence to show that the adrenals are under the control of the nervous system, and are actually excited to increased activity in times of emotional stress.

THE EFFECT OF ADRENALIN ON MUSCULAR POWER. — It has long been known that a person in time of emergency displays unsuspected strength. The familiar phrase "the strength of desperation" refers to this fact. There is some reason to believe that this increased muscular power may be due to the influence of adrenalin in augmenting the metabolism of the muscles. Since a person in time of stress actually has in his blood more adrenalin than at other times, "the strength of desperation" can be thus explained.

THE EFFECT OF ADRENALIN ON BASIC METABOLISM. — Quite recently it has been shown that adrenalin belongs in the group of hormones that regulate basic metabolism. The method of demonstrating this fact is to inject into the veins of a person a small amount of adrenalin and then to measure his resting metabolism. The effect of the injection is to increase the metabolism considerably above the normal level. Since no external work is done in basic metabolism, the effect of increasing it by injections of adrenalin is to cause the body to produce more heat than it otherwise would (Chap. VIII). There is also evidence that when the amount of adrenalin in the blood is less than normal, as, for example, following injury to the adrenal bodies, the basic metabolism is also less than normal.

THE RELATION OF HORMONES TO RACIAL CHARACTERISTICS. — Very recently the suggestion has been made that the traits which distinguish one race of human beings from another, and which we call racial characteristics, may be due to a difference in the hormones which the individuals of the different races produce. The importance of the suggestion lies in the fact that since racial characteristics are hereditary, being transmitted from parents to children generation after generation, the means of inheritance so far as racial characteristics are concerned, goes back of the characters themselves to the glands in which the hormones are manufactured. To illustrate, the straight black hair and reddish skin of the American Indian, as contrasted with the yellow hair and fair skin of the Northern European races, are due, according to this view, to differences in hormones, but the differences in hormone production are themselves inherited.

Summary. — Through the combined action of nervous and chemical correlation, animals develop symmetrically and their bodily processes perform their functions harmoniously; they make the necessary adjustments to the environment, both in time of quiet and in time of stress, and carry on the activities essential to racial reproduction. A failure in adjustment means, to the individual, impaired efficiency, bodily injury, disease, or death; to the race, failure in perpetuation, which to some extent, no matter how slight, diminishes the breadth of the front which the next or succeeding generations must present to their environment if the race as a whole is to survive.

CHAPTER XVII

DISEASES DUE TO MALADJUSTMENT

Disease May Be Defined in general terms as abnormality in the functioning of living protoplasm; in other words, as a condition of things in which metabolism is not proceeding as it should. Metabolism (see Chap. VIII) is an affair of the individual cells. The disturbance of metabolism which constitutes disease is therefore, in the last analysis, also an affair of individual cells. But, as the previous chapters in this section have tried to make clear, the cells which make up the body do not function independently; what one cell does may influence the activity of cells even at great distances within the body. It is evident, therefore, that maladjustment, or the failure of the various cells to interact properly, is a fruitful cause of disease. For example, if the cells that make up the heart muscle do not function properly the circulation of blood is impaired and the cells throughout the body will suffer, the exact degree depending on how far the transportation system falls short of normal efficiency.

The Maladjustments from which cells suffer are often the immediate result of improper functioning of the mechanisms for correlation. Thus we have a group of diseases due to impaired hormone control, and another group due to impaired nervous control. The maladjustment may be nutritional, that is to say, the materials necessary for metabolism may fail to be furnished of proper sorts or in correct amounts. A third group of maladjustments may result from mechanical injuries of one sort or another, although with regard to these it should be noted that the immediate results of mechanical injury are not ordinarily classed as diseases.

There are certain remote effects of injury, however, which are properly called disease because they involve failure in the internal adjustments of the cells. These will be considered briefly in a subsequent paragraph.

Finally, there are the numerous and serious maladjustments which arise from the struggle for existence among competing organisms and which are familiar in the so-called infectious diseases. For convenience in presentation, the diseases which fall under this latter head, instead of being included here, will be considered separately in the section on "Associations of Organisms" (Chap. XX).

Nature of Disease. — Metabolism is made up of three different stages, (1) the taking up of materials by the cells, (2) the utilization of these materials in the chemical processes which go on within the cells, and (3) the discharge of the waste products which result from the chemical processes. Disease is a disturbance, either in the *amount* of metabolism, in which case the quantities of material consumed, the volume of the chemical activity, and the amount of waste products poured out may be increased or diminished; or it may be a change in the *character* of the metabolism, in which case the substances utilized by the cells will be different, the character of the chemical processes will be changed, and the waste products poured out will be of different sorts. It is true, of course, that in many diseases — and perhaps in most — both the amount and character of the metabolism are altered.

Symptoms of Disease. — By definition, a symptom of disease is a bodily manifestation resulting from the disturbed metabolism which constitutes the disease itself. A healthy body, functioning normally, has certain representative appearances which are recognized as attributes of health. In man, for example, there is a certain range of rapidity of heart-beat which is characteristic of good health. When the heart rate is outside this range, either slower or more rapid, it usually constitutes a symptom of disease. In so complicated a body as that of man, symptoms are of various sorts because disturbances of metabolism can produce so many different effects. It is out of the question in a book of this sort to make a complete list of the symptoms of the different kinds of disease, yet some of the more important may be mentioned in order to show their relation to the underlying derangements of metabolism.

Symptoms Due to Changes in Rate of Metabolism. — Probably the commonest disturbance of metabolism is that in which there is a whipping-up of the chemical activity, causing materials to be used up at more than the usual rate; the chemical processes within the cells go on more rapidly than normal, and an increased volume of waste material is poured out. The commonest symptom of this particular condition is that rise in body temperature which constitutes *fever*. It is true that the temperature of the body can rise to the fever point without metabolism actually being increased, through interference with the loss from the body of the heat that is produced in normal metabolism, but in the vast majority of fevers there is an underlying increase in the basic metabolism. Another symptom related to fever is the rapid wasting-away of the body. Obviously, anyone consuming material rapidly must suffer bodily wastage unless he replaces the material with equal rapidity; but in most fevers food consumption is slight or absent. Accompanying fever are such symptoms as the rapid heart rate mentioned earlier, a hot, dry skin, headache, and the general feeling of ill-being known as *malaise*. In cases where the disease takes the form of decreased metabolism there is usually a lowering of body temperature, accompanied by feelings of lassitude and slowed heart action.

Symptoms Due to Alteration in the Character of Metabolism are of so many kinds that only a few can be mentioned. The symptoms of many nervous diseases come under this head, as do symptoms of such diseases as diabetes, to be spoken of shortly. It is probable that the various aches and pains which used to be called rheumatism are symptoms belonging to this category and indicating that the character of the metabolism in some or all of the cells of the body is departing from normality. Numerous symptoms traceable to deficiency in diet in respect to vitamins (Chap. X) also come under this head.

Impaired Hormone Control. — In Chapter XVI, in which chemical correlation was considered, the normal action of some of the hormones was described, and in connection with the description it was pointed out that disturbances in hormone production could not fail to bring about alterations in the metabolic activities of some or all of the cells of the body. Diseases of this character are unfortunately fairly prevalent. They are difficult to deal with because up to the present time almost nothing is known as to the underlying cause of impairment of hormone production. It is known that hormone manufacturing glands become either under-active or over-active, but why the glands should thus depart from their usual degree of activity, or what regulates that activity in the first place, is for the most part unknown. Evidently there is here a great field for further biological and medical investigation. To illustrate how disease is caused by impaired hormone control some examples are cited in paragraphs below.

Under-Activity of the Thyroid. — Sometimes it happens in individuals that the thyroid gland becomes impaired and produces less than the normal amount of thyroxin; the result is to depress the basic metabolism and for the individual to show a series of symptoms which are the direct consequence of this depression; among these symptoms may be mentioned a diminished utilization of food. Obviously, if there is less metabolism less food is required. Since the individual is quite likely to eat at about the usual rate, he is almost sure to deposit the surplus in his body in the form of fat. It is perhaps not going too far to say that in general persons with a tendency to obesity are persons in whom the thyroid gland tends to be slightly less active than normal.

Another symptom which displays itself, particularly where the deficiency of thyroxin is marked, is a decrease in the efficiency of the nervous system. Nervous and intellectual sluggishness are evident, in severe cases being so pronounced as to approach imbecility. There are several human strains known in which the thyroid gland is

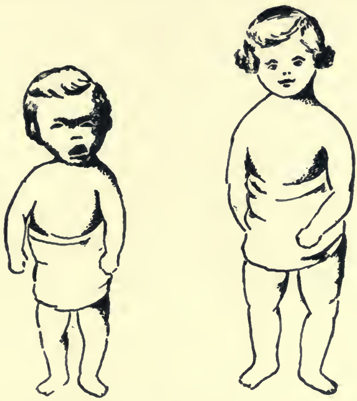


Fig. 46. — Drawing from a photograph to show the appearance of child, 23 months old, with deficient thyroid, and the same child after administration of sheep's thyroid for 11 months.

hereditarily either seriously defective or wholly inactive. Children inheriting this deficiency are doomed from birth to partial or complete idiocy if nature is allowed to take its course. One of the striking medical triumphs of the latter part of the last century was the discovery that extracts of the thyroid gland of meat animals could be administered as a part of the diet to persons with deficient thyroid, and that the body would thus obtain enough of the hormone for its requirements. Complete cures have been and are being wrought thus in cases in which deficient thyroid is the only serious abnormality (Fig. 46).

Over-Activity of the Thyroid. — The reverse change in the thyroid may also take place and excessive amounts of secretion be produced. When this happens the general level of basic metabolism is raised, the symptoms exhibited being those resulting from increased metabolism. Increased food supplies are naturally required to carry on the heightened metabolism and sufferers from this condition are invariably exceptionally hearty eaters, notwithstanding which they are usually emaciated. The increased metabolism of the nerve-cells has, as would be expected, the contrary effect to the lowering of metabolism, the nervous processes are speeded up. Unfortunately, this does not bring about, as one might expect, a corresponding improvement in intellectual power. On the contrary, the result is a rather marked irritability, together with a tendency to instability of disposition which in severe cases amounts to mental derangement. It is evident that efficient nervous functioning requires that the basic metabolism of the nerve-cells be pitched on neither too low nor too high a scale. The quality of operation of the nervous mechanism is not determined by the rate at which it works but by the underlying degree of excellence of the apparatus itself.

Pituitary Gland Impairment. — There is a disease from which adult human beings sometimes suffer, in which various bones *resume* growth after having attained the normal adult condition. One bone that is commonly affected is the lower jaw. The patient first becomes aware that something is wrong by observing that his teeth no longer meet, that his lower jaw has grown to an extent sufficient to throw the lower teeth out of alignment with those of the upper jaw. The bones of the extremities may also resume growth, enlarged knuckle-joints and enlarged finger- and toe-joints being a result. Study of this disease shows that it is due to an increase in the activity of the pituitary body.

Diabetes. — This disease, which results from deficiency of the pancreatic hormone, is unfortunately common and appears to become more so. A vast amount of study has been devoted to it of recent years, and while no important progress has been made in preventing the hormone-manufacturing cells from going wrong or in replacing the deficient hormone, as is done when the thyroid glands fail to function, by administering material in the food, it has been found possible in many cases to deal successfully with the disease through a strict regulation of the diet. Since the effect of pancreatic hormone deficiency is to impair the ability of the tissues to use sugar, the method of treatment is obviously through regulating the diet so that the patient can get along without sugar. Up to the present, this is the direction in which progress has been made.

Impaired Nervous Control. — When one considers the complexity of the adjustor mechanism in the higher animals, together with the dependence of functional metabolism on the operation of this mechanism, the possibilities of disturbances in metabolism arising through nervous impairments are seen to be manifold. The impairment of nervous control can be attributed, in general, to one of two things, actual destruction of nervous tissue whereby nerve pathways are broken, or alterations in the metabolism within the nerve cells whereby they are caused to function in some abnormal manner.

Impairments Due to Tissue Destruction. — There are various diseases whose symptoms are the direct result of the destruction of nervous tissues. Among these is a disease previously mentioned, locomotor ataxia, more correctly called *tabes,* in which there is destruction of nerve tissue in the lower end of the spinal cord with consequent interruption of important sensory pathways from the legs. In the disease infantile paralysis, there is also a destruction of nerve tissue within the spinal cord, in this case affecting motor nerve-cells and thus causing muscular paralysis. In apoplexy there is injury to that part of the brain whence proceed the nervous impulses by which volitional muscular acts are carried on, an injury which again results in paralysis.

Impairment Due to Alteration of Normal Metabolism. — The higher brain functions, namely, association, volition, appreciation (as of art or literature), the faculty of reason, which is the highest development of the property of association, the feelings or emotions, the condition of consciousness or awareness, all accompany and in all probability depend on the functional metabolism in the higher nerve-cells. It follows that alterations in this metabolism are likely to result in perversions of these high mental functions. On account of the delicacy and complexity of the nervous interactions which constitute mental functioning, a slight disturbance of metabolism may and frequently does lead to marked departure from normal mental and emotional activity, and such disturbance is likely to manifest itself in turn in alterations in bodily functioning. Conditions in which this situation prevails to a marked degree are familiar to medical practitioners and are grouped under the general name of *hysteria*. — The chief characteristics of this condition are: first an enhancement of the bodily effects of emotion, so that violent outbursts of joy, sorrow, or anger result from trivial causes; and second a loss of the sense of proportion in making associations, so that factors which to a normal individual are either of minor importance or are deemed unworthy of inclusion in the associative process are exaggerated by the hysteric to become of supreme importance. When one recalls that the use of associated memory as a guide to conduct will evidently cause those associations which appear most important to take first place in the regulation of conduct, it is clear that this exaggeration of minor or unworthy associations, with the accompanying minimizing of really important memories, is bound to lead to departures from normal behavior.

Neurasthenia is the technical name of a condition commonly called nervous prostration. It is another condition due to impairment of metabolism in the nervous system, usually directly traceable to over-fatigue, protracted over-work, or continuous worry. It is characterized by bodily restlessness, by inability to obtain refreshment in sleep, and by undue attention to self. Neurasthenics usually think about themselves and their bodily condition to the exclusion of more interesting and more important topics.

Direct Treatment of Nervous Disorders. — Inasmuch as the physiological basis of nervous disorders lies in disturbed metabolism of nerve-cells, the logical method of treatment is obviously to take such measures as will remove the cause of disturbance. From what has been said in previous chapters it will be clear to the student that this is a very difficult matter, owing to our imperfect knowledge of the normal functioning of the cells of the central nervous system. But wherever the disturbing cause can be found and removed, recovery occurs. We may, therefore, confidently expect that with advancing knowledge of the nervous system will come the discovery of procedures appropriate to the treatment of diseases of this type.

Treatment of Nervous Disorders by Psychotherapy. — In hysteria, and to a slightly less extent in neurasthenia, both the intellectual and emotional states of the patient are abnormal, chiefly in the direction of the exaggeration of ideas or emotional manifestations, which in their proper perspective are harmless enough, but when dominant are both undesirable and unwholesome. Associated memories are established as has been emphasized previously, in the central nervous systems as a result of the inpouring of sensory stimuli through the organs of sense. It follows, therefore, that they may be in part controlled by controlling the sensory stimuli to which the patient is subjected.

The trained physician understands this fully, and while seeking the real underlying cause of disturbed nerve-cell metabolism in order to correct it, also takes pains to prescribe effectively to the patient such agreeable and interesting sensory stimulations as will divert his mind from the unwholesome associations and replace them with new and favorable ones.

Many well-intentioned but ignorant cults have been founded on an imperfect understanding of this method of treatment. They, of course, achieve a certain measure of success in dealing with nervous disorders by purely psychic means, but equally, of course, do not remedy the actual cause. They constitute, moreover, a public menace in many instances, because they carry their method of treatment over to diseases of all sorts where the psychopathic element is either entirely lacking or of negligible importance, as, for example, smallpox or diphtheria.

Malnutrition. — By malnutrition is meant any failure of protoplasm to obtain the materials which are essential to its successful metabolism. The most obvious condition of this sort is simple starvation, which is not ordinarily included among diseases. Strictly speaking, diseases of malnutrition are due to lack of one or several of the particular items which the cells require. For example, growing children are sometimes insufficiently supplied with lime salts, or it may be that for some obscure reason their protoplasm is unable to utilize lime salts even when supplied in abundance. In either case, normal bone growth is impossible, giving rise to diseases of which *rickets* is a type, with excessively bowed legs and other indications that the bones have not obtained sufficient lime. In Chapter X, interesting food accessories known as vitamins are mentioned. There are a number of diseases known which are due to scarcity of these in the diet. It may happen that the mechanism for transferring oxygen (see Chap. XI) becomes inefficient through the failure of the body to manufacture adequate amounts of hemaglobin to provide for the required transport of oxygen. The disease *anemia* is an expression of this condition.

Poisoning. — By far the greater number of ills to which flesh is heir are the result of direct interference with the metabolism of protoplasm through the agency of particular chemical substances which, because they affect protoplasm in this manner, are known as poisons. Poisonous substances are very common in nature, it being a curious feature of plant metabolism that a great many kinds of plants produce and store within some part of their structure chemical substances which are harmful to animal protoplasm. There are also a number of inorganic or mineral compounds known that are poisonous to protoplasm. Where the bodily disturbance is due to the taking into the stomach of a known poisonous substance, the condition is referred to as acute poisoning, and is not ordinarily considered to be a disease. But if the poison is introduced into the body as part of supposedly good food, or is produced by any means within the body itself, it then becomes a cause of disease.

Disease Due to Mechanical Injury. — The effect of mechanical injury, or of a burn, is to destroy some living tissue. Obviously, the more severe the injury or the burn the more such tissue is destroyed. Destroyed tissue is in part sloughed off at the surface of the body, and in part taken up and absorbed within the body. One of the important medical discoveries of the Great War was that the products absorbed into the body from injured tissues are highly poisonous. Surgeons have long known of a condition of collapse following severe injury, to which they have given the name " wound shock. " It is now known that the symptoms of wound shock are due to the poisoning of the body by the absorption of the decomposition products of the injured tissues. It has also been shown that the prolonged suffering and slowness of recovery in cases of severe burns are due to the absorption into the body of poisonous products from the burned areas. Great advances in treatment promptly followed these discoveries, since all that is necessary to prevent the poisoning is to make sure that none of these poisonous products can be absorbed into the system. The surgeon does this by carefully removing all injured tissue which might decompose and become a source of poison.

SECTION 5

ASSOCIATION OF ORGANISMS

CHAPTER XVIII

ASSOCIATION OF ORGANISMS

Nature of Association. — The number of individuals composing a species remains practically the same from century to century. There may be a marked increase when conditions are unusually favorable, and again there may be lean years when there is an equally sharp decline, but over a long period of years the average is fairly uniform. Furthermore, the number of young produced by the members of the species is greatly in excess of those arriving at maturity (see Chaps. XXVI and XXXV). Some of the young are driven into unfavorable situations, others are destroyed by enemies, and always there is a fierce struggle for food where only a comparative few emerge as conquerors. In this combat the individuals of most species of different kinds of animals are wholly self-reliant, depending upon their own strength and keenness of sense to escape destruction. But while there are many species where "life is a continuous free fight," it can not be denied that among higher animals especially there are associations of individuals where the strong protect the weak and display a spirit of coöperation and mutual aid akin to that in man. Again, there are many kinds of animals and plants in which one individual enters into mutually advantageous relations with another animal or plant of a totally different type. And, finally, there are many species which in the keen struggle for life have taken up positions on or in the bodies of other organisms from which they derive their nourishment. The association of organisms is therefore a broad, comprehensive term, including the union of living things of the same or different species, where the results are of most varied character.

Family Groups, Herds. — The simplest example of mutual aid appears in the case of *family groups* where, as in the case of swans, geese, certain apes, antelopes, elephants, and many other species, a keen-sensed parent leads and protects the offspring of different ages.

In the *herd* a few or many family groups become merged into a larger association of individuals, which may number thousands. Examples are found among wild sheep, deer, and several species of antelope, where a female may lead, or among several other kinds of antelopes and bison where one or more powerful males act as leaders. In this case also the strong lead the weak to the feeding grounds and protect them against the attacks of enemies.

Bee Colonies. — Beyond this point several series of examples could be cited which illustrate an increasing coöperation and division of labor, culminating in complex social organizations such as those of the honey bee, ant, and man. In the bumble bee for instance, we find a type of communal life advanced a stage beyond that of the family group or herd. In the spring a female, that has passed the winter in some sheltered nook, emerges, selects a site for a nest, constructs cups for a mixture of honey and pollen, that she collects, and on this raises a brood of from three to twenty young. These become immature females or workers that henceforth care for other young, enlarge the nest and leave the queen mother the sole duty of producing the family. Males appear in the fall together with certain females, which become queens the following year, while all the others die with the coming of winter.

The honey bee community, in a general way, resembles that of the bumble bee. A queen heads the colony, comprising many thousands of immature females or workers, and attends to the egg-laying process that takes place at the annual rate of a million eggs for several years. The workers attend to all of the remaining duties of the colony, caring for the young, constructing comb, gathering honey, evaporating it to the proper consistency, ventilating the hive, warding off enemies, and otherwise playing a part in one of the phases of animal activity most absorbingly interesting from a human standpoint.

Ants. — Among the ants the social organization reaches the highest development in one respect, for there is not only a division of labor among the individuals of the colony but they are structurally fitted to perform certain duties and only these. As in the bees, a queen heads the colony, in which the members are winged males and females, destined to leave the nest and found new colonies, and large and small sized workers and soldiers. The workers construct the nest, collect the food, that varies widely in character among the hundreds of species, while the soldiers, as is to be expected, defend the home against the attacks of invaders, chiefly insects. Each class or caste is thus indispensible and coöperates with the others to form a unit of a very high type.

A Comparison, Ant and Man. — Among the species of animals that form mutual benefit associations, the ants are the only ones thus far mentioned whose special duties are correlated with marked structural peculiarities. Yet it would be hazardous to claim for this reason that these insects represent a higher type of communal life than the bees. Both appear to indulge in equally varied activities, and it is certain that both lead eminently successful lives. Whatever may be the verdict in this case, it is evident that the social organization of man, with its complex division of labor and coöperation, is independent of any structural differences among its members. The plumber and the blacksmith are physically not different from the carpenter and bricklayer. Their activities, like those of all the other classes of workers, are a matter of training; and training rests upon high brain development. There is here the element of choice, or the power to direct the activities of the body along any one of several lines, whereas the ant and other lower animals are little more than dumb machines whose structure determines within narrow limits their lifetime duties.

Symbiosis. — The examples cited to illustrate coöperation and mutual aid have thus far been concerned with individuals of a single species. There are, however, many cases where one animal enters into a partnership of mutual benefit (*symbiosis*) with another totally different kind of animal, or one plant becomes associated with another plant, or a plant and animal may merge interests. In the lichens, for example, that incrust fences, old roofs and similar structures, two plants are in intimate union, a green one-celled alga and a fungus. It is assumed that nutritive products manufactured by the green plant are utilized by the fungus, which repays the debt by furnishing moisture and offering protection. Unicellular plants are also present in large numbers in many animals, such as the green hydra, sea anemones, and certain worms, where, it is believed, a beneficial interchange of food materials takes place.

Many species of ants feed upon a sweet liquid that issues from the body of certain aphids or plant lice, which are small insects feeding upon plant juices. In return the ant protects the aphid from enemies, transports it to new feeding grounds, or carries it underground, where food is provided. Several species of hermit crabs, living in the empty shells of snails, carry sea anemones attached to their houses (Fig. 47). The crab is protected by the stinging cells of the anemone. which enjoys a plenteous food supply in consequence of being carried about.

Commensalism, or Messmatism. — There are many examples of the association of two different species of organisms where one partner only derives a benefit.

For example, various species of sponges are provided with rather spacious canal systems through which a current of water is continually passing. These passages are frequently inhabited by several species of crabs and worms that, safe from attack, live upon floating nutritive material. The sponge gains nothing by the partnership; neither does it appear to suffer any inconvenience. The same one-sided benefit is enjoyed by many species of crabs that attach fragments of sponges, seaweeds, and

Fig. 47. — Hermit Crab in snail shell covered with sea anemones.

other organisms to the backs of their shells, and are thus so effectually concealed that they escape the attacks of many sharp-eyed enemies. Here again the advantage appears to be on the side of the crab. The small fishes that find a safe retreat among the stinging tentacles of jelly-fishes, the crabs and other organisms that are attached to the bodies of turtles, and the small animals that live in the shells of oysters, snails, and related species, are further examples of this widespread type of partnership.

Parasitism. — It is a very short step indeed from messmatism to parasitism. Let the crab, living as a messmate in the sponge, begin to feed upon the substance of the sponge and it becomes a parasite. Parasitism, therefore, is an association, with one member, the parasite, gaining its livelihood from the other, termed the host. Associations of this nature are exceedingly common. With animals, at least, it has been affirmed that every species, save the very smallest, serves as host for at least one species of parasite.

Many parasites, such as ticks, fleas, and leeches, live on the outer surface of the host, and are termed external parasites. Others living in the digestive tract, muscles, or blood stream are called internal parasites. Also, there are many species, such as the tapeworm and trichina, whose organization requires that they spend their entire existence in one or at most two or three hosts. These are permanent parasites. Finally, there are many others, such as the flea and mosquito, that move freely from one host to another and are classed as temporary parasites.

Parasitic Plants. — There are also many plants that are parasitic upon other plants or animals. Among the higher types the best known example is probably the mistletoe, species of which attack forest and cultivated trees. It is a bushy shrub (Fig. 48) with yellowish green leaves, and is attached to the host by means of specially modified roots which are believed merely to absorb water and dissolved salts. These substances are then combined into more complex compounds by the activity of the parasite itself.

In the dodders, a group of plants related to the morning glory, and attacking many kinds of herbs and low shrubs, the leaves are absent and the stem appears like a twining yellow or red thread (Fig. 49). At frequent intervals the stems and branches are provided with roots which absorb from the host plant the water, sugar, and mineral salts necessary for life of the parasite. When starved the dodder may form chlorophyll and manufacture some food, but under favorable conditions it is wholly parasitic. Other examples of parasitism among the lower plants are described in later chapters in connection with the subject of disease.

ANIMAL PARASITES. — Parasitic species have been found to occur in every one of the larger animal groups

FIG. 48.— Mistletoe parasitic on oak.

with the exception of the sponges and that to which the starfishes, sea urchins and their relatives belong. In some of these groups the list of such animals is comparatively small, while in others a large number have assumed this mode of existence.

Among the unicellular species, there are thousands that are parasites, and, although the great majority infest the lower animals, there are several that produce very serious human disorders. Various diseases of the digestive tract, relapsing fever, sleeping sickness, and malaria, are caused by one-celled parasites. Among the flatworms also there are several hundred parasitic species familiarly known as tapeworms (Fig. 50) and flukes. The flukes may be either internal or external parasites; the tapeworms invariably inhabit the digestive tract. Many species of thread worms (Fig. 51) are likewise parasitic,

Fig. 49. — Dodder parasitic on cockle-burr.

and while a few infest plants the greater number live in animals and are in several cases responsible for certain human diseases. Lice, fleas, and ticks are also dreaded pests in many instances, especially owing to the fact that they carry disease-producing organisms.

STRUCTURE OF PARASITES. — It is very certain that all existing parasites have descended from free-living, non-parasitic ancestors. Where the parasitic habit has been of comparatively short duration, or where the activities

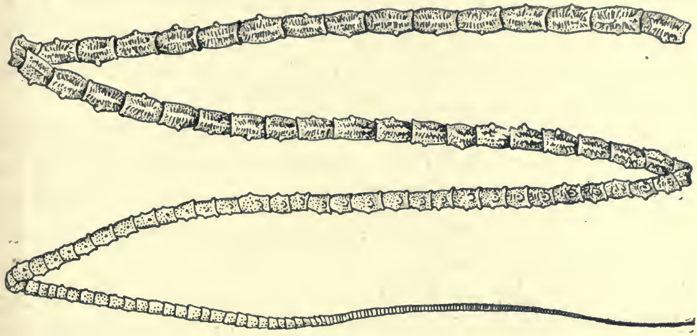


FIG. 50. — Adult tape-worm, *Multiceps multiceps*, from the intestine of the dog. (Natural size; after Hall.)

of the parasite are confined to the skin of the host, the effects on the parasite of such a mode of life are not especially marked. The mosquito, for example, flies from host to host, and possesses organs of locomotion and sensation of the usual insect type. On the other hand there are numerous types that are wholly dependent upon one host, and these are often so highly modified that their relationships are difficult to determine. In the Sacculina, an animal related to the barnacles and parasitic on a crab, the body is scarcely more than a bag filled with eggs and attached to a root-like absorbing system penetrating the tissues of the host. In the tapeworms, that cling to the wall of the digestive tract and absorb digested materials through their body wall, the organs of locomotion and digestion have entirely disappeared. In the

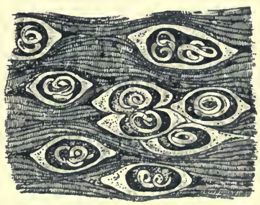


FIG. 51. — Encapsuled trichinae in trunk muscle of pig. (Greatly magnified; after Braun.) From Kellogg and Doane, *Econ. Zool.*

greater number of species the effects of parasitism are not so marked, yet in practically every case there are special clinging organs — hooks, spines, claws, and suckers — and an unusual development of eggs, as there are great difficulties in the way of young reaching a new host. One species of tapeworm, for example, lays 80,000,000 eggs a year, and it is probable that not more than one or two offspring will gain another host.

Degeneration. — The term degeneration often implies in the popular mind that animals which have lost one or more organs as a result of parasitism are unfit; that an active organism with delicate senses, relatively great strength, and powerful organs of offense and defense is better fitted for life's battle than a parasite. According to such a belief a hornet or a lion is more successful in the struggle for existence than a tapeworm or a hookworm. Such, however, is not the case. The very fact that these species exist is sufficient evidence that each is well adapted for a particular mode of life. In one case stings and claws help to win the battle; in the other, suckers and a suitable absorbing system play an important part. In both cases the individuals leave offspring and the species persists. Biologically speaking, each is equally successful.

Life Histories. — The life histories of parasites are important from a scientific standpoint, and practically the successful treatment of many diseases depends upon a thorough knowledge of the development of the causative organism. In the case of most external parasites the problem is comparatively simple, but with many of the internal parasites, one or two immediate hosts must be inhabited before the adult stage is reached, and so the subject becomes complex. Two examples will serve to illustrate this fact: A tapeworm inhabits the dog. One of its eggs, that has passed from the host, and become attached to grass, is eaten by a rabbit. The tiny worm hatches in the intestines, bores its way into a blood vessel, and is carried to a position in some organ. Here it remains until the rabbit is eaten by a dog and the liberated worm attaches itself to the intestinal coat, grows, lays eggs and thus completes the cycle; in the hookworm, a small threadworm inhabiting the intestine of man, the eggs escape from the host, develop to a considerable degree in the ground, and the young worms then bore through the skin on the soles of the feet of barefooted laborers. Entering the blood, they are transported to the lungs, where they bore their way through the wall, make their way to the throat, and are swallowed. In the intestine they adhere by hooks, and complete the cycle of development.

Effects of Parasite on Host. — In the case of an animal whose skin is pierced by the proboscis of a mosquito the injury and loss of body substance is unimportant. Even when a parasite, such as a tapeworm, is a permanent resident, the injury due to its attachment and absorption of nutritive materials is not of any great importance. It may happen, however, that the slight break in the skin or wall of the digestive tract or in the outer surface of plants may serve as a point of entry for other parasites, such as bacteria, molds, and various one-celled animals, whose effects may be of a most serious character. In some cases the secondary parasites may be carried in the proboscis of a fly, flea, or mosquito and, passing through the skin when this is pierced, cause plague, sleeping sickness, malaria, and many other terrible scourges. Also there are many known cases of parasites occurring in such great numbers that the blood vessels of the host have become clogged to a serious and even fatal extent. Finally, there are many parasites, both plant and animal, whose wastes, liberated in the body of the host, cause some of the most serious diseases afflicting man and the domesticated animals.

CHAPTER XIX

DISEASES OF PLANTS

THE ECONOMIC IMPORTANCE OF PLANT DISEASE can hardly be overstated, for it is evident that the lessening or prevention of crops is a very serious matter. The United States Department of Agriculture estimates the loss by plant disease in the year 1919 as follows: 190,000,000 bushels of wheat, 200,000,000 bushels of corn, 86,000,000 bushels of potatoes, 18,000,000 bushels of apples, 1,742,000 bales of cotton.

Rust alone, in some years, has entailed the loss of 200,000,000 bushels of wheat, while scab "caused in 1919 the loss of nearly 60,000,000 bushels of wheat."

THE CAUSES OF DISEASE may be either lifeless or living; they may be external to the plant or within it; they may consist in unfavorable features of the environment externally or the interference of other organisms. Only the second type falls properly under the head of "associations of organisms"; but because there are other causes of disease than parasites, we shall also consider examples of disease due either (1) to unsuitable environment or (2) to internal causes.

UNSUITABLE ENVIRONMENT

THE SOIL may be of such composition that it is said to be alkaline or acid. In certain areas in the far west the presence of unusual quantities of sodium or calcium salts makes the soil alkaline; whereas, on the other hand, especially in wet places, the soil may be acid because of the presence in it, or in its solutions, of acids formed in the course of the decay of organic waste. Excessively hard soil may cause disease because it interferes mechanically with the growth of roots. If the soil is excessively wet, its proper aeration is prevented. If it is too dry, the plant suffers from lack of water. These produce abnormal or diseased conditions in the plant, disturbing normal physiological activities, resulting in unusual and unhealthy appearance and lessened crop production. All of these difficulties — alkalinity, acidity, as well as mechanical defects — may be alleviated by tillage.

Tillage. — In many parts of our country the American farmer, while liberal in the use of water and fertilizer, gives insufficient attention to the physical condition of the soil. Deep plowing, for example, which keeps down weeds and exposes fresh surfaces to the action of air and light, also brings toward the surface fresh parts of the soil from which food materials may be the more readily extracted.

Polluted Air. — Certain air pollutions may cause chemical injury and disease in plants. In the air of cities, or in the vicinity of industrial plants in which coal or ore containing sulphur is burned or roasted, sulphurous vapors are invariably present. These cause disease by interfering with the normal functions of the plant, especially those connected with food manufacture (photosynthesis) (Fig. 52). Pollution of the air by solid particles, whether of soot or dust from roads or such works as cement manufacturing plants, may cause such impairment of the clarity of the air as greatly to reduce the amount of light reaching the surface of the earth, or the solid particles may form an opaque coating over the leaves and so prevent the absorption of light by the chlorophyll-containing cells. In either event, the amount of food manufactured may be greatly reduced.

Moist and Dry Air. — The humidity of the air may sometimes by sudden change cause disease, not always recognized as to its origin. Sudden dryness of the air, such as sometimes accompanies high wind, may " burn " foliage, especially when it is young. On the other hand, sudden increase of humidity may cause such a change in the cells and tissues that eruptions known as "emergences" or "intumescences" may develop. These emergences are outbreaks, through the epidermis or bark, of soft underlying tissues in which the pressures rise over-rapidly by reason of a sudden check to evaporation.

FIG. 52. — The Effect of Sulphur Dioxide Fumes from a smelter upon the forest two miles away

HEAT AND COLD, LIGHT AND SHADE. — Prolonged exposure to unfavorable temperatures may produce disease, showing itself mainly in changes in color of the foliage, though extreme cases may exhibit injury as serious as untimely leaf-fall. Insufficient or excessive light will also show itself in abnormal color of the foliage; and very insufficient light, as is well known, will be followed by fall of the leaves.

INTERNAL CAUSES

It must be admitted, at least for the present, that the so-called internal, or physiological, causes of disease are accepted at all only because other and external cause has not been recognized. Thus the malady known as "little peach," and another called "sour sap," are undoubtedly due to physiological disturbance; but what may be the reason for the physiological disturbance is not yet clear.

FASCIATION, which constitutes a deformity, is due to plants or plant parts growing so rapidly and so close together that they become more or less merged or fused. In consequence, a wide or band-like stalk of several or many dandelion heads grown together carries at the top an oval instead of a circular head of blossoms. Similarly, the California poppy, particularly in a season of abundant rain and moderate temperatures, forms such fusions, several flowers being borne at the tip of band-like merged stalks. The suckers which spring up around the bodies of trees or shrubs may be similarly merged into band-like structures. These occasional fusions or fasciations are similar to those which take place in succeeding generations of plants under cultivation. In all such cases such fusions or mergings seem to be due to failure of the plant in one or more of its correlations, growth in one direction becoming unduly rapid or unduly slow, so that the symmetry of the plant is not maintained and deformities arise which reveal the diseased condition.

THE LIVING CAUSES OF DISEASE: INFECTIONS. — In considering the living causes of disease, or what may be called infections, one should distinguish at once between the mechanical injury caused by the invading organism and the disturbance of the normal physiological activity of the host. For example, one may puncture a leaf or twig with an instrument of the same size as the ovipositor of a "gall fly" and produce a wound which in ordinary circumstances will promptly heal; but if a similar wound is produced by the fly, which deposits an egg at the bottom of the puncture, it will not promptly heal. A gall will grow around the developing grub. The distinction between mechanical injury and the subsequent reactions of the host to continuing stimulation of the invading organism may be illustrated by the following examples:

ANIMAL PARASITES

Worms. — The commonest worms to cause disease in plants are thread worms or nematodes. These attack the roots or other parts of their characteristic host plants, e.g., potatoes, flower bulbs, etc., entering the adjoining tissues and being covered by enlargements often attaining considerable size. In these abnormal growths, which are sometimes called galls, these animals reach maturity at the expense of the host plant which feeds and shelters them. These worms not only rob the host of food, but may also poison it to a greater or less extent by their excretions.

Fig. 53. — Leaf Gall on California White Oak.
Kellogg, *American Insects.*

Flies of various sorts, particularly those called gall flies, are known to cause the formation of leaf- and stem-galls, the structure and composition of which, as well as their appearance, are often very striking. Thus on a certain species of oak the large balls which form on the twigs — sometimes called oak balls instead of oak galls — are common. These spherical enlargements or outgrowths form around grubs which hatch out from eggs deposited in the young tender bark of growing twigs in the spring. Galls, in addition to consisting of a large amount of extremely light spongy tissue, contain also a larger proportion of tannin than other parts of the oak, and for this reason mature galls have been used for centuries as a source of ink.

Other species of insects cause the formation of galls on leaves of oak (Fig. 53) and other plants. The same oak-leaf may form two or more different kinds of gall. It is obvious from this fact that the diseased structures called galls take on a form which is due not only to the host but to the species of insect depositing the egg which is to hatch into the parasitic grub. We have here, then, a very interesting demonstration of the specific action of the different agents of disease acting on the same organism, the host reacting in characteristic though different fashion to the attacks of the different individual organisms. One may often see as many as half a dozen different kinds of gall on the same white oak leaf, due to the invasion of this leaf by as many different species of gall-flies.

The formation of galls with their characteristically diverse shapes, the tissues of various sorts composing these galls, the substances which act as stimuli resulting in these overgrowths, the nature of the association, all these are subjects of extreme interest.

Pine Galls. — In this group may be mentioned another peculiar gall, formed without mechanical injury, but due to the deposit of its eggs by a fly at the base of and between the needles of the Monterey pine as these come out in the spring. The grubs hatch as the very young leaves begin to grow out into the light from the sheath which encloses them. There is no wound, there is mere contact between grub and tender leaf-base. The leaves grow to only half or a third their normal length, but are two or three times the normal thickness at the base. These short thick leaves give to Monterey pine twigs a very curious appearance when there is extensive galling. One of the effects of this in the case of Monterey pines is the failure of the branch, and often of the whole tree, to make the usual amount of wood; hence it is seen that the effect of this disease is not limited to the immediate point of injury.

THRIPS, "RED SPIDER." — Pear and other fruit trees are subject to attack by small insects such as thrips, and by "red spider," etc., which cause true disease and not simple mechanical injury, for the trees which these insects attack yield less than the normal amount of fruit.

PLANT PARASITES

FUNGI. — The fungi form a very large division of the vegetable kingdom. They have in common the one quality of dependence, they cannot make their own food. Hence they must provide themselves with food, either by robbing other organisms or by living on the products or remains of other organisms. The fungi are divided according to their food habits into saprophytic and parasitic, the former living on dead material, the latter on living plants or animals. Certain smaller fungi are the immediate cause of disease in plants, while the larger fungi, known as mushrooms and toadstools, are mainly saprophytic. Fungi causing plant disease are nearly all of minute size. They are commonly spoken of as rusts, mildews, rots, and smuts.

NATURE OF DISEASES DUE TO FUNGI. — Fungi bring about their characteristic disturbances of the normal life of their host plants by abstracting from the host the food which they require, and by the mechanical or chemical injury which they do in addition. Thus they may grow superficially in and upon the tissues of the host, or they may penetrate very deeply. In other words, they may cause deformities by purely mechanical means, pushing the tissues of the host apart, although in almost every instance it is evident that the excretions and secretions of the fungi exert a poisonous influence on the adjacent or even over remote parts of the plant. This may be illustrated in the following specific diseases:

The Potato Fungus, the Vine Mildew, the Onion Mold all grow in the tissues of their host, push the cells of the leaf apart and injure or kill the cells, presently emerging by breaking the epidermis and sending out through the crack their reproductive bodies.

The Rusts. — The rusts of wheat and many other plants are due to minute fungi, the spores of which either infect the grains or are scattered from the parent plant and subsequently infect the young plants by entering the leaf through the stomata, in either case attacking mainly the tissue of the leaf and thereby interfering with the processes of food manufacture upon which the profitable cultivation of the plant must depend. Another rust is one which forms the cedar balls on the juniper or cedar trees of the eastern half of the continent. A similar one is to be found on the leaves of the wild mallow of the Pacific Coast.

The Mildews. — Another group of fungous diseases is known as the mildews. The one with which people generally are most familiar occurs on the foliage of the rose. The varieties of rose differ very considerably among themselves in their susceptibility to mildew. They are all more or less susceptible, however, according to the condition of the weather. It is perfectly possible to control this disease by the simple expedient of spraying. That the mildews cause very real injury is proved by observation of the behavior of dahlias. These may be blooming abundantly in the garden; but when extensively attacked by mildew on their leaves, they cease to bloom and remain sterile for the rest of the season.

It is not easy to see why or how the influence of the parasite on blooming can be so direct as it appears to be.

Smuts, of which corn-smut is probably the most familiar, cause a great deal of damage among cultivated plants. The blackness or smuttiness is due to the formation of black one-celled reproductive bodies (spores) which are thrust out through the epidermis of the infected part.

Bacterial Infection of plants is now recognized to be the cause of certain common maladies, some of which are of great economic importance. Thus pear blight, a bacterial infection of the inner bark, causes the flowers to abort so that the quantity of fruit formed may be very seriously reduced. Again, so-called wilt in cucumbers, etc., may completely destroy a valuable crop. This disease is due to the infection of the water-conducting tissues by a certain species of bacteria. Alfalfa and other plants develop at the top of the root or base of the stem enlargements known as crown-galls. These also are due to bacterial infection and, because of the nature of the tissue growths following such infections, comparisons have been made between these growths and their infecting cause with cancer in the human body. It cannot be denied that there are certain resemblances in the behavior of the cells of infected tissue in crown-galls with the growths taking place in cancer.

Root Tubercles. — The roots of leguminous plants, such as peas, beans, clovers, and alfalfa, generally form enlargements known as tubercles or nodules. Examination of these shows that they also are the seat of bacterial infection. The infection takes place through the root-hairs; the infecting bacteria traversing the root-hair and penetrating into the outer portion of the root produce such an irritation that an outgrowth, in some cases resembling a lateral root, is formed. This consists mainly of thin-walled cells in which the infecting bacteria multiply very rapidly. The formation of these tubercles is seen, therefore, to be the result of infection. It is a departure from the normal, and so far as the habits of the plant are concerned, it is a disease.

In this instance, however, the formation of the tubercles resulting from bacterial infection in these plants is of great benefit, for the bacteria in these tubercles fix the free nitrogen of the air, thus adding to the soil nitrogenous compounds of the utmost value to the host plant and to other species, wild or cultivated. While the tubercles on the roots of leguminous plants are a disease, they benefit a great variety of other organisms, and presumably — directly or indirectly — the leguminous plants themselves. In this respect we have a very unusual condition, for disease is naturally considered to be quite the reverse of advantageous both to the individual and to the community.

Treatment of Disease in Plants. — The methods of dealing with disease in plants fall into the same general classes as the methods employed for human beings namely, prevention, medical and surgical treatment. Thus the instruction of the public in the means of maintaining its own health, and the health of the living organisms employed by man for his purposes, are both receiving the most skillful attention. Just as the concern with public health has resulted in preventing or greatly reducing the occurrence of typhoid fever, so the intelligent study of the conditions of plant diseases enables us to control them through preventive measures much more certainly than by treatment when they break out.

The Prevention of Disease. — The means of prevention, in addition to those which may be spoken of as general hygiene, consist specifically in the application of sprays and dusts to individual plants, thus attempting to prevent infection. Such treatment is obviously limited to those parts of the plant above ground and so protected by water-proofed epidermis that the poisonous sprays or dusts will not injure the tissue of the host, while they poison the bacteria, fungi, or insects which might otherwise infect and infest the larger plant. The application of dusts by blowing on foliage and bark is designed to interfere mechanically as well as chemically with the invasion of host by parasite. Sprays differ from dusts mainly in the manner of application, for though they also are blown upon the foliage and bark, they are suspensions or solutions in water, and the poisonous material left by evaporation acts both mechanically and chemically upon the invading organisms.

The Medical Treatment of Disease with the object of curing also consists in the application of sprays and dusts designed to offer mechanical inconvenience to parasites or to exert a poisonous influence upon them. Thus Bordeaux mixture, a spray, may serve not only to prevent infections but may also be used in the treatment of mildews or other fungi. Sprayed upon the leaves of roses, vines, etc., attacks of mildew may be cured entirely by this means.

The Surgical Treatment of Disease. — In case of invasion below the surface of the host, surgical treatment must commonly be resorted to in plants, and in the more serious cases amputation cannot be avoided. In order to prevent the spread of infection from one part to another, the same precautions must be employed in sterilizing or destroying all infected tissues and in sterilizing the instruments used in operation. In fact, with the modifications required by the differences in the organisms, the same principles of hygiene control the treatment of plants as of animals. It is thus evident that the practice of "tree surgery" involves great care in the treatment of living tissue and in the handling of instruments (sterilization). Where care and skill are lacking the result can entail only pecuniary and other loss.

Summary. — The causes and treatment of disease are essentially similar in plants and animals. Loss from unfavorable weather or other environmental conditions, lack of proper coördination in the vital processes of the organism, attack and invasion by other organisms, can be greatly reduced if not entirely prevented by general hygiene and by medicaments which may also be employed in treating individual cases of disease. In extreme cases surgery must be resorted to for removing a diseased part which might if neglected involve the whole. Insects, fungi, and bacteria are the principal causes of plant, as well as of animal, disease.

CHAPTER XX

DISEASES DUE TO HARMFUL ORGANISMS

Some Kinds of Organisms Produce Poisons in the natural course of their metabolic activities. Among the minute organisms that lead parasitic lives on or within the bodies of larger organisms are numerous varieties of which this is true. These are injurious to their hosts. Others seem not to affect their hosts one way or another. The case presented by organisms parasitic on and producing disease in plants forms the subject matter of much of the last chapter. Here the discussion will be restricted to injury produced in *animals* by microörganisms.

The Ways in Which Microörganisms Cause Harm in Animals are principally three. They may grow and multiply in food, generating poisons and so making it dangerous. They may cause excessive putrefaction of the intestinal contents, with resulting ill effects to the body. Or they may grow on or within the body itself, poisoning it directly.

Food Poisoning. — From time immemorial individuals, and sometimes whole communities, have been stricken with disease as the result of eating spoiled food. Among striking instances are the wide-spread poisonings which have occurred in Europe from time to time, due to a fungous growth on rye which contains a poison known as ergot. When this rye was ground into flour and made into bread, whole communities that consumed the bread became ill and many died.

Decomposition of protein foods by putrefactive bacteria in the presence of too little oxygen sometimes gives rise to substances commonly called ptomains which are poisonous to man if taken in food. At the present time considerable prominence is being given to a kind of food poisoning known as *botulism,* in which canned food becomes poisonous through the growth within it of microorganisms whose waste products are injurious to the human body.

Prevention of Botulism. — The organisms of botulism produce spores (see Chap. XXV) which are very resistant to heat. If any of these spores happen to be present upon spinach or string beans or other vegetables, some of them may escape destruction during the canning process and may therefore be able to develop into active organisms and multiply enormously within the can. Both the active organisms and the poisons which they produce are destroyed at the temperature of boiling water, so that if the food is heated to the boiling point shortly before being eaten it cannot possibly produce botulism poisoning.

Intestinal Putrefaction. — It has long been known that the intestinal tract in the higher animals harbors many organisms. For the most part these are minute, being either plant forms, bacteria, or one-celled animals, protozoa. Indigestible and undigested constituents of the food afford highly favorable nutritive material for them, so they thrive and multiply. For the most part their presence makes no difference, so far as we know, to the organism which serves as host; but on occasion their growth is accompanied by the production of poisonous material which can be and often is absorbed from the intestine into the blood, and so is distributed throughout the body. If the intestine fails to be evacuated at sufficiently frequent intervals, the production and absorption of these poisons goes on uninterruptedly and constitutes a definite cause of disease. This condition is commonly referred to as auto-intoxication, signifying that the body is poisoning itself. It has received less attention than it should because of its common occurrence and comparatively mild ill-effects, but there can be no doubt that human efficiency is definitely lowered as a result of this kind of poisoning.

THE METABOLIC ACTIVITIES OF PARASITIC ORGANISMS. — In previous paragraphs it has been shown that organisms occurring in foods or within the alimentary tract may produce poisons in connection with their metabolic activities. It is also true that certain kinds of organisms may live on or within the body and produce poisons by which the body may be harmed. These make up the group of so-called disease-producing organisms. It should be noted that the distinction between disease-producing organisms and such organisms as do harm through causing food spoilage or intestinal putrefaction depends on whether they affect the body directly or indirectly. The true disease-producing organism is one which is parasitic upon or within the body and liberates its poisons directly in the cells or body fluids. The presence of these organisms upon or in the body in numbers sufficient to cause harm constitutes what is technically known as *an infection.*

THE RELATION OF HOST AND PARASITE is a maladjustment of association. Infection from the purely biological point of view is an incident in the struggle for existence. Parasitic organisms must establish themselves in certain relations with host organisms or they will perish. The ideal relation of parasite with host is obviously one in which both parasite and host flourish, i.e., *symbiosis,* for if the parasite destroys the host it presently finds itself deprived of its source of nourishment and must find a new host, or die. Infections that injure the host are, from this point of view, maladjustments in the associations of organisms.

CLASSES OF DISEASE-PRODUCING ORGANISMS. — Three classes of organisms are recognized as capable of producing infection; those which are undoubtedly plants, those whose relationships are uncertain, and finally, those which are undoubtedly animals.

1. *Organisms that are undoubtedly plants.* — It should be noted that these contain no chlorophyll and therefore cannot manufacture their own complex foods, but are true parasites, deriving their nourishment from the body upon or within which they find lodgment. They belong botanically either to the bacteria or to the higher fungi.

Bacteria are small, one-celled plants (Fig. 54). Some of them are spherical and some of them are straight, bent, or coiled rods. Their length rarely exceeds three or four thousandths of a millimeter, and their

FIG. 54. — The Bacteria That Cause Tetanus or Lockjaw.

diameters are usually not far from one thousandth. Their cell-structure is exceedingly simple, so simple, in fact that it is doubtful whether they have a real nucleus such as is to be found in almost all other cells.

The fungi cause comparatively fewer diseases in animals than they were shown in the last chapter to do in plants. Those which are causes of animal diseases are very simple filamentous fungi.

2. *Organisms whose relationships are uncertain.* — There is a group of disease-producing organisms known as *spirochetes* which cannot at the present time be definitely assigned to either the plant or the animal kingdom,

and they are therefore classed as uncertain. There are also a great many organisms which can produce disease, but are so minute as not to be visible even under the highest powers of the microscope. Moreover, on account of their small size they pass through very fine filters, a circumstance which causes them to be grouped under the head of *filterable viruses,* a virus being a fluid which is capable of producing infection, and a filterable virus one which can produce infection after being filtered. This obviously means that the organisms are so small that they can pass through the filter.

3. *Organisms that are undoubtedly animals.* — Under this head come both protozoa and metazoa. In later paragraphs specific illustrations of both classes will be given.

Bacterial Disease. — Several common diseases are of bacterial origin; among them may be mentioned tuberculosis and typhoid.

Tuberculosis is due to the growth within the body of tubercle bacilli (see Fig. 55) which commonly make their

Fig. 55. — Bacteria That Cause Tuberculosis.

way through the respiratory passages into the lungs, where they establish themselves and form little hard masses known as tubercles. Tuberculosis is not confined to the lungs but may also affect almost any other part of the body. What is now known to be tuberculosis of the lymphatic system was formerly called scrofula, or " King's

Evil," this latter name being due to the superstition that if the sufferer from scrofula could get the king to touch him he would be miraculously cured. The organisms of tuberculosis are very likely to be present in the air, as a part of the dust, since every sufferer from pulmonary tuberculosis expels great numbers every time he expectorates. In the more common forms of tuberculosis the poison produced by the organisms is either mild or is in small quantities, so that the actual poisoning is gradual and the patient passes through a long period of slow decline. In pulmonary tuberculosis the impairment of health is due, in considerable part, to the interference with respiration which results from the destruction of lung tissue by the growth of the tubercle bacilli in the lungs. Occasional infections of tuberculosis are seen in which the organisms are highly virulent, and the disease runs a rapid course to a fatal termination. Very many lives have been saved since the discovery that sunshine and air free from dust, and abundant and nourishing food are sufficient, in combination, to cure ordinary tuberculosis, provided early diagnosis is obtained.

Typhoid is due to the typhoid bacillus which is present in vast numbers in the intestines of every sufferer from the disease, and sometimes in the intestines of well persons who are known as "typhoid carriers." If the excreta of these individuals find their way into drinking water or into milk, the organisms present in the water or milk will remain alive for a considerable period of time, so that persons drinking the contaminated fluids introduce the organisms into their intestinal tracts. From there the typhoid germs make their way into some of the cells of the mucous membrane lining the intestine, and by growth and multiplication become very numerous. Each one produces some poison which stays within it so long as it is alive, but when it dies the poison is set free to be conveyed about the body in the blood and to do injury.

PUS-FORMING ORGANISMS. — There are several kinds of bacteria (Fig. 56) that establish themselves ordinarily just below the outer surface of the skin or in correspondingly exposed positions within the mouth or other passages of the body. These organisms are called pus-formers, because the dead bodies of the organisms become mixed with white corpuscles and a certain amount of fluid to form pus. Ordinary pimples and boils are familiar results of the establishment of pus-forming organisms just under the skin. Most of the pus-forming organisms produce poisons which pass from the infected spot into

FIG. 56. — One Type of Pus-Forming Organism (Streptococcus).

the body fluids and so are distributed about the body. Certain of these organisms produce very violent poisons and give rise to the condition formerly known as "blood-poisoning."

PUS-POCKETS. — The common sorts of pus-formers produce a relatively mild poison and the body in which they are present is referred to as having a low-grade infection. It has long been known that in certain regions, particularly around the roots of the teeth and in the tonsils, low-grade infections of this type may become established and continue for years. The typical course of events is for the organisms to live along, month in and month out, multiplying only as fast as they die, and so not increasing in numbers, producing only small amounts of pus and not much poison, such pus and poison as are produced being absorbed into the body without doing obvious harm. At intervals, probably because of some disturbing influence that has affected the body, what is known as a flare-up occurs, when the pus-formers multiply with great rapidity and produce large quantities of pus and poison, along with definite bodily symptoms of more or less severity. After a longer or shorter period of activity, the affected tonsil or ulcerated tooth quiets down and gives little trouble for another period of time. Of recent years, definite evidence has been secured that these low-grade infections are responsible for acute rheumatism, formerly called inflammatory rheumatism, which in turn often results in valvular disease of the heart. Even though such an acute trouble may not develop, bodily harm is done, although the symptoms often come on so gradually that the patient is unconscious that anything is the matter with him other than that he seems to feel continuously less fit and to be upset more readily than formerly. The method of treating low-grade infections is to get rid of the masses of organisms where the pus and poison are being produced. Where the seat of infection is the tonsil, this is accomplished by its simple removal. It is not too much to say that the practice of dentistry has been revolutionized within the last decade by the recognition of the ease with which infection can establish itself about the roots of the teeth, and of the frequency with which such infection is reflected in distant parts of the body as a result of the pouring out of poison from the area of infection into the blood.

Common Colds. — Probably the most common, and certainly the most frequently repeated infections from which individuals suffer are those which cause common colds. There are various reasons why colds are prevalent. In the first place, it is now believed that there are half a dozen or more different organisms which may cause colds. Furthermore, all of them float about freely in the dust of the air, and so are breathed in more or less continously. The respiratory passages are therefore rarely if ever entirely free from organisms which are capable of causing colds if they get a chance to establish themselves within the body. They are lying in wait, so to speak, so that any relaxation of the resistance of the body enables them to gain a foothold.

Catching Cold. — It has been long known that a sudden chilling of the body, as from sitting in a draft, is apt to result in a cold. Quite recently, the explanation of this fact has been furnished by the discovery that when the outer surface is chilled rapidly there is caused, by a mechanism which cannot be described here, a partial shut-off of the blood-supply to the mucous membranes of the respiratory passages. This interference with the proper nutrition of the cells reduces their resisting power sufficiently to allow the organisms of colds to establish themselves and to develop. It should be understood that a rapid chilling, rather than simply the fact of being cold, is the condition which is likely to start the infection into activity. However, one should bear in mind that individuals may also be especially susceptible to infection as a result of under-nutrition or of exhaustion, and so may develop colds without there having been any special exposure immediately before the attack. Obviously, the best preventive of colds would be to have the respiratory passages free from the organisms which cause them; since this is not possible in practice, the alternatives are the maintenance of the body in the best possible health and the avoidance of such exposure as is likely to cause rapid chilling of the body surface. The regular taking of cold baths, where good reactions are secured, is an excellent means of keeping high the general resistance against colds.

Disease due to Higher Fungi is comparatively rare. There is in parts of California what is known as San Joaquin Disease, which resembles tuberculosis of the lungs in many of its symptoms, but is due to the presence within the lungs of mold-like fungi instead of bacteria.

Disease due to Spirochetes. — The spirochete is an organism spiral in form. One can be imagined on a large scale by supposing a bit of string to be wound round the finger and the finger withdrawn without disturbing the string. The commonest spirochete disease is syphilis (Fig. 57). The poison of this disease is very injurious to living tissues, so that bad sores are early consequences of the infection, and wide-spread destruction, particu-

Fig. 57. — A Common Kind of Spirochete.

larly of part of the spinal cord, a later manifestation. Although curable, syphilis is extremely stubborn, so that only skilful and thorough treatment eradicates it completely when it once becomes established within the body.

Diseases due to the Filterable Viruses. — Many of the commonest diseases, such as measles and scarlet fever, are due to organisms too minute to be seen under the microscope. A characteristic of many of them is that they are directly contagious, that is to say, simple contact with the patient often suffices to cause one to become infected.

Protozoan Diseases. — Malaria is a good example of disease due to a one-celled organism (Fig. 58) which is known to be an animal. This organism establishes itself in the red corpuscles and by interfering with their functioning hinders the normal transportation of oxygen by the blood. Moreover, the poisons produced by the malarial parasite bring about definite symptoms of which chills and fever (Fig. 59) are the most familiar. The drug *quinine*, found in the bark of the cinchona tree, destroys malarial organisms, so that if quinine can be introduced at the time when the organisms are active in the blood, the body can be freed from infection.

FIG. 58. — The Protozoan That Causes Malaria.

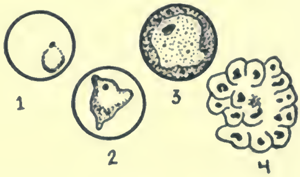


FIG. 59. — Successive Stages in the Life History of the Malaria Organism. The period of high fever is during the transition from stage 3 to stage 4.

There are several species of amœba (Fig. 60) that live in the human alimentary tract and by means of the poisons which they produce bring about a form of dysentery known as tropical or amœbic dysentery. This

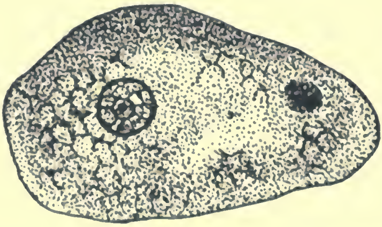


FIG. 60. — An Amœba from the Human Digestive Tract.

disease occurs chiefly in the tropics and is found in temperate regions only in persons who have come from tropical climates.

DISEASE DUE TO METAZOA. — There are various highly organized parasites which may cause disease. Among them is the hookworm, an organism which has attracted much attention of recent years because of the extent to which it has lowered the efficiency of the population in those regions where it is abundant. The organism is present in large numbers in the intestinal tract of affected persons, and is expelled with their excreta. Where sanitary precautions are not observed and the excreta are allowed to become mixed with the soil, these organisms are present in abundance at the surface of the ground. When one walks with bare feet over such an infected spot, some of them are likely to penetrate the skin of the sole, whence they work their way upward among the body tissues, and ultimately to the alimentary tract from which they will be expelled in course of time, to serve as possible sources of further infection. From the above description it is evident that the hookworm can flourish only in regions where the simplest sanitary precautions are neglected, and where the population is either too poor or too slothful to wear shoes. It should be noted, however, that the chief manifestation of hookworm infection is marked bodily lassitude, so that the lack of sanitary precautions is in part due to the lowering of vitality consequent on the disease. Fortunately for the welfare of those districts, including parts of the United States and large areas in Central and South America, where hookworm infestation occurs, quite simple treatment with the drug thymol, combined with simple sanitary regulation, suffices to stamp out the parasite promptly and effectively.

VIRULENCE.— A fact that must be taken into account in any attempt to understand the course and spread of infectious disease is that its producing organisms may differ greatly from time to time in what is called *virulence*. Under certain circumstances the organisms, although present, may produce only few cases of disease and these mild. Under certain other circumstances nearly everyone exposed may be infected and the individual cases may be very serious. These differences are undoubtedly due to alterations in the metabolism of the disease-producing organisms themselves, and while not much is known about the conditions which govern these differences in virulence, the differences themselves are of utmost practical importance, for a period of exceptional virulence is almost sure to mean an epidemic of the particular disease.

Defenses of Organisms. — Every infectious disease is a strife between the individual infected and the disease-producing organisms by which the infection is established. Since not all people that are exposed to infection take it, there must be a means of holding the infection at bay. Furthermore, if the invading organisms were allowed to develop and multiply without restraint they would produce poisons in sufficient quantity to destroy their host. The fact that animals recover from infection is proof that they have some means of combatting the organisms of disease. What these are is to be learned presently.

Prevention of Infection. — Disease-producing organisms are very widely scattered and are quite likely to be taken into the body with the air that is breathed or with the food or water that enters the mouth. The prevention of infection depends in the first place on keeping organisms which enter the respiratory or alimentary tracts from getting in among the body tissues where conditions for growth are favorable. This is accomplished by presenting unbroken surfaces which the organisms are not able to penetrate. There is no doubt that a very large part of our freedom from infection depends on intact surfaces. To the organisms of disease, not only the outer surface of the body, i.e., the skin, but also the mucous lining of the respiratory and digestive tracts, are possible areas through which entrance into the body may be gained. An organism which is breathed in with the air is likely to lodge upon the mucous membrane of the lungs or bronchial tubes, and if it penetrates the membrane it finds itself in the warm and moist body substance where growth can proceed readily. Similarly, organisms taken in with food have only the lining of the alimentary tract between them and the body substance. Abrasions or inflammations of any of these surfaces may afford just the needed portal of entry for virulent disease-producing organisms. One of the reasons why common colds are so frequently followed by more serious infections is that the irritation of the mucous membranes brought about by the cold makes the membranes easily penetrable by other more dangerous organisms.

The Overcoming of Infection. — After the organism has passed the barrier of the body surface and established itself in a favorable location among the tissues, the necessary conditions for rapid growth and multiplication with the accompanying development of disease would seem to be present. There exist, however, certain mechanisms in the body which oppose the active growth of the invading microbes. If these mechanisms are wholly successful the organisms are destroyed before any chance to multiply is afforded, and so the infection does not even get started. If the resistance of the body is less prompt, and yet reasonably effective, the organisms multiply for a time, producing and pouring out their poisons, and so the symptoms of acute disease appear. Presently, however, the body rallies its mechanisms of defense, counteracts the poisons, and destroys the organisms, and thus recovers completely. In still other cases, either on account of exceptional virulence on the part of the invading organisms, or an inefficient defensive mechanism on the part of the infected individual, the development of the organisms and the production of poisons by them become marked enough to destroy the life of the victim.

The body has two distinct means which it rallies separately or in coöperation in the effort to overcome infection. The first of these is certain of the white blood-corpuscles, to which, on account of this very action, the name *phagocytes* (scavenger cells) has been applied. The second is a method by which the poisons, or the organisms which produce them, or both, are attacked by chemical means, and to this is given the name of the *immunity-reaction.*

THE ACTION OF PHAGOCYTES. — Probably not all of the white blood-corpuscles exert the so-called phagocytic action. In those that do, the action consists in wandering about by amœboid motion (see Chap. XIII), the direction of the motion probably being influenced by chemical substances given off by the invading organisms. Whenever contact is made with a microörganism — a bacillus of typhoid, for instance — the phagocyte presses closely against the bacillus and by movements of its protoplasm engulfs it completely. Once within the body of the phagocyte the organism is digested and destroyed. It is an interesting fact that if phagocytes are in the presence of large numbers of a particular kind of organism, such as the typhoid bacillus, the number of organisms a single phagocyte will engulf is quite definite, so definite in fact that it can be used as an index of the efficiency of the body in defending itself against typhoid, since evidently the more organisms each phagocyte will engulf the more readily will the body rid itself of all the organisms which have invaded it. A further curious fact about the action of phagocytes, and a fact of very great importance in the whole process of overcoming infection, is that if the typhoid bacillus, to use the same illustration, becomes established in the body and begins to multiply so that poisons begin to be poured out and the symptoms of disease begin to show themselves, a chemical reaction goes on in the cells of the body, producing a material which affects the bacteria in such a way as to cause each phagocyte to engulf many more of them than formerly. The details of this action are not at all clear, but of the fact and its value as a means of overcoming disease there can be no doubt. The protective inoculation against typhoid, which reduced the occurrence of that disease to such an extent that from being a frightful destroyer of life at the time of the Spanish War, there was only a handful of well-authenticated cases in the American army during the Great War, is a practical application of this reaction by which the power of the phagocytes to engulf and destroy typhoid organisms is greatly increased.

THE IMMUNITY REACTION. — Many diseases, among them smallpox, pneumonia, and in fact the majority of the more prevalent infections, stimulate the body, in which the disease has gained a foothold, to produce substances known as *anti-bodies,* which are capable of (*a*) destroying foreign organisms or (*b*) of neutralizing the poisons which they produce. This disease-resisting property of the anti-bodies is merely a special and very useful application of a general power that living protoplasm has of getting rid of foreign proteins. It will be recalled that foreign proteins, as such, rarely come into contact with the living cells of the higher animals, because all proteins that are taken in with the food are digested into their constituent amino-acids before being absorbed into the body fluids. It is possible, however, to inject proteins directly into a vein, or they may obtain access through infection, the bodies of disease-producing organisms and the poisons they produce both being largely protein in character.

It is characteristic of the cells of the highly organized animals that when foreign protein comes into contact with them they react by producing anti-bodies. The effect of the anti-bodies is to precipitate the protein or dispose of it in some other way. An important feature of the anti-bodies is that there is a particular sort for each kind of protein, and when the cells of the body react to the presence of a foreign protein, the anti-body they produce is the particular one by which that protein is disposed of.

DIPHTHERIA. — There are a few kinds of disease-producing organisms, of which the diphtheria bacillus (Fig.

61) is the best-known example, which do not penetrate into the body and become distributed through it, but locate in some particular region, in the case of diphtheria, the region being the mucous lining of the throat. The organisms grow there and multiply actively and pour out their poisons. These are absorbed into the body, distributed through it by the circulation, and poison the individual cells. The poison, which is known as the *toxin* of the disease, stimulates the cells to produce the anti-bodies which in this case constitute *anti-toxin.*

FIG. 61. — The Bacteria That Cause Diphtheria.

Whether the patient survives or succumbs depends on whether the anti-toxin is or is not produced in sufficient quantities to neutralize the toxin.

ARTIFICIAL ANTI-TOXIN. — It is possible to grow diphtheria organisms in test tubes in a suitable culture medium, and thereby produce large quantities of toxin. This toxin is then injected into healthy horses in quantities not sufficient to poison them seriously, but adequate to stimulate their cells to the production of anti-toxin. After a suitable interval has elapsed, during which the cells of the horses' bodies are manufacturing anti-toxin, blood, which will of course contain it, is withdrawn, the corpuscles removed, and the clear liquid put up in suitable form for introduction into the bodies of diphtheria patients. Thus the poison which is being produced within the body of the patient can be neutralized directly without the necessity of waiting for the cells to react and produce anti-toxin.

IMMUNITY. — Most disease-producing organisms retain within their own bodies the poisons which they produce and only give them up as they are destroyed. In order to combat these successfully the body cells must do more than produce the anti-toxin for the neutralization of poison. They must produce in addition anti-bodies which attack and destroy the organisms themselves. This actually happens, so that one who is ill from such a disease as pneumonia is producing within his tissue anti-bodies which are actively destructive to the pneumonia organisms as well as able to neutralize the poisons which the organisms produce.

SMALLPOX AND VACCINATION. — An account of immunity would be incomplete without brief reference to smallpox. Two hundred years ago this loathsome disease was so prevalent throughout the civilized world that adults with un-pock-marked faces were objects of public attention. A certain famous beauty, Lady Mary Montagu, went so far as to adopt a practice well known in Constantinople, of having herself infected with smallpox, it having been observed that persons who survived deliberate infections escaped with less pock-marking than the general run of victims of the disease. Where pock-marked faces were so prevalent, the current belief that milkmaids were more likely than other persons to have smooth skins was bound to attract considerable attention. Jenner, a young physician who looked into the matter shortly before the end of the Eighteenth Century, became convinced that there was some real relation between the sores which milkmaids frequently got on the palms of their hands from the udders of cows afflicted with cowpox and their relative immunity to smallpox. Following up this idea, he prevailed upon the parents of a young boy to allow their son to have material from such a cow pressed into an abrasion on his skin. This was the beginning of vaccination. Although bitter hostility was encountered from all sides, the practice almost immediately vindicated itself, and Jenner, during the later years of his life, was hailed as a great benefactor of his race. The possibility of vaccination rests upon the fact that the organisms of cowpox and virulent smallpox are so nearly identical in their protein composition that the immune bodies which the tissues produce for one serve completely to attack and destroy the other. This close protein relationship of a severe with a mild infection has made it possible to make a very satisfactory beginning toward ridding the civilized world of one of its most fatal and loathsome diseases.

Defenses of Communities. — As civilization advances and men tend more and more to cluster in communities, conditions become more and more favorable for the organisms that produce disease in human beings. These organisms are parasitic within the bodies of men and certain kinds of higher animals, so that their chance of existence is greater the more persons are within reach. Furthermore, to maintain the purity of water, milk, and food supplies becomes increasingly difficult as the population becomes denser. The contamination of these substances with organisms that produce disease is for the most part contamination with human excreta. To prevent sewage from getting into drinking water and into the water with which milk-cans are washed seems like a simple undertaking, but in practice it presents a great many difficulties, due either to indifference on the part of the educated public or to ignorance on the part of others. Communities cannot safely rely wholly upon the intelligent coöperation of all their members, but must organize definite safeguards against contamination of water and food supplies, e.g., water systems, pasteurization of milk, screening of food from flies, etc.

Contamination of the Air from dried sputum, or from the coughing of persons with disease of the respiratory tract, must also be reduced as much as possible, through a combination of education and active measures of repression by legally constituted health authorities. (Hence "Don't spit" ordinances.)

Direct Infection can be controlled by quarantine, that is, by isolating the affected persons until the organisms of disease within their bodies have been destroyed. Quarantine measures are not difficult to enforce, provided the disease is discovered in time by the authorities. The difficulty here is that mild cases are apt not to come to the attention of physicians and so fail to be reported. Thorough-going medical inspection in the public schools is an important aid toward the control of contagious disease.

CHAPTER XXI

INSECTS AND DISEASE

Beneficial and Harmful Insects. — Many insects, such as the silkworm moth, honey bee, lac and cochineal bugs, as well as several species which prey upon insect pests, are of great benefit to man. The great majority, amounting to perhaps 300,000 named species, confer no special benefit and work no harm. A considerable number, such as bees and wasps and certain species of ants and true bugs, may produce injury ranging from trifling to serious by injecting poison into the body of another animal by means of stings or piercing mouth parts. And finally there are mosquitoes, certain flies and fleas, which in true parasitic fashion subsist upon the blood of an uncomfortable though not seriously threatened host.

Such was about the nature and extent of our information along this line prior to 1880. Since that date a large amount of work has been done with parasitic insects, and it is now known that while they of themselves are rarely more than annoying pests they are very important agents in the *distribution* of some of the most serious scourges afflicting man and many of the lower animals.

How Insects Transmit Disease. — In a few instances only are diseases actually produced by insects. The burrowing flea of tropical countries, for example, tunnels its way beneath the human skin, and with its progeny may destroy a certain amount of tissue. Certain flies in their larval or young stages may also occasionally infest the human body and destroy the cells. To this extent these insects do interfere with the proper functioning of the body, and hence may be said to be the direct cause of disease. Generally speaking, however, the diseases with which insects have to do are actually produced by bacteria and unicellular animals. The insect merely serves as a carrier for these lesser organisms. They may attach to the hairs or the outer surface of the insect's body and be carried from place to place; or the disease-producing parasite may actually live within the body of the insect, and there undergo certain stages in its development before being transmitted to some other organism.

Flies and Typhoid Fever. — The first of the two methods whereby insects transport germs is exemplified by the history of the ordinary house fly. In the course of its wanderings, always on the search for decomposing organic matter, it may settle upon the excreta of a diseased patient, pick up a million or two bacteria (as has been repeatedly proven) that attach to the pads of its feet or elsewhere on the body, and then alight upon food or drinking and cooking utensils and dislodge thousands of bacteria in the process. By this means disease germs are widely distributed, and unfortunately find new hosts in which to live and multiply.

The habits of the house fly are now so well known to the physician and sanitarian that he is able to prescribe effective means of control. He knows that by disinfecting the excreta of typhoid patients he can prevent the fly from becoming a carrier of the disease organism. Moreover by screening all animal excreta, where the flies breed, he can greatly reduce the number of flies. By "swat the fly" campaigns he can still further reduce their numbers, especially if this be done late in the season. Then by insisting on having all foods screened or otherwise protected from flies he prevents the few that remain from doing serious harm.

Flies and Sleeping Sickness. — Through the medium of the press much publicity has been given to sleeping sickness, a terribly fatal disease afflicting whites and blacks alike in certain districts of tropical Africa. The first symptoms of an attack are often relatively slight fever and skin disorders, but gradually these become more pronounced, and after months or even years the nervous system is affected, the victim lapsing into a state of unconsciousness from which there rarely is a recovery. After an immense amount of labor it has been determined that this scourge is due to minute, slender and actively moving blood parasites which are carried from man to man by the skin-piercing blood-sucking tse-tse fly. This insect is a dull brown faintly banded species bearing a general resemblance to the ordinary house fly. It makes its home in thickets along the borders of streams and marshy districts, and, as is to be expected, sleeping sickness is confined to these same moist "fly belts." Other forms of this disease are known to attack cattle, horses, mules and camels in the Eastern Hemisphere, while a related affliction is common among horses in Central and South America. It has been demonstrated that while it is not possible to cut down all the brush in an infested district, the region may nevertheless be made comparatively safe by removing the thickets from the neighborhood of water bodies, bridges and fords.

Flies and Other Diseases. — The reputation of the house fly, or the typhoid fly as some scientists have suggested it should be called, is further blackened by the fact that it may also be the agent responsible for spreading several other disorders affecting man. It is certainly known that these insects may fly at least ten miles from their birthplace, and may carry any one of not less than sixty different kinds of organism attached to their bodies, among which are the germs of diphtheria, infantile paralysis, measles, leprosy, tuberculosis, Asiatic cholera, scarlet fever and several other important diseases. House flies are also known to carry the eggs of several species of parasitic worms occurring in man. It is an established fact that both eggs and germs are dislodged as the insect walks over cooking and drinking utensils, food and the human body, and it may indeed be true, as many students of the subject believe, that disease is spread over wide areas by this process. "Swatting the fly" is a wise preventive measure, and the additional precaution of screening manure piles and other breeding places of this species is the ounce of prevention that may remove the need for the pound of cure.

Mosquitoes and Malaria. — The second method whereby disease-producing organisms are transmitted from one individual to another is complicated by the fact that the insect concerned is itself parasitized by the microbe. In other words, the insect acts as a so-called secondary host in which the parasitic organism undergoes certain stages before it is suited to a life in the human body. The malarial parasite is an example of this where certain species of mosquitoes are the distributing agents.

The parasite responsible for the malarial disease is a very minute unicellular animal, which upon being introduced by the bite of a mosquito into the blood stream of man attacks the red blood corpuscle, enters it, consumes its substance and then divides into a large number of smaller cells. These escape into the blood, attack new corpuscles and repeat the process. In a few days millions of these parasites may be present in the blood, and their destruction of the corpuscles is responsible for the paleness of the skin characterizing this disease. With the rupture of the blood cell, and the escape of the imprisoned parasites, waste products are liberated, and acting as poisons produce the usual fever and chills. At the time when the young parasites escape into the blood they may be killed by giving properly graduated and timed doses of quinine.

Malarial Parasites in the Mosquito. — There are not less than 1000 named species of mosquitoes, yet probably not more than a half dozen are capable of transmitting the malarial disease (Fig. 62). These few species are characterized by spotted wings and by tilting their

FIG. 62.— A non-malarial mosquito, *Theobaldia incidens*, male, standing on the wall. (About twice natural size.)
Kellogg and Doane, *Economic Zoology*.

bodies upward at an angle when at rest, while the body in other species is held parallel to the surface on which it rests. If a malarial patient is bitten by a mosquito some parasites are certain to be withdrawn in the process. One

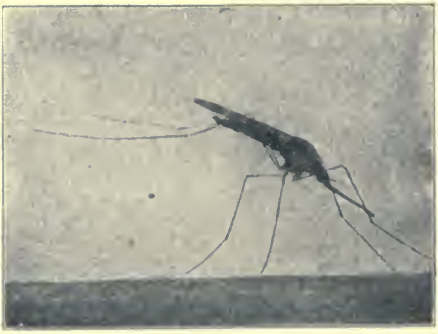


FIG. 62A. — A malarial mosquito, *Anopheles maculipennis*, female, standing on the wall. (About twice natural size.)
Kellogg and Doane, *Economic Zoology*.

of two things now takes place: If the mosquito is a non-malarial one the parasites are digested along with the blood and their history is closed. If it is a malarial species the parasites in its digestive tract continue their activities, and soon bore through the stomach wall and enter the tissues. A complicated series of changes then takes place, resulting in the development of an enormous number of spindle-shaped cells, which make their way into the salivary gland of the insect. When a mosquito at this stage bites a human being the parasites escape through the wound into the blood, and once more enter upon their so-called life cycle.

Yellow Fever and Mosquitoes. — The sudden onslaught, deadly character of the disease, and the helplessness of the population of the stricken district to ward off attacks, have made yellow fever one of the most dreaded of human diseases. Efforts were made in former times to combat the scourge by isolating the patient, fumigating every article sent out and otherwise treating the case as though it were smallpox. But these attempts, entailing a vast amount of labor and expense, proved of no avail. People who had never been near a yellow fever victim were smitten, and the only safe course was to leave the region.

In the year 1900, while the American troops were in Cuba, a Yellow Fever Commission was appointed to make a thorough investigation of this disease. Acting upon the suggestion of Dr. Finlay of Havana that a certain species of mosquito is the responsible agent in transmitting the disease, Dr. Carroll of the Commission allowed himself to be bitten by a mosquito that previously had fed upon four patients suffering from the fever. In a short time he was stricken and ultimately recovered. One of his co-workers, Dr. Lazear, was accidentally bitten by an infected insect and died. Other men allowed themselves to be bitten, and five days later developed the characteristic symptoms. After a long series of investigations it was proved that (1) yellow fever is transmitted in no other way than by one kind of mosquito; (2) that to transmit the disease the parasites must be devoured by the mosquito during the first three days of the fever;

and (3) twelve days must elapse before the mosquito is able to infect another person. The parasite thus resembles that of malaria in that it completes certain stages of its development in a secondary host, the mosquito.

Remedial Measures. — It was perfectly evident to every clear-thinking individual that when the mosquito was shown to be responsible for the transmission of malaria and yellow fever these insects should be exterminated. Theoretically this was a relatively simple matter. All that appeared to be necessary was to drain the marshes or pour oil on the water and thus smother the young aquatic "wrigglers." In reality the task was and continues to be one of gigantic proportions. Many districts, such as the valley of the Amazon, are too large to be drained or oil-coated. In other regions the ignorance and indifference of the people has proved to be an almost insurmountable obstacle. Nevertheless there are enlightened communities where millions of dollars have been spent for drainage, house to house inspection of possible breeding places, the introduction of mosquito-devouring fishes and other remedial measures. The results amply justify all of the expense of time and labor. Today yellow fever is practically wiped out from the larger seaports in the Western Hemisphere where formerly its ravages were most severe. Malaria is more stealthy in its attack, and the general public is more inclined to take it as a matter of course and allow the mosquito to carry on its deadly warfare. It is important to note, however, that annually not less than 10,000 people die from this disease in the United States alone, and the yearly monetary loss due to the reduced efficiency of suffering workers amounts to many millions of dollars. When these facts are generally known, and the part the mosquito plays in the grim tragedy is understood, it is safe to say that malaria will become as rare as yellow fever.

Plague. — This disease, sometimes known as black death, has for many centuries been one of the most terrible diseases known to man. Early in the Christian Era it raged for more than fifty years and swept away the people of many districts. Again in the latter part of the Fourteenth Century an outbreak occurred that spread over the entire world, and destroyed, it is estimated, 25,000,000 people. In more recent times other epidemics have occurred, and, while of less extent, their effects have nevertheless been frightful.

During one of these recent outbreaks it was discovered that a minute germ invariably occurs in the bodies of plague-afflicted patients, and it was also proved that this germ when it gains access to the blood of other individuals produces the disease. It has been known for centuries that when there is an outbreak of plague there is also a high death rate among rats. These animals might therefore in some way be responsible for the disease, but in what way was discovered less than twenty years ago.

Fleas and Plague. — It is now known that dogs, cats, mice, and especially rats, are subject to the attacks of plague, and furthermore it has been shown that when such animals die of the disease the fleas which infest their bodies leave and seek new hosts. The new victims may be almost any of the warm-blooded animals, and when attacked by the flea they develop the disease owing to germs introduced into the body. This same insect may escape and inoculate new hosts, or the same patient may be bitten by other fleas, which then transmit the disease to other animals. And thus the disease spreads, due in every instance to the activity of this one type of insect.

These results are now definitely established, and have led to the introduction of international sanitary measures which have for their goal (1) the destruction of rats and other flea-carrying animals in plague-infested districts, and (2) the isolation of stricken human beings.

The value of such precautionary measures has been abundantly demonstrated in several instances, and justifies the belief that henceforth it will be possible not only greatly to reduce the number of cases, but to prevent the spread of the disease.

Other Insects and Disease. — Once more attention is directed to the fact that most insects are harmless, and the comparative few that are known to transmit disease can be kept within bounds when a community exercises a reasonable amount of care. But unfortunately there are communities where cleanliness is not a virtue, and lice, bedbugs and cockroaches flourish. An examination of these insects amid such surroundings discloses the fact that they, like the fleas, often carry on their bodies large numbers of disease-producing germs, and it is now thoroughly established that typhus and the related trench fever are carried by lice. There is also considerable evidence that plague and infantile paralysis are borne from one animal to another by the bedbug. Tuberculosis, typhoid fever and Asiatic cholera are believed by some scientists to be spread by cockroaches. And there are several other diseases, attacking man as well as many domesticated and wild animals, where insects are strongly suspected of being the means of distribution.

Mites, Ticks and Disease. — Although these organisms are more closely related to the spiders than they are to the insects, their habits and methods of transmitting disease are so similar that they may be conveniently treated in this chapter. The mites are not certainly known to transmit disease in man, but the fact that they are responsible for itch, scab, mange and other skin disorders brings them under suspicion. The ticks are invariably voracious parasites which pierce the skin of the victim with needle-like mouth parts and gorge themselves with blood. In this operation they may suck up minute organisms which produce a considerable number of diseases affecting man and the lower animals. Relapsing and Rocky Mountain or spotted fevers in man, the deadly and enormously costly Texas cattle fever, certain disorders affecting poultry and many other diseases are due to tick-carried parasites.

Government Sanitation. — The foregoing paragraphs present only the barest outline of the important subject of insects in relation to disease, and of necessity fail to give anything like an adequate conception of the enormous amount of work that has been done and is now being carried on in this and other countries. The U. S. Public Health Service, with branch offices in practically every state and city of the Union, not only enforces quarantine regulations and prevents the spread of disease, but its trained officials are investigating disease-producing organisms and their means of disposal. The United States Department of Agriculture, state agricultural schools, experiment and field stations throughout the country are likewise devoting much of their time and money to the study of disease in both animals and plants. Colleges, public schools, and physicians are also playing a prominent part, and together with bulletins, reports, magazine articles and the press are educating and arousing the general public to take an active part in this warfare against insects and disease.

SECTION 6

DEATH

CHAPTER XXII

DEATH AND THE DURATION OF LIFE

NATURE OF DEATH. — Death is defined as the cessation of life. An organism that for weeks or years has moved, undergone waste, repair, and growth, and has responded to stimuli, finally ceases these activities. It dies, and the protoplasm composing its body never regains its capacity in this respect, but decomposes into simpler, more elemental and lifeless compounds. The advent of death is preceded, at least in higher animals, by old age changes in which the operations of the cells gradually slow down. Even when death occurs, its effects are not instantaneous. The nervous system fails in its functions, the heart stops beating, breathing ceases; but the cells of the skin and hair may continue to develop for hours, and the white corpuscles exhibit their characteristic movements. Among many of the lower animals these differences in cell vitality are even more marked, several functions of the body continuing for a considerable period even though the head be severed. A number of animals, such as the opossum and certain insects, may feign death, and the cases of so-called suspended animation, in which a human being, for example, sinks into a torpid condition, are often such perfect counterfeits of death that the closest scrutiny is necessary to detect the difference.

HIBERNATION OR WINTER SLEEP. — A type of partially suspended animation, death-like in its general features and known as hibernation or winter sleep, normally occurs in numerous animals during the cold season when food is scarce. In the fall several species of bears, hedgehogs, prairie dogs, squirrels, bats, and other higher animals construct nests, and, even before the coming of the winter, withdraw into these retreats, and enter upon a period of sleep lasting from two to four months. No food is taken during this time, the pulse is very feeble, breathing movements are slight and occur at long intervals, and the heat generated by the oxidation of the fatty tissues, especially when it is retained by the walls of the nest, is sufficient to keep the animal from freezing. During hibernation, therefore, all of the chief functions of the body are being carried on, it is believed, but they are slowed down almost to the point of complete inactivity.

Summer Sleep. — In tropical and desert countries, where drought prevails for months at a time, many species of animals and plants undergo the so-called summer sleep that resembles hibernation in certain of its features. Many snakes, beetles, crocodiles, and alligators, upon the approach of the dry season, bury themselves in the mud, and, with activities at low ebb, exist in a dormant condition for months. Among the lower animals there are certain snails and slugs that surround the exposed portions of their bodies with a coat of slime, and in this state may exist without feeding for at least two years. Practically all of the freshwater unicellular animals may be dried into inert shrivelled masses, exposed to the burning sun, and blown about by the wind, and continue to exist in an apparently lifeless condition until a more favorable time. Numerous plants likewise dry up and shrink to small size, while the seeds, like the eggs of many animals, are protected by heavy coats to enable them to withstand excessive drying for several years.

Effects of Freezing. — It has long been known that numerous species of animals and plants may be frozen solid yet regain their customary activity when again brought into favorable conditions. As a matter of fact this normally occurs every winter in cold climates. For example, in the Arctic region of North America the ground freezes to a depth of several feet, and the plants and most of the animals that live at or near the surface are completely frozen for several months. In this category are trees, shrubs, and herbaceous plants, worms, snails, insects and lower forms of life. Also in the shallow ponds and streams of Alaska there is a species of fish (Dallia) that every winter is frozen solid. Individuals caught in November have been kept in this condition until the following March, and upon being thawed out appeared none the worse for the experience. There is some evidence that bear animalcules, a low species of animal, found frozen in glacial ice, may have existed in this imprisoned condition for many, possibly scores, of years. It is conceivable though not probable that some of the activities of the body may be carried on in these frozen organisms, but there is no visible sign of life and the death limit is certainly close at hand.

Length of Life. — According to an old saying, "a wren lives three years, a dog lives three times as long as a wren, a horse lives three times as long as a dog, and a man lives three times as long as a horse." Although these figures are somewhat inaccurate when the average length of life is considered, they call attention to the fact that the life of every species of animal and plant is limited. A worker honey-bee lives six weeks, and between this limit and the hundred-year existence of the elephant and eagle other species can be found with almost any intermediate period of activity.

The explanations offered by biologists to account for these facts have been of the most varied character, and yet none at the present time meets with general approval. Some scientists have asserted that size determines the age limit; that large animals live longer than small ones. This is undoubtedly true within limits. An elephant is twenty-five years of age before it attains full size, and a series can be arranged as follows: elephant, 100 years; horse, 40 years; blackbird, 18 years; mouse 6 years;

butterfly, 1 year. Nevertheless, when this explanation is critically examined many exceptions appear. A horse lives 40 years, but so does a sea anemone or a toad; a pig lives 18 years, and so do some of the crabs. Mere bodily size is therefore not the sole determining factor.

Weismann's Theory. — Toward the close of the last century, Weismann, a famous German zoölogist, formulated a theory that appears to be more in accord with what is known of the subject. He emphasized the fact that in many species of animals, all of the sex cells are liberated at one time; and, if the offspring are not subsequently cared for by the parents, the latter die at once or exist for a short time only. Where the eggs are not laid in one season, but during a period of weeks or years, it is obvious that the span of life is more extended, but here also it lasts but little longer than the time of sexual maturity. Where the young are cared for the lives of such parents are continued for a relatively much longer time after the close of the reproductive period than in the other cases cited.

The number of individuals of a species remains approximately the same from century to century. There may be fluctuations, one year being represented by many more individuals than another, but in the long run the average is practically uniform. This must mean therefore that for every parent that dies there is another individual to take its place, whether the reproductive period be long or short.

Application of the Theory. — The great length of life of the elephant is thus correlated with the fact that it is a slow breeder. It does not produce offspring until twenty-five years of age, and at a maximum probably does not give birth to over fifty. The eagle does not build its nest until it is several years of age, and it has been estimated that it does not lay over one hundred and fifty eggs. In both of these instances the number of descendants is small, but they receive parental care. On the other hand, the Virginia oyster lays forty millions of eggs, but these are not cared for. Accordingly the number of young stands in close relation to their chances of coming to maturity, and (according to this theory) the length of time required to produce a sufficient number of offspring to replace the parents is closely correlated with the average length of life of the mature individual. It is difficult to see, however, how the correlation actually fixes the limit of the life of any individual.

Old Age Modifications. — Infancy, youth, middle life, and old age are merely stages in the process of growing old. During infancy the chemical changes in the cells go on at a rapid rate, cell divisions occur at frequent intervals, the protoplasm increases to a great extent, and the body grows to a marked degree. Beyond this point the increase in weight in the human species is much slower and, after gradually slowing down, stops at about twenty years in the case of the female and twenty-four in the male. During this time the proportions of the body undergo changes which continue throughout life, and are usually so definite that they accurately indicate the age of the individual.

Inner changes also are characteristic of the body at various stages of its growth. In old age the bones contain a relatively large amount of mineral salts and become brittle. The cartilage also is impregnated with mineral salts and in consequence becomes less elastic. The muscles lose their vigor, and the hair its pigment. The lens of the eye loses its elasticity and the ability to distinguish near objects clearly. The metabolism of the body becomes more imperfect, and what appear to be degenerative changes affect the nervous system.

Immediate Causes of Death. — Popularly it is believed that the vital machine "wears out" or "runs down," but beyond this point no details of the process are forthcoming. The physician is inclined to state that a man is as old as his arteries, meaning that if the characteristic old-age thickening of the walls of the blood-vessels does not occur the attendant disorders are absent and life is likely to be prolonged. But here again no satisfactory reason is given for the so-called hardening of the arteries. According to other students death is due to changes in the nervous system, or in the rate of metabolism, or in the relation of the nucleus to the cell protoplasm, or to the modification of the physical or chemical constitution of the cell; and once more details are lacking.

Still other investigators have suggested that the body, as a result of its activities, generates poisons other than those eliminated by the skin and kidneys, and these accumulating in the cells prevent their operation. Metchnikoff aroused great popular interest in this subject by the suggestion that in man the large intestine harbors great numbers of bacteria whose excretory poisons, absorbed by the body, produce disturbances ultimately resulting in death. But attempts to destroy the bacteria have not been productive of marked results so far as the lengthening of life is concerned.

It appears to be true that very often, if not invariably, some one organ ceases to function and hence throws the others out of adjustment. Beyond this point no scientist has given a very satisfactory explanation of the immediate causes of death.

Immortality of the Unicellular Organisms. — It is a startling fact that death is not a characteristic of the lowest forms of life. An amœba or paramœcium, for example, multiplies by the division of the cell into equal halves. Parent A in the process becomes offspring B and C. There is no death; no corpse. These simple organisms are thus potentially immortal. Some individuals, to be sure, may be boiled, crushed, starved, or carried into unfavorable situations where they perish; but these are cases of accidental death only, and under no circumstances do such cells produce descendants. In other words, every one of these primitive creatures is the descendant of pre-existing parental cells. These statements have been criticized from various angles by different scientists, but the fact nevertheless remains that "no one-celled organism ever lost an ancestor through death."

Death in Multicellular Organisms. — The many-celled organisms are likewise descendants of pre-existing parents, yet in this group death is a regularly recurring process. Wherein lies the difference in this particular between the multicellular and unicellular species? The answer is forthcoming when the development of the first-named class is critically examined. The egg-cell of the hen, for example, by repeated divisions gives rise to an individual in which the cells become differentiated into two very distinct types, those of the body proper and the germ cells. The body is the more obvious and impressive, and appears to be the more important. It is fitted for a definite set of conditions and displays a series of complex activities of gathering food, avoiding enemies, and begetting and caring for the young. Nevertheless it is a mere sheath for the reproductive elements that it nourishes and protects, and which alone are capable of producing the succeeding generation.

In the lowest multicellular organisms, such as Gonium, each cell reproduces its kind, while in higher types, where the division of labor is more complete, only the germ-cells have retained this power. The body when emptied of its reproductive cells thus becomes a worthless husk, and while the protoplasmic stream flows from germ-cell to germ-cell, death claims the body at each generation.

Death an Advantage to the Species. — The food supply of every species of plant and animal is limited; more individuals are produced than can possibly exist throughout the normal lifetime, and it therefore is evident that in the unceasing struggle for existence the fittest individuals should persist if the species is to be kept up to a high standard. Man is no exception to this rule. Whatever our sentiments may be in the matter, it must be evident that permitting the physically and mentally unfit to reproduce their kind is a serious menace to the race. Moreover, it is also true that the most perfect individuals of any species of animal or plant become increasingly crippled and defective the longer they live; and accordingly there is a pressing need for the development of new and more vigorous offspring to take their places. When these descendants have been produced, and after they are cared for — if this is characteristic of the species — the life work of the parents is at an end. The interest of the race, invariably above that of the individual, is best served by the removal of the old and decrepit. Death, therefore, is an advantage to the species.

Summary. — Death, which bears a close resemblance to suspended animation, is the complete and permanent stoppage of the vital functions. It occurs normally at a time after the period of sexual maturity and the care of the young has come to a close. Among the unicellular organisms and the germ cells of multicellular species, death is an accidental process. It merely affects the body that encloses and nourishes the reproductive elements. Death, therefore, is a benefit to the race in removing individuals which otherwise would tend to crowd out the more vigorous and useful offspring.

SECTION 7

THE ROLE OF MICROORGANISMS

CHAPTER XXIII

DECOMPOSITION

The Disposal of Organic Wastes. — The syntheses which are carried on by plants in their own bodies, and the metabolic changes in the bodies of animals, produce, among other things, insoluble substances which, because they are insoluble, are of no immediate use to the plant or animal after they cease to be parts of the living mechanism, that is, after they are excreted or after the organism dies. These matters would accumulate and cumber the earth if they were not removed. Removal is accomplished by the slow processes of "weathering" and by decomposition, chiefly fermentation, and putrefaction. Weathering consists in the operation of inanimate influences, the action of the oxygen of the air, of light, heat, frost, water, wind, drying, etc. The other processes are carried on by living things, mainly micro-organisms, which operate by means of the enzyms already referred to in Chapter VII.

Decomposition. — Fermentation and putrefaction are particular forms of decomposition, the products of which often distinguish them. Thus alcohol and the offensive odors of decay mark respectively a certain fermentation, namely alcoholic, and certain putrefactions. In all these cases there are energy changes and changes in chemical composition. Decay which takes place with offensive odors is called putrefaction. Some forms of disease (e.g., gas-gangrene) are actually fermentations or putrefactions. The changes which are termed decay, fermentation, putrefaction, decomposition, and those which are the actual cause of disease, are fundamentally alike. Some of the chemical and energy changes taking place in decomposition are the same as those which take place in the bodies of the living organisms which produced the materials acted upon. Thus digestion and decomposition, the metabolic processes involved in respiration and certain fermentations, and the post mortem changes immediately following death have many features in common, the most significant of which is enzymic action. (See Chap. VII.)

KINDS OF DECOMPOSITION. — (*a*) *Digestion.* This topic, mentioned here because it is a part of the general subject, has been discussed elsewhere (Chap. VII) at sufficient length. It is accomplished by enzyms which act upon various sorts of organic matter.

(*b*) *Autolysis.* This is the name given to decomposition taking place in bodies immediately after death, and is entirely independent of invading organisms. It is accomplished by enzyms formed by the organism previous to its death. It may be more than suspected that some at least of these changes taking place after death are the same as those taking place before death. Autolytic changes undoubtedly take place in the bodies of plants as well as animals, although even less is known about autolysis in plants than in animals.

(*c*) *Metabolism for Energy Release.* In both plants and animals the use of food as fuel results in its decomposition and the liberation or release of energy. The carbohydrates and other non-nitrogenous compounds are oxidized directly or indirectly in the metabolic processes, the oxidation, when completed, resulting in the production of CO_2 and H_2O, with the liberation of energy. The energy liberated may be immediately used for work in the form of muscular or other movement, locomotion, etc.; but if not used for work, it will escape as heat.

(*d*) *Protein Metabolism.* The complex nitrogenous compounds of carbon known collectively as proteins — constituents of living protoplasm — are converted in the course of their basic metabolism into simpler compounds such as urea and uric acid, excreted by animals in the urine, but with no corresponding excretion by plants. This difference between the behavior of plants and the behavior of animals may be more apparent than real, but present knowledge throws no light on the matter. The nitrogenous compounds produced in the metabolic activities of plant cells seem to be used again by them in the reconstruction of proteins. (See Chap. V.)

(*e*) *Carbohydrate Fermentation.* Sugar, starch, cellulose and its derivatives (wood, etc.), and similar compounds, are broken down in the process called fermentation, with the formation of alcohols, acids, and other substances, and finally CO_2 and H_2O. This process is always due to the activities of microörganisms and is brought about by means of enzyms which they manufacture. In the various stages of the oxidations which constitute essential parts of fermentation, corresponding amounts of energy are liberated which commonly show as heat.

(*f*) *Putrefaction.* In putrefaction, organic compounds containing nitrogen — many of them with sulphur or phosphorus in addition — are broken down, commonly with the production of offensive odors, ultimately to ammonia and carbon dioxid.

THE AGENTS OF DECOMPOSITION. — Animals, bacteria, and fungi are ordinarily the immediate agents of decomposition. In many cases the enzyms produced by the living organisms are known to facilitate or accelerate if not to accomplish the decomposition. Hence the inference is easy that all decompositions, whether autolytic or carried on by invading organisms, are accomplished by enzyms.

THE PRINCIPLES OF DECOMPOSITION. — The principles controlling decomposition will become clearer if we study certain examples, bearing in mind that we must examine (*a*) the substance to be decomposed, (*b*) the organism producing the decomposition, (*c*) the enzym by means of which the organism brings about the decomposition, (*d*) the material products, and (*e*) the energy changes. The relation of the decomposition, whether inside or outside the body of the organism producing it, to the rest of the metabolic activities of the organism should also be considered.

ALCOHOLIC FERMENTATION, so-called from one of its principal products — the other being CO_2 — is used by man in raising bread, in the manufacture of fermented liquors, and in the manufacture of alcohol for use in the arts, as fuel, etc. Owing to its importance it has been studied with great care and increasing skill. Among the most important contributions to our knowledge of the whole subject are those made by the eminent Frenchman, Pasteur, whose studies of the so-called "diseases of wine" led to definite knowledge of the processes involved in the making of alcoholic liquors. In alcoholic fermentation sugar is the substance acted upon. In bread dough and in beerwort malt sugar is derived from starch in flour and in germinating grain. The same is true of corn and potato mash from which Bourbon and Irish whiskies were obtained. In the must of grapes the fermentable sugar, fructose, already exists. Different species of yeasts are the organisms producing the decomposition. The yeast used in bread-making and in beer-making is one found commonly in the air and cultivated on a commercial scale with the result that superior strains or varieties of yeast are now obtainable, just as the florist furnishes superior strains or varieties of roses and chrysanthemums. The fermentation of wine is accomplished by means of the wild yeasts found on the skins of the grapes. The superior quality of wines of certain districts and of certain seasons is due in part to the superiority of the local varieties of yeast, though due also in part to the favorable conditions at the time of wine-making, and to the superior substances contained in the grapes. The alcohol obtained from corn and potato mashes may equal in purity the alcohol obtained from other fermentable materials; but the illicit manufacture of alcohol from such mashes often results in the production of liquors the bad qualities of which are due to the presence of other substances than the particular alcohol for which the fermentation was carried on. Thus, jackass brandy, moonshine whiskey, and the other liquors illegally produced owe their objectionable qualities to the products of other organisms, such as the molds, rather than to pure yeasts. They contain so-called fusel oils, a name given to other alcohols than that obtained from the "clean" fermentation of grain or grapes. The effect of the fusel oils is much more violent than that of ordinary ethyl alcohol.

THE ENZYMS CONCERNED. — The hydrolytic enzyms produced by the cells of the barley grain are (1) *amylase* which digests starch, converting it into malt sugar (see Chap. VI), and (2) *maltase,* which splits malt sugar with the addition of a molecule of water into the fermentable sugar, *glucose.* The chemical relations of these sugars may be indicated by their respective formulas. Thus malt sugar is $C_{12}H_{22}O_{11}$ while glucose is $C_6H_{12}O_6$. The action of maltase is represented by the equation

$$C_{12}H_{22}O_{11} + H_2O = \underset{\textit{glucose}}{2C_6H_{12}O_6}$$

(3) The oxidizing enzym *zymase* converts the sugars into alcohol and CO_2, releasing a certain amount of energy, some of which can be measured as heat. Thus it is seen that a part of the sugar which was originally made from CO_2 and H_2O by means of energy absorbed by the chlorophyll pigments in green leaves, is re-converted into CO_2 and part of the energy is released. Thus

$$\underset{\textit{glucose}}{C_6H_{12}O_6} = \underset{\textit{alcohol}}{2C_2H_5OH} + 2CO_2$$

COMMERCIAL USES OF THE PRODUCTS. — In raising bread CO_2 is the essential product of the fermentation.

In wine- and beer-making, as in the manufacture of alcohol, the production of alcohol is the essential result. The CO_2 is valuable in the manufacture of beer and in the production of champagne and other "sparkling" wines. The alcohol itself produced being a partly oxidized compound, can be further oxidized by burning; this may be done in the body, in a lamp, or in an engine, or by bacteria. In the first three cases the result is complete oxidation and the production of CO_2 and H_2O and energy.

$$\underset{\textit{alcohol}}{C_2H_5OH} + 3O_2 = 2CO_2 + 3H_2O$$

Acetic Fermentation. — In the last case, oxidation by bacteria, oxidation is incomplete,

$$\underset{\textit{alcohol}}{C_2H_5OH} + O_2 = \underset{\textit{acetic acid}}{CH_3COOH} + H_2O$$

the products being acetic acid — familiar to us in vinegar — and a certain amount of energy, some of it recognizable as heat. If the action of the bacteria is allowed to continue the result will be the oxidation of the acetic acid to CO_2 and H_2O and the liberation of the rest of the energy.

The Souring of Milk. — This process, involved in the manufacture of many foods and drinks, has also been carefully studied on account of its technical and commercial importance. Cow's milk, as well as the milk of other animals, contains a sugar of the same proportional formula as cane and malt sugars, called milk sugar, sugar of milk, or lactose — $C_{12}H_{22}O_{11}$, which may be acted upon by many different organisms, both large and small. When milk is digested or acted upon by certain bacteria or by certain yeasts, it sours, a curd forms, and the butter fat may be separated off. The reaction, so far as the sugar is concerned, consists in the splitting of the lactose molecule into four molecules of lactic acid because of the action of the bacterial enzym known as *bacterial zymase.*

$$C_{12}H_{22}O_{11} + H_2O = 4C_3H_6O_3$$

But if other bacteria which form an enzym called *lactase* are present, milk sugar will be split, after the addition of a molecule of water, into glucose and another sugar called galactose. This can be converted into alcohol and lactic acid by further bacterial enzym action. Koumiss, kephir, yogurt, etc., are milk derivatives used as drinks by certain races, which are now occasionally prescribed and consumed in limited quantities in this country, and which are obtained by the action of bacteria and yeast on the milk of cows, goats, etc. These various products are formed at the same time that a certain amount of energy is released, and as they can be still further oxidized until CO_2 and H_2O are the end products, still further amounts of energy may be obtained from them. Finally, all the energy used in the manufacture of sugar in the first place will be released, the organisms concerned being duly nourished by the various ingredients of the milk.

THE ROTTING OF WOOD. — The cell-walls of plants constitute the bulk of their remains, consisting of cellulose or some derivative of it, as in the wood of trees. Some animals are able to digest these substances by means of enzyms which act upon them and convert them into sugar which they proceed to use in the usual way. Thus, goats can digest cellulose, although we cannot. Bark- and wood-borers digest wood and produce sugar. Fungi are the chief agents in clearing away the remains of plants. Many fungi are able to dissolve their way through wood of both living and dead plants by means of proper enzyms. When fungi attack and thus digest the cell-walls of living plants they cause disease. When the same materials are acted upon by organisms living upon the lifeless remains of these same species, the result is beneficial. The action in both cases is by means of appropriate enzyms. Thus *cytase* dissolves pure cellulose, while *hadromase* dissolves wood. The final products in all cases are CO_2 and H_2O.

COMMERCIAL FIBER PRODUCTION. — Pectinase dissolves the substance which cements the walls of the fibrous cells of flax and other fiber-producing plants. *Pectinase* by its activities releases the fibers for weaving or other mechanical treatment. In practice, the fibers of flax and other textile materials are obtained on a commercial scale by a process of rotting in water known as retting. This is accomplished by one or more species of bacteria living in water, the desired action of which is the production of pectinase which dissolves the fiber-cementing material. However, as general decay accompanies this specific action, the strength and color of the fiber are impaired and the process is to this extent objectionable. Attempts have been made to carry on retting by means of pure culture, and it is conceivable that under certain conditions at least the product may be improved in this way. It is also conceivable that autolysis may be made to yield the desired result without corresponding injury. In these fermentations, as in the others above described, the cell-wall materials are digested by being converted into sugars which furnish the fungi, bacteria, or other organisms with the food which they require.

Decomposition of Fats and Oils is accomplished by the action of organisms. Thus, for example, in butter which we eat and butter which we keep too long, the enzyms are *lipases*. These, whether formed in the intestine or by bacteria, break down the fats to glycerine and fatty acids. These in turn may be further broken down or oxidized in the cells, until finally CO_2 and H_2O are the end products. Corresponding amounts of energy are liberated in the successive stages of decomposition.

Decomposition of Nitrogenous Waste. — It has been shown (Chap. VIII) that some of the nitrogenous food and some of the nitrogenous material of the animal body are broken down in basic metabolism and thrown off, being excreted mainly by the kidneys in the form of urea. This partly oxidized compound serves as food and fuel for certain species of bacteria, which further oxidize it to ammonia and CO_2. The liquid organic nitrogenous wastes are thus broken down to their original status of raw materials which are restored to the soil, and the energy involved in their manufacture is once more released.

THE SOLID NITROGENOUS WASTES, consisting of proteins, amino-acids, and the intermediate products, undergo successive decompositions by the corresponding bacteria which are nourished thereby, ammonia and CO_2 being the end products. In the course of such decompositions offensive odors may be produced. Hence the name putrefaction is applied to them. But whether the process results in the production of evil smells or not, the results are the same, the release of energy and the production of simpler and simpler compounds until the residue finally appears as ammonia and various sulphates and phosphates.

PUTREFACTION IS BROUGHT ABOUT chiefly by bacteria, aided to some extent by fungi. The number of kinds of bacteria accomplishing these changes is very large, and the exact chemical reactions produced by each are as yet only imperfectly known. While bacteria requiring free oxygen (*aerobes*) are able to decompose proteins, this ability is shared by certain species of bacteria (e.g., Bacillus botulinus) which can be active only in the absence of free oxygen (*anaerobes*). Many of the former can carry the process to completion, giving rise to CO_2 and ammonia (NH_3). The anaerobic bacteria cannot usually carry decompositions so far, and the two sorts form intermediate products which are more or less different.

PUTREFYING SUBSTANCES are of many sorts and from many sources — meat, milk, eggs, seeds, are familiar materials which putrefy. Compounds which undergo actual putrefaction are proteins and their primary derivatives. From these proteins, mainly by bacterial activities, though fungi may also take part, the amino-acids are formed, which may in turn be broken down to still simpler compounds.

THE PRODUCTS OF PUTREFACTION. — While the end products CO_2 and H_2O and ammonia are readily enough recognized, there are a great many intermediate products, many of which are only temporary. The first products are similar to those produced in digestion, and include peptones and albumoses, which are decomposed into the animo-acids. A number of gaseous compounds may also be formed, among which are methane (CH_4) and hydrogen sulphide (H_2S). Bubbles of methane and sulphuretted hydrogen may often be seen rising from the muddy bottoms of swamps, and sulphuretted hydrogen is given off by rotten eggs and by the decaying remains of plants and animals accumulated in the mud at the bottom of slow-running polluted streams and in ponds. Sometimes H and N are also given off. The volatile compounds which characterize putrefaction include mercaptan, skatol, and indol, substances the composition of which has been fairly worked out; but undoubtedly in addition to these, and associated with putrid odors, are others not yet known which give the characteristic smells to the putrefactions of different materials.

PTOMAINES form one of the most interesting groups of degradation products from protein. They are simple compounds of C, H, O, and N, produced by bacterial decay in food. They resemble the alkaloids used in medicine and include some of the most violent poisons known. Bacterial toxins, on the other hand, are characteristic metabolic products of certain species of bacteria, and are largely independent of the food upon which they are living.

THE PUTREFACTION PROCESS may be best illustrated by a specific instance. Thus we may discover the body of a cow recently dead, lying on the ground. This body contained at the time of death many bacteria within its digestive tract, and it becomes infected with other destructive bacteria, none of which can be held in check by the dead organism as they would have been had the body continued to live. The activities of these bacteria result in the production of enzyms which carry on hydrolysis — the splitting of proteins into simpler organic nitrogenous compounds, like the albumoses and peptones — which are themselves broken down by other enzyms to animo-acids. The putrefying carcass, furthermore, bloats from the production of gaseous substances within the cavities of the body, and the series of decompositions includes the production of those offensive odors which indicate to us the presence of a dead animal. As the body of the animal breaks down mechanically as well as chemically, the final products of decay are liberated, escaping into the air or washing into the soil, thus becoming once more available as raw materials for the manufacture of food by plants.

SUMMARY. — From the illustrations which have been employed it should be clear that the decomposition of *carbohydrates* and *fatty substances* consists of successive phases. These consist in processes resembling those which go on in the plant or animal body and properly termed digestion. The products of digestion, whether inside the living body or in excreta or in lifeless remains, may be oxidized, thus liberating energy which may be used by the active organisms. The final result in every case so far investigated is the liberation of the energy originally stored by photosynthesis or by other metabolic processes, and the setting free of the C in the form of CO_2 and H in the form of H_2O. Thus through all the multifarious transformations of substance there has been no loss of material or of energy. The free energy of the sunlight has been stored up in organic compounds as potential energy, to be liberated either by the organism which stored the energy or by others in their various activities.

The proteins are broken down in the animal body itself by digestion, etc., and in the lifeless remains of animals and plants, by the aid of other organisms, mainly bacteria and fungi. Here also the substances and the energy used in food manufacture are returned in useful form again to the air and the soil from which they were taken. In the ordinary course of nature there is little or no disturbance of the balance in a given area. Only where man or fire or some other accident (volcanic) intervenes is there any considerable departure from the regular cycle.

CHAPTER XXIV

THE FERTILITY OF THE SOIL

The Exhaustion of the Soil by Plants would occur in a comparatively short time unless there were some way to replace the substances which they remove. In an earlier chapter it was shown by chemical analysis that the bodies of plants contain the elements carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur, potassium, magnesium, calcium, iron, silicon, sodium, and chlorine. It was further demonstrated by the water culture method that all of these except the last three are indispensable to green plants. All of them except carbon and oxygen are derived entirely from the soil in water solution. Suitable soluble salts of nitrogen (nitrates), phosphorus (phosphates), and potassium are scarce in most soils. Hence their prompt return to it in a form suitable for use is a prime requisite in maintaining the fertility of the soil.

Natural Fertility. — In a state of nature the compounds removed from the soil are, after a longer or shorter sojourn in the bodies of plants or animals, usually returned to it in the same vicinity, where they are acted on by a series of microörganisms and fitted for use again. Under such conditions there is no exhaustion of fertility, but there may actually be an increase of it, by means to be explained presently.

Fertilizers. — Under cultivation it usually happens that the crops are removed from the fields and little or none of their substance returned. The loss thus sustained must be made good by the application of fertilizers. By this term the agriculturalist means compounds or mixtures which contain the elements in which the soil is deficient. The remains of plants and animals and their wastes have been used as fertilizers from time immemorial and are naturally among the best, since they contain the very elements which were removed from the soil.

Certain deposits of rock are rich in phosphates which can readily be made available for plant use. Cyanamid, a waste product of certain manufactories, contains available nitrogen. Guano is the excrement of certain sea birds which has been deposited for ages on some islands off the Pacific shore of the rainless region of South America. It is rich in nitrogen compounds. Sodium nitrate, or Chili saltpeter, is mined in northern Chili and shipped to Europe and the United States. Potash, composed of potassium compounds, is extensively mined in Germany and is obtained to a less extent in the western United States. During the war it was secured from sea weeds. Nitrogen compounds are now being manufactured from the free nitrogen of the air by the use of electricity.

Animal Wastes. — In previous chapters it has been shown that some of the carbohydrate foods are used in the formation of protein by plants. The latter substances are used chiefly to build new protoplasm or to repair the wastage of mature cells. Once a part of the living machine, it is relatively fixed, but not absolutely so. In the very process of living, protoplasm produces certain waste compounds containing nitrogen, which are excreted from the body in the urine. The last chapter described the changes induced in these by bacteria, whereby they are broken down to ammonia (NH_3) compounds.

Microörganisms. — There are many kinds of bacteria (Fig. 63), fungi, and small animals in the soil. Some bacteria are concerned with fermentations and putrefactions, but several are directly concerned with changes in the compounds of nitrogen and sulphur which have to do with soil fertility. For present purposes, the following will be discussed: (1) The nitrifying bacteria; (2) The nitrogen-fixing bacteria; (3) The denitrifying bacteria; and (4) The sulphur bacteria.

THE NITRIFYING BACTERIA. — There are two separate and distinct sorts of bacteria concerned in changing ammonia compounds into usable nitrates. The first kind can utilize ammonia and oxidize it to nitrous acid compounds called nitrites. The second set can make no use of ammonia compounds, but must have nitrites which they

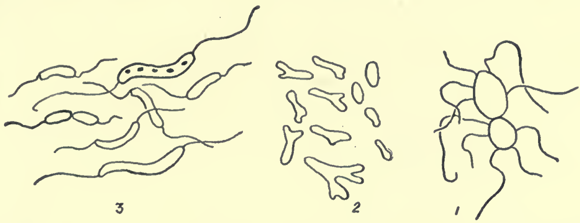


FIG. 63. — Soil Bacteria. Fig. 1, Azotobacter, a motile bacterium living in the soil which is able to fix the free nitrogen of the atmosphere and leave it behind after its death in such a form that it can eventually be used by higher plants. Fig. 2, Tubercle bacteria, which inhabit the soil and invade the roots of clover and other leguminous plants, causing the plant to form tubercles in which the bacteria live. They also fix free nitrogen and thereby enrich the soil. Fig. 3, Sulphur bacteria living in soil water. They are able to utilize the gas, hydrogen sulphide, as a source of energy by oxidizing first the hydrogen to form water and later the sulphur to form compounds of sulphuric acid.

oxidize to nitrates, being thus dependent on the first sort.

THE NITRITE BACTERIA. — There are several different species of soil bacteria which can change ammonia compounds into compounds of nitrous acid called nitrites. They all seem to have essentially the same mode of life. This is indicated in a simple way by the formula: NH_4OH (ammonia) $+ 2O_2$ (oxygen) $= HNO_2$ (nitrous acid $+ 2H_2O$ (water). Of course the actual chemical processes are more complicated because the ammonia may occur in the soil in other compounds, e.g., ammonium carbonate $(NH_4)_2CO_3$. The reaction is presumably brought about by the action of an oxidizing enzym formed by the bacteria. It is also one which yields energy, which the organisms use to change CO_2 or some carbonate (e.g., $CaCO_3$, calcium carbonate) into such compounds as are useful to them in carrying on their life activities.

The Nitrate Bacteria cannot use ammonia or its compounds, but are restricted to the nitrites formed by the organisms discussed in the last paragraph. Presumably by means of an enzym they oxidize nitrous acid and its salts to nitric acid and its salts somewhat as follows: $2HNO_2$ (nitrous acid) $+$ O_2 (oxygen) $=$ $2HNO_3$ (nitric acid).

Nitrifying Organisms and Higher Plants. — The contrast between these two sorts of nitrifying bacteria on the one hand and the higher plants and other bacteria on the other is a striking and important one. Higher plants depend on complex carbon compounds for the energy to carry on their life processes (i.e., metabolism). They use some of this energy to transform simple nitrogen compounds like nitrates into the vastly complex ones which constitute an important part of their protoplasm. These bacteria do just the opposite. They can use only simple compounds of carbon like CO_2. This they build into such complex forms as they require by the energy derived from oxidizing nitrogen compounds. Furthermore, they leave the nitrogen in just those compounds which are required by the higher plants.

Effects of Cultivation. — Both sorts of nitrifying bacteria work best in soils with an alkaline reaction and are injured by wet acid soils. For this reason they usually thrive under cultivation because this tends to secure proper aeration and suitable distribution of moisture, and prevents the formation and accumulation of injurious acids.

The Nitrogen-fixing Bacteria are so called because they take free atmospheric nitrogen and unite it with hydrogen and oxygen from water to form *complex* compounds. This reaction is one in which energy is stored up. The bacteria derive their energy to do this and to carry on all their other metabolism from the oxidation of carbon compounds such as sugar which occur in the soil. These are derived chiefly from the remains of plants consisting largely of cellulose and similar materials.

Through the activities of these bacteria actual additions of available nitrogen compounds are being made to the soil. It is interesting to note how these nitrogen-fixing organisms supplement the work of the nitrifying bacteria. The latter are engaged in changing already existing compounds of nitrogen to simple nitrates and cannot do their work in the presence of soluble carbohydrates. The former also form nitrates, but they do it by fixing free nitrogen and must have suitable organic food to do so. And so they are most efficient just when the nitrifying bacteria are least efficient.

A considerable variety of soil organisms can fix nitrogen: (1) Free-living soil bacteria, (2) Soil bacteria living symbiotically with algæ, (3) Bacteria living symbiotically with certain leguminous plants in root tubercles, (4) Certain fungi called Mycorrhiza, living symbiotically on the roots of a number of species of trees and shrubs.

Free-living Soil Bacteria able to fix nitrogen are numerous and of several different kinds (Azotobacter, Granulobacter, Amylobacter, Clostridium). Although they are not equally numerous in all soils, they seem to be almost universal in their distribution. Provided by cultivation with suitable conditions of growth, they will multiply and enrich the soil in almost any part of the world. The bodies of these bacteria are said to be richer in nitrogen than any other living things so far investigated.

Bacteria Symbiotic with Algæ. — In the surface layers of the soil there is enough light for some lowly algæ. They, of course, fix carbon by photosynthesis and need nitrates. It is said that some sorts of nitrogen-fixing bacteria form a symbiotic arrangement with them in which the algæ receive nitrates in return for the sugars or other soluble carbon compounds which the bacteria absorb from them. The exact facts appear not yet to be determined in respect to the relation existing between these classes of organisms. It has been recently reported that some of these algæ can fix their own nitrogen.

Tubercle Bacteria. — It is a widely known fact that clover and some other leguminous plants enrich the soil. This bit of knowledge had passed into common slang in the phrase, "too poor to grow beans," long before its scientific explanation had been worked out. On the roots of such plants there occur small swellings variously called nodules or tubercles. Inside them are found numerous bacteria of a special sort. When the plant is young its roots are attacked by the bacteria which penetrate into them through the delicate root hairs and establish themselves in the outer layer of root-cells. The root reacts by multiplying these cells in number, thereby forming a sort of tumor-like outgrowth in which the bacteria are confined. Here they fix nitrogen, deriving the energy to do so from the carbon compounds obtained from the root-cells. In return the root uses their nitrogen compounds.

Mycorrhiza are masses of fine hyphæ or filaments of certain sorts of fungi which attack the roots of some kinds of trees and shrubs. They penetrate the root and take from it organic carbon compounds. Outside, they ramify through the soil. They have the power to fix nitrogen, which they share with the roots. This arrangement appears to be so satisfactory to both partners that some of these trees no longer even form root hairs but absorb all their water and salts through the fungus. This arrangement illustrates another interesting adaptation of organisms to their environment; for most of these trees grow in soils which are poor in nitrates and also unfit for the growth of the nitrifying bacteria.

Denitrifying Bacteria are those which reduce nitrates, i.e., break up the compound and liberate the nitrogen as a gas. Obviously, from the point of view of conserving soil fertility, they are undesirable. Fortunately they thrive best in wet and poorly aerated soils and do not do much damage in properly cultivated soils. Drainage, aeration, and addition of lime to neutralize the acids are the usual means of holding them in check as well as promoting the activity of the nitrifying organisms.

Sulphur Bacteria. Sulphur is taken from the soil in solution as a compound of sulphuric acid (H_2SO_4) and built into the proteins and some other compounds of plants and animals. In putrefaction it is commonly liberated as hydrogen sulphide (H_2S) gas, familiar as the odor of over-ripe eggs. In this form it is usable by types of soil and water bacteria which oxidize the hydrogen to form water and store the sulphur in their bodies. When the supply of hydrogen sulphide runs short they oxidize this stored sulphur to form sulphuric acid and its sulphates.

The Carbon Cycle. — It is clear from what has been said in this and preceding chapters that almost the only source of the carbon of organic carbon compounds is the CO_2 of the air. This is combined with H_2O by green plants to form foods and fuels. These in turn are used by nearly all living things as their source of energy. In their metabolism they oxidize carbohydrates and fatty foods to CO_2 and H_2O. Thus the carbon withdrawn from the air as CO_2 by the green plants in the process of photosynthesis is eventually returned to it when the food is oxidized by the protoplasm of some animal or plant. Fuels are also oxidized in stoves and furnaces, and yield CO_2 and H_2O. The same carbon has been in this manner used over and over again by successive generations of organisms (Fig. 64).

The Nitrogen Cycle, like that of carbon, permits the same nitrogen to be used repeatedly. Starting with the abundant supply in the atmosphere, it is first made available by nitrogen-fixing organisms. Accumulating in the soil by the activities of these organisms, the nitrates are taken up by green plants and combined with sugars and sulphuric and phosphoric acid compounds, to form amino-acids and proteins. These are used to form living protoplasm or to repair its wastes. When dead, protoplasm

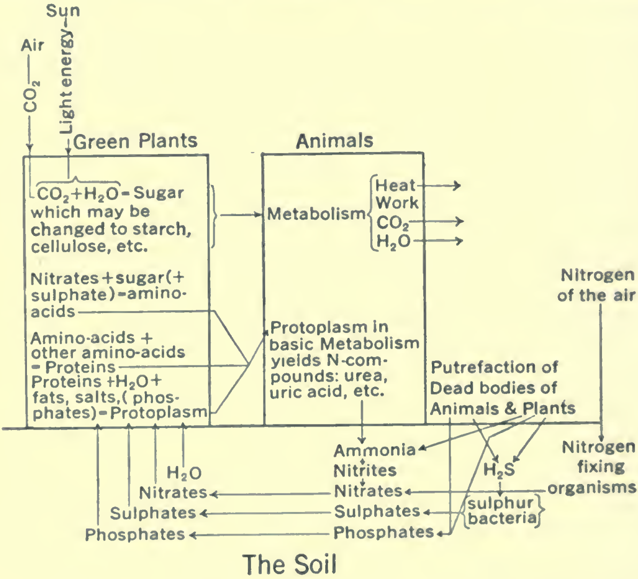


FIG. 64. — A Diagram to show some of the transformations of carbon and nitrogen in the course of their utilization by living organisms. Note that the air constitutes the great source or reservoir from which both carbon and nitrogen are drawn by the metabolism of plants. Note further that only green plants can withdraw the carbon from the air to manufacture sugar and only certain sorts of bacteria and other low forms of plants can utilize free atmospheric nitrogen. All animals depend on these plants directly or indirectly for their usable compounds of carbon and nitrogen. The sun is the original source of the energy used to synthesize sugar and other organic compounds of carbon and nitrogen. In the various transformations which these compounds undergo until finally released as carbon dioxid, water, nitrates, etc., all the energy which was originally locked up in them is again freed in the form of work or heat.

and its wastes are both decomposed by putrefaction and yield ammonia, which in its turn is oxidized to nitrate. These may be either used by green plants again or reduced to gaseous nitrogen by the denitrifying bacteria, and so complete the cycle.

SULPHUR AND PHOSPHORUS CYCLES. — It has already been explained that sulphur taken up by plants as sulphuric acid compounds is built into protoplasm and reappears during putrefaction of dead plants and animals as the malodorous gas, hydrogen sulphide. This in turn is eventually restored to the soil as sulphates by the action of the sulphur bacteria. Phosphorus enters the plant as a phosphate and becomes a part of the cells. On their death and decomposition it reappears as phosphoric acid and unites with lime or other earthy material to form phosphate again.

THE ENERGY CYCLE differs from the material cycle just discussed in that it is not a closed one so far as the earth alone is concerned. The energy for photosynthesis comes from the sun in the form of light. It is locked up in food and fuel. When liberated by metabolism or combustion it reappears in the form of chemical energy, heat, or mechanical work. In these forms it is eventually dissipated into space or stored up in other chemical compounds or in energy of position, when expended in raising a weight, for example. In no case is it again usable directly by green plants. In the case of fuel burned to run an electric light plant, some of it could be used again. Whether that which escapes into space ever returns as light is a question not answerable in the present state of knowledge.

PART II

SECTION 8

GROWTH AND REPRODUCTION

CHAPTER XXV

CELL-DIVISION

The Growth of Organisms. — In earlier chapters it was shown that living things grow by the transformation of certain sorts of food into their living substance, and that complex organisms are composed of very numerous cells highly specialized to perform their particular functions. And furthermore it was indicated that all the different sorts of cells in a complex organism arise from a single original one by division. Growth of a higher animal or plant thus consists of three things: (*a*) the making of new protoplasm whereby the individual cell becomes larger, (*b*) the division of the cell when it attains its appropriate size, and (*c*) the gradual specialization of different cells to perform their individual functions.

Cell Growth and Division. — Assuming the ability of protoplasm to take food of a suitable sort and assimilate it into its own substance and thereby increase the amount of living cell contents, it is now desired to direct attention to the fact that cells have a definite limitation to their increase in size. When a cell reaches the size characteristic of the particular plant or animal of which it is a part, it either ceases to grow or it divides. Very little is known respecting the mechanism which determines what this size must be. On the contrary, the advantages of size limitation are obvious. Since cells take in food and excrete their waste through their surfaces, it follows that the rate of this exchange will be determined by the extent of the surface. The surface of a cube or ball increases as the square of the diameter (Fig. 65). The volume increases with the cube. Thus doubling the diameter of a spherical cell would multiply its area four times (i.e., the square of 2) and its volume eight times (i.e., the cube of 2). The result would be that the volume or amount of protoplasm to be supplied through the surface of the cell would have increased twice as much as the surface through which it is to be supplied. Clearly, further increases in size would finally reach a point where the volume of protoplasm in the cell could not be sup-

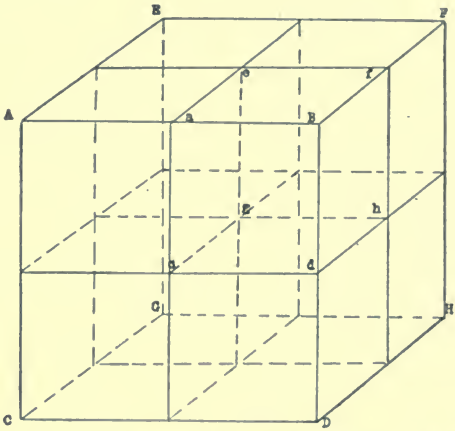


Fig. 65. — The Comparative Surfaces of Solids. The edge of the larger solid is 2 in. on each side. It therefore contains 8 cu. in. Each side is 2 x 2 in. and hence 4 sq. in. in area. The whole area is thus 24 sq. in. A cube of 1 in. on the side, as e.g., the one in the upper right corner of the larger one, *a*, B, *c*, *d*, *e*, *f*, *g*, *h*, contains 1 cu. in. and has a surface of 6 sq. in. From these figures it is clear that doubling the side increases the area 4 times but at the same time increases the solid contents 8 times. In other words the contents increase twice as fast as the area. Although not quite so obvious this fact is equally true of a sphere or any other shape of solid.

plied through its surface in an adequate manner. It is not improbable that this state of affairs may act as the stimulus to division. Plant cells usually meet this situation by forming a large vacuole which reduces the volume of protoplasm accordingly. As we should expect from this fact, plant cells are on the average larger than those of animals.

The Mechanism of Cell Division is very much better understood than the stimulus which brings it about. In the great majority of cells division begins with the nucleus, which undergoes a complicated process known under a variety of names, nuclear division, mitosis, karyokinesis. This process can be best studied in the growing animal embryo or in the growing regions at the tips of roots (Fig. 66) or stems. Before we can understand the

Fig. 66. — Cells from the Growing Region of the Root Tip of an Onion. Note carefully the different sizes and shapes of the cells and that the chromatin is in a different stage of development in different cells.

process it will be necessary to consider the structure of the nucleus.

The Resting Nucleus in most cases consists of a surrounding envelope known as the nuclear membrane, a semi-fluid sap, a network of chromatin, and a nucleolus (Fig. 67). The most important part, at least the most permanent part, of it is the chromatin. In the cell which is not in a state of division the chromatin appears in stained specimens to consist of irregular threads which frequently intersect. They are of very irregular size and shape and almost always much thickened wherever they join one another. Chromatin is called by this name (derived from the Greek word for color) because its substance colors easily and beautifully when various dyes are applied to it. The stuff of which it is composed is a very complex nucleo-protein, or more likely an aggregation of many slightly different complex proteins. The nucleolus is also a protein body. It appears to be some-

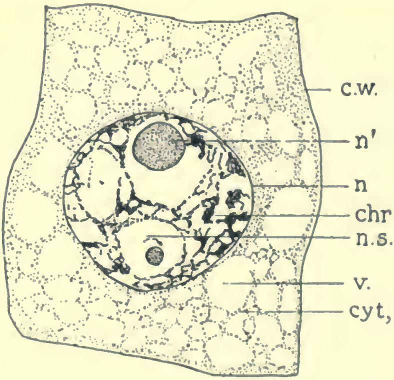


Fig. 67. — A Typical Plant Cell, from the root tip of the Spiderwort (Tradescantia virginica). *c.w.*, cell wall; *cyt*, cytoplasm; *n*, nucleus; *chr*, chromatin; *n.s.*, nuclear sap; *n'*, nucleolus; *v*, vacuole filled with water and dissolved substances.

what less complex in its chemical structure and is not a permanent organ of the nucleus. It is thought by many to be rather of the nature of a supply of food for the growth of the chromatin than an actual living organ. It is certainly not an absolute necessity, since many nuclei do not possess nucleoli. Still less is known about the chemical nature of the nuclear sap. It seems likely that it is a colloidal solution of proteins, but whether it is living or not is not yet determined. The nuclear membrane is now known not to be a part of the nucleus proper but merely a thin membrane produced by the action of the nuclear sap on the surrounding protoplasm.

The Behavior of the Chromatin in preparation for and during nuclear division is most interesting and important (Fig. 68). The fibers of the net become dissociated from one another in such a way that long threads are formed. Sometimes one continuous thread appears; at others a number of separate threads are formed. They gradually elongate and become slender and uniform in diameter. Then a phase begins during which the thread shortens and thickens. If there is a single thread it now breaks into a certain definite number of separate seg-

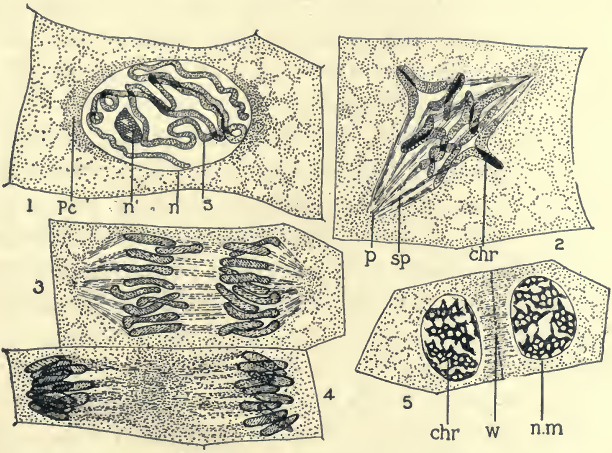


Fig. 68. — Selected Stages in Cell Division of Cells of the Root Tip of the Spiderwort. 1. The chromatin has organized itself into a long slender thread or spireme and the cytoplasm begins to show indications of the organization of the spindle. 2. The spireme has broken into fragments, the chromosomes, each of which is split lengthwise and arranged at the middle of the spindle where the two exactly equivalent halves are being separated. 3. The halves are completely separate and moving toward their respective poles of the spindle. 4. The chromosomes have arrived at the poles and are aggregated in a close mass but have not yet been surrounded by a nuclear membrane. 5. The nuclear membrane and nuclear sap have formed and the chromosomes are beginning to undergo a process of vacuolation which will eventually reduce each one to a state more or less resembling a very much broken rubber sponge. *p.c.*, polar cap of cytoplasm out of which the spindle fibers are organized; *n.m.*, nuclear membrane; *s*, spireme; *n'*, nucleolus; *sp*, spindle fibers; *p*, pole of spindle; *chr*, chromosomes.

ments called *chromosomes.* This number is fixed and constant for the cells of any particular plant or animal.

The Formation of the Nuclear Spindle. — At the time the chromosomes begin to be developed from the chromatin net the cytoplasm around the nucleus presents an unchanged appearance. As they proceed with their development, fibers begin to appear at two sides of the nucleus. They are formed from the cytoplasm itself merely by a rearrangement of its structure. Each fiber has one end directed at a point a short distance from the nucleus, technically known as the pole of the spindle, and the other toward the nucleus itself (Fig. 68.1). Sometime during the formation of the nuclear fibers the nuclear membrane disappears, thus leaving the chromosomes free in the cell. Some of the spindle fibers then extend to them and become attached. The spindle fibers converge to two poles on opposite sides of the nucleus, and some fibers from each pole become attached to each chromosome. The processes so far described belong to the preparatory stage of division, technically known as *pro-phase.*

The Splitting of the Chromosomes. — After the fibers are attached to the chromosomes the latter line up and form a flat figure midway between the poles. Each then splits lengthwise to form two exactly similar halves (Fig. 68.2). The split occurs in a plane at right angles to the spindle so that the fibers from one pole are attached to chromosome-halves on their own side. The respective halves next migrate toward the pole to which their spindle fibers are directed. This stage of nuclear division is called *metaphase.*

The Anaphase (Fig. 68.3) covers the period during which the chromosomes are moving toward the poles of the spindle. It is easy to observe what occurs, but difficult to explain how it is brought about. Some observers are of the opinion that the fibers undergo a contraction and draw the chromosomes along with them. Others think that the fibers are not solid at all but merely represent lines of force along which the fine protoplasmic granules become arranged like the iron filings in the field of a magnet. In support of the latter opinion is the fact that the polar ends of the fibers do not seem to be attached to anything solid enough to permit them to exert a tractive force on the chromosomes. Moreover, the polar ends often seem to dissolve away even before the chromosomes have completed their movement. When we consider that we do not yet understand at all well how any sort of protoplasmic movement is produced, it should not be surprising that this particular sort should still be obscure.

THE TELOPHASE AND THE RECONSTRUCTION OF THE NUCLEUS (Figs. 68.4 and .5). — When the chromosomes arrive at their respective poles they at first draw close together and often become so crowded that it is difficult to distinguish their individual outlines (*telophase*). The next step ordinarily consists in the appearance of a new nuclear membrane closely surrounding the crowded chromosomes. Shortly it will be seen that the membrane is enlarging and that there is now a small amount of nuclear sap. It is the current opinion that the membrane is merely a thin layer of cytoplasm of a more solid character than the rest. In fact a very similar layer is present on the outside, next the cell-wall, if there is one, or forming the outer covering of one-celled animals. If one punctures the outer layer of protoplasm with a fine needle the more fluid part at once runs out through the hole, but as soon as it comes in contact with the surrounding water it immediately forms a new membrane. It is supposed that the cytoplasm reacts in this same way to the nuclear sap as soon as it is formed, and thus gives rise to the nuclear membrane.

INDIVIDUALITY OF THE CHROMOSOMES. — As the nucleus expands, the rod-like chromosomes also begin to expand and to become distended by vacuoles, possibly of nuclear sap. This process might be roughly likened to the holes formed in dough by the gas produced by yeast. The final result is to reduce each chromosome to a ragged network. These individual nets become closely associated in the nucleus and presently it is no longer possible to tell where one stops and another begins. In exceptional cases the individual nets can be recognized at all times and so we know that in these particular organisms each chromosome maintains its own individuality at all times. Although this cannot be directly observed in most plants and animals there is much indirect evidence to indicate that it is true for them also.

THE DIVISION OF THE CELL-BODY does not occur until after the nucleus has completed its division. About the middle of the spindle, there is left a mass of fibers which extend entirely across from pole to pole and are not attached to the chromosomes. As they shorten the ends are drawn in toward the middle and thickenings are formed at the middle point. Eventually these touch and spread out to form a sort of membranous plate across the middle of the cell. A split appears in this plate and the two halves separate slightly so that a cell-wall can be laid down between and joined at its edges to the old wall. When all this has been accomplished it remains only that the two new cells should again grow to full size and either become differentiated in their final form or else repeat the division process.

SUMMARY. — The important points to bear in mind are:

1. That the nucleus contains a definite fixed number of chromosomes for each and every kind of animal or plant.

2. That each chromosome maintains its own identity throughout all the changes of form.

3. That each increases its substance through growth, and divides lengthwise into two identical halves.

4. That one half of each goes to each new nucleus.

5. That the net result of the whole process is to guaran-

tee that each cell of the plant or animal body has exactly the same number and kind of chromosomes.

N.B. It will be shown later that actually each cell has its chromosomes in pairs, one member of each pair being originally derived from each parent. It will also be shown that the members of each pair are nearly, though not necessarily exactly, alike.

CHAPTER XXVI

REPRODUCTION IN ANIMALS

Reproduction. — Each species of living thing persists from century to century, while the life of the individuals composing it is of comparatively brief duration. A dog or rabbit, for example, comes into existence, grows to a definite size, lives its allotted time, and provides for the continuation of the race by producing offspring to take its place. This process of producing new individuals, and thus insuring the perpetuation of the species, is known as reproduction.

In the many-celled animals the division of labor among the cells composing the body is associated with the development of male and female reproductive or germ-cells, which under certain conditions to be described later, develop into new organisms. This is known as sexual reproduction. In a host of lower animals the body divides to form two offspring; or bud-like outgrowths are formed which separate from the body and become new individuals. Sex cells, in such cases, play no part whatever, and hence this type of multiplication is known as asexual reproduction. In both types of propagation the new individual has its beginning in one or more cells derived from the parent. The living material is passed from one generation to the next. "All life from pre-existing life" is to-day a rule without a single known exception.

Spontaneous Generation. — Although it has been known for thousands of years that animals and plants beget their kind, it was also held until recent times that this rule is frequently broken in cases of supposed spontaneous generation where it was believed non-living material becomes transformed into living substance. Fishes and frogs were thought to be developed from mud, many insects from the juices of plants, and a horde of organisms was supposed to originate in decomposing masses of organic matter. In the Middle Ages certain physicians maintained that scorpions were generated in a plant, the sweet basil, and the public was warned against smelling it lest scorpions be generated in the brain and insanity result. Even in our own day we hear of horsehairs that are said to change into snakes, and earthworms and mosquitoes that rain from the sky.

Doubt was first cast on such a belief by the Italian naturalist Redi, who in 1660 performed the simple experiment of tying gauze over the mouth of a jar containing decaying meat, and proving that fly maggots were not spontaneously generated. Other investigators experimented with different forms of life with the same result. The bitterest fight was waged about the bacteria, or minute plants, which in some cases at least did appear to arise spontaneously. In 1861, Pasteur, the great French scientist, took the field, and as a result of carefully safeguarded experiments showed that even here spontaneous generation does not occur. Incidentally it may be added that Pasteur's work laid the foundation for the science of bacteriology.

Budding. — In asexual reproduction there are two main types — unequal division of the body or budding (Fig 69), and equal division known as fission (Fig. 4). At first sight it may appear that this is a somewhat artificial distinction, but in reality it is of fundamental importance, as will appear later.

Hydra (Fig. 7) affords an excellent example of budding in which the first indication is a pouch-like outgrowth of the body-wall of the side of the animal. As this increases in size tentacles and mouth appear on the free extremity, and after further growth the bud constricts its base and, separating from the parent, leads an independent life thereafter.

In many sponges small buds develop on the inside of the body and with the death of the parent, or even before, become freed and grow into the adult condition.

Among the worms, especially the jointed or segmented worms related to the earthworm, there are many striking examples of budding. In certain species the body develops a head near the middle after which the hinder portion with the new head becomes detached as a new individual and swims away. In the case of the palolo worm of the Fiji and Samoan islands this hinder section never develops a head, yet it swims about in the fall months in countless numbers, and is collected as a highly prized article of food.

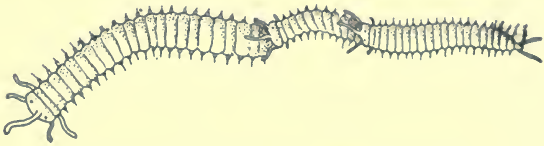


Fig. 69. — Budding in a Marine Worm.

Fission. — Fission, or the equal division of an organism into two daughter individuals, is a widespread mode of asexual reproduction with the lower animals. Among the unicellular organisms, for example, it is undoubtedly the most common method of multiplication. In the amœba, that may be taken as a type, the nucleus first divides, and then the cell protoplasm gradually draws apart until the connecting strand separates and two offspring thus arise. In the sea anemone, related to hydra, the body occasionally divides into equal parts, and among certain small species of flatworms fission appears to occur whenever there is abundant nourishment.

In all these cases, and others that might be cited, the half-sized descendants grow to the size of the original parent, and repeat the process if conditions are favorable.

Before leaving this subject an important distinction between budding and fission should be noted. An organism may produce a few or many buds, but it ultimately dies. In fission, on the other hand, the parent vanishes in the creation of two descendants out of the same material and no death occurs (see Chap. XXII).

Results of Asexual Reproduction. — The upper limits of sexual activity are reached in the case of the shipworm or teredo and certain species of tapeworms that lay 70,000,000 eggs a year; yet even this number of individuals is far short of what is known to be asexually produced in much less time by many unicellular organisms. In Stylonychia, a close relative of Paramœcium, the body divides once in every eight hours. In six days, if favorable conditions could be maintained, the number of offspring would be countless and their combined mass would weigh approximately fourteen pounds. In thirty days the aggregate, it has been estimated, would be a million times greater than the sun. Although such excessive numbers are never realized, there is rapid multiplication during favorable periods, and some cells are certain to be carried into situations sufficiently favorable to enable them to persist.

It will be seen that while this mode of reproduction tends to produce almost unlimited numbers, it obviously produces individuals that closely resemble each other. Sexual reproduction, on the contrary, for reasons that will be shown in a subsequent chapter, is much more likely to result in offspring that are unlike and are therefore more favorable subjects for the process of evolution.

Regeneration. — Regeneration is the ability of an animal or plant to replace lost parts. In certain species among the lower animals this may lead to the production of new individuals, and thus be a form of asexual reproduction. The sponges, many relatives of hydra, worms of various kinds, the starfishes, and several other animals are without firm protective envelopes and hence are subject to frequent mutilation, by the action of waves, for example. In each case the damage is repaired and where the body is torn in two the missing portions are often replaced and two individuals result. A flatworm may be broken into more than two hundred pieces and each will form an entire new individual.

Crabs, insects, and spiders, when seized by one of their legs, will often separate the limb from the body, which then scuttles off to a place of safety. Lizards and some species of salamanders drop the tail when roughly treated, and while the actively wriggling appendage occupies the attention of the enemy the rest of the body generally escapes. Many starfishes frequently undergo a similar process of self-mutilation, while a number of species of the related sea cucumbers will throw out the entire digestive tract when molested. In most cases the missing portions are replaced by the process of regeneration, which is thus seen to be of prime importance to the existence of many species of animals.

Regeneration in Higher Animals. — Among the higher animals the process of regeneration is limited. In the frog and related salamander, the limbs that have been bitten or cut off will regenerate, but death results if the body is cut in two. An amputated finger in the case of man is never replaced, though regenerative changes occur that are of high importance. The skin grows over the damaged area, and beneath it the connective tissue, which ordinarily binds the body-cells together, forms a compact mass of scar tissue. This becomes penetrated by regenerated blood-vessels and by nerves when the injury is slight. Broken bones are repaired, but muscular and nervous tissues are never regenerated to any large degree, nor are internal organs replaced by regeneration.

A workman in an automobile factory, who has always made bolts, cannot successfully make tires. And apparently in much the same way a nerve-cell that conducts impulses, cannot assume the duties of digestion. In other words, the power of regeneration in organisms is most highly developed where the division of labor is comparatively slight and decreases as the cells become increasingly specialized.

Sexual Reproduction. — In every animal, with the exception of the simplest types, the cells of the body belong to two very distinct groups. There are those constituting the body proper, and others known as reproductive or germ-cells. The first form by far the greater part of the individual and are more or less specialized to perform a series of activities associated with food getting, avoidance of enemies, and the care of the young in many cases. These functions, however, merely serve to maintain the life of the individual, and sooner or later are terminated by death.

The germ-cells, on the contrary, take no part in these bodily activities, but after being nourished for a time by the body are capable, under favorable conditions, of development into new individuals that thus perpetuate the race. Since these reproductive elements are structurally unlike in the male and female, and are associated with the sex of the individual, this form of multiplication is known as sexual reproduction. In a subsequent paragraph it will be shown that even among the unicellular animals sexual reproduction occurs, and accordingly is probably characteristic of every species of animal. Multiplication by the sexual method depends on germ-cells or gametes, and not on body-cells, while in the asexual type the new individual is produced by body-cells alone.

The Sex-Cells. — Male animals produce germ-cells known as sperms or sperm-cells, while the female gives rise to eggs. The sperms are developed in a compact organ named the testis; the eggs are formed in an equally well-defined organ, the ovary. Each egg or sperm is a single cell. The sperms differ in shape as much as the species producing them. Nevertheless all agree in being very small, and the majority are slender thread-like bodies. In a typical example (Fig. 70) the nucleus is a highly compact body in the head of the tadpole-shaped cell, while the remaining protoplasm is drawn out to form a slender thread that serves as a locomotor organ. Each sperm is thus a cell whose form fits it for active swimming movements, enabling it to come in contact with an egg in the process of fertilization.

Eggs, with few exceptions, are spherical cells, without the power of movement, and contain food material, usually in the form of yolk. Where the young animal early shifts for itself, as in the case of the sea urchin, or

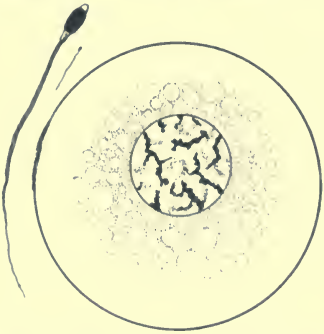


Fig. 70. — Egg and Sperm Cells. Smaller sperm of same magnification as egg, in which some of the food yolk is shown.

where it draws its food supply from the body of the parent, as in the rabbit, the amount of yolk is small and the egg scarcely measures over one or two hundredths of an inch in diameter. Nevertheless such ova are many hundreds of thousands of times larger than the sperms of the same species. At the opposite end of the series the amount of yolk is enormous. In a Japanese shark, for example, the egg is over eight inches in diameter, in the ostrich it is over three inches, in the domestic fowl one inch, and in many other fishes, lizards, and turtles the egg cells are only slightly smaller.

Accessory Sex Organs in the higher animals are those by means of which sperms and eggs are brought together.

Very few eggs and no sperms can develop into new individuals without fusion with the gamete of the other sex. In some aquatic animals this is very simple, since the mass of eggs which the female lays in the water attracts the male, probably by the stimulation afforded by some chemical substance which they give off, and causes him instinctively (see Chap. XV) to deposit the sperms in contact with them. In land animals this is not possible, and it becomes necessary for the female to retain the eggs in a special organ where the male may deposit the sperms in order to permit their fusion with one another.

Fertilization consists in the fusion of two cells, an egg and a sperm, each of which is a highly organized unit without the power of further division. At the beginning of the process the sperm-cell attaches itself to the surface of the egg (Fig. 71) and apparently is carried inward by movements of the egg protoplasm. During its continued journey into the interior the sperm nucleus gradually enlarges through the absorption of fluid until finally it becomes of the same size as the egg nucleus with which it comes in contact.

Results of Fertilization. — The important results of fertilization are two-fold. In the first place the union of the two sex-cells, each alone incapable of division, supplies a stimulus that impels the fertilized egg to undergo a large number of divisions resulting in a new individual. In the second place each of these sex-cells carries a definite number of chromosomes characteristic of the species. Let the number be four; the nucleus formed by their union thus contains eight. At every cell division these are accurately halved and distributed so that each cell of the body receives an equal number of paternal and maternal chromosomes. The high importance of this fact will be considered in connection with the subject of heredity, but at this point it may be pointed out that chromatin is the bearer of hereditary traits and the offspring inherits equally from either parent. The new individual is certain to be slightly different from either parent or their ancestors and there is a chance that it may be better fitted to continue the race. (See Chap. XXXV.)

INDIVIDUALITY OF THE CHROMOSOMES. — It has been stated in the preceding paragraph that all of the body-cells and the reproductive elements, throughout the greater part of their development, have a definite number of chromosomes. And this number is established at the

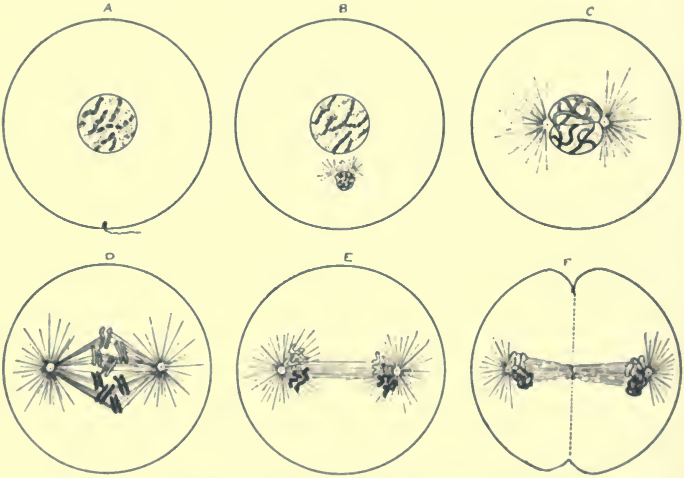


FIG. 71. — Diagram illustrating the fertilization of the egg and early development. *A*, entrance of the sperm. *B*, approach of sperm to egg nucleus. *C*, union of nuclei. *D*, splitting of chromosomes (those of sperm solid black). *E*, separation of the chromosomes prior to *F*, the division of the embryo into two cells.

time of fertilization by the union of the egg and sperm nucleus. Some of the insects, for example, have eight chromosomes, certain sea-urchins sixteen, some of the worms twenty-four, while there are forty-eight in man. If there are eight chromosomes in the fertilized egg, this characteristic number can be counted at each of the thousands of succeeding divisions. Indeed, in some species it is possible to follow the chromosomes from one cell to another. In others there are certain size differences among the chromosomes that appear unchanged from one cell generation to the next, and hence suggest that here also these bodies are self-perpetuating units. Also there is a wealth of evidence in connection with breeding experiments which practically amounts to definite proof that chromosomes retain their individuality. In other words, four of the eight assumed chromosomes in every body-cell are the direct descendants of those introduced by the sperm, while the others are from the egg. Just as individuals or cells are the lineal offspring through thousands of generations of other individuals or cells, so are chromosomes the descendants of pre-existing chromosomes.

Fertilization of Unicellular Animals. — Among the unicellular animals where obviously there are no special reproductive cells, there is nevertheless a fertilization process that in its essential features resembles that of higher animals. In Paramœcium, for example, two individuals come in contact and partially fuse together for a few hours' time, and during the period undergo a complicated series of nuclear changes. Without considering the process in detail it may be said that chromatin material is exchanged and when the two cells separate the nucleus of each is a fusion product as in the case of the nucleus of the fertilized egg. Each individual thus may be said to have fertilized the other. In several other species there are small actively swimming individuals, usually considered to be males, that permanently fuse with and thus fertilize larger female individuals.

It is generally believed that the introduction of new chromatin into the cell results in a changed individual that may be better fitted to perpetuate the race than the previous type. But that the union of the two unicellular organisms results in an increased capacity for cell division is a debatable matter. In some individuals it appears to be the case, in others it is quite the contrary. Evidently the two processes are not so closely associated as in higher types, but the subject requires further investigation.

Early Development. — The union of two germ-cells, as has been pointed out, results in every animal in a single-celled fertilized egg. Beyond this point its developmental path depends upon the kind of organism it is, although there are certain fundamental resemblances throughout.

In the starfish, which we shall use as an example, the fertilized egg divides by the ordinary process of division into two cells of equal size (Fig. 72). These again divide into four, these into eight, and so on until hundreds of cells of nearly equal size are produced. During this segmentation period, as it is termed, when the cells are dividing without forming any definite organs, a cavity appears in the midst of the cells, and increasing in size as the cells increase in number, becomes the hollow of a spherical one-layered group. The young starfish or embryo resembles a tennis ball, and at the end of thirty-six hours has attained the *blastula* stage.

The Gastrula and Body Layers. — With the increasing division of the cells, the blastula becomes somewhat flattened on one side, and is finally pushed inward in much the same manner as one pushes in the side of a hollow rubber ball. The cup-like depression deepens and finally becomes a comparatively slender sac known as the primitive gut or intestine. The embryo is now in the *gastrula* stage.

At about this time certain cells, appearing like minute amœbae, migrate from the tip of the primitive gut and wander about in the fluid within the cavity between the gut and outer cells. The embryo now comprises an outer, inner, and middle cell layer, respectively named the ectoderm, endoderm, and mesoderm. To anticipate, it may be said that the ectoderm gives rise to the skin, sense organs, and nervous system; the endoderm forms the lining of the digestive tract and the larger part of the digestive glands, such as the liver and pancreas; while the mesoderm develops into all of the other organs of the body, such as muscles, blood, body cavity, and germ-cells.

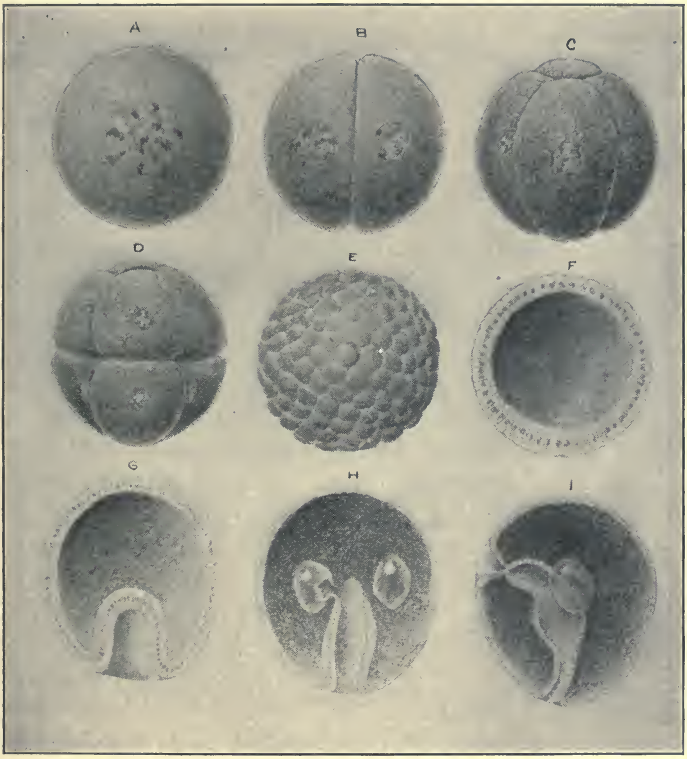


Fig. 72. — Early Development of a Starfish. *A*, *B*, *C*, *D*, early segmentation states, *E*, early blastula, *F*, late blastula in section, *G*, early gastrula; *H*, late gastrula showing budding of body cavities from tip of gut (front view), *I*, side view of *H*, showing development of mouth.

Later Development. — The hydra and the related sea anemones and jelly-fishes are little more than modified gastrulæ, and accordingly do not develop much beyond this point. In the higher groups, on the contrary, the body layers undergo many changes in attaining the adult condition. The starfish, for example, forms two pouch-like outgrowths on the tip of the intestine that finally sever their connection, like bubbles blown from a pipe, and ultimately form the body cavity, which contains the digestive tract, and the germ-cells.

At about the time the body cavity is developing, the mouth cavity appears as a depression in the ectoderm opposite the free end of the gut with which it finally comes in contact. The walls at the point of union become perforated and the alimentary canal thus becomes a tube open at both ends.

VERTEBRATE DEVELOPMENT. — The development of the starfish, as thus described, is in a broad way essentially the same as that occurring in most of the larger groups of animals. Beyond this stage the growth of the individual is largely a matter of detail without profoundly modifying the fundamental plan of the body. The frog, for example, passes through a gastrula stage, develops a body cavity, and thenceforth travels a developmental path that is characteristically vertebrate. The most striking feature of this early period of growth is the development of the central nervous system, which in the late gastrula stage makes its appearance as two folds, close together, that extend the length of the animal along the back (Fig. 73). These increase in height, meet and fuse along the mid-line, and the tube thus formed separates from the skin and sinks beneath it.

The mouth cavity that has formed, as in the starfish, develops in all classes of vertebrates four or five gill-slits that finally open to the exterior, as in a fish. In later life the gills disappear in the air-breathing vertebrates. The digestive tract lengthens, forms a stomach, and develops pouches that finally result in liver, pancreas, and, except in the fishes, lungs. Organs of special sense are in large measure modifications of the ectoderm and are of too complicated a character to permit of a brief description.

Limbs arise, a skeleton is formed, the blood-vessels make their appearance, and with growth changes that give the body its final shape the skin gives rise to the scales, feathers or hair that are characteristic of the adult.

Growth. — In the development of an animal from the egg to the adult the body absorbs yolk and other food substances, forms protoplasm in excess of that which is destroyed, and thus grows. In early life, especially, the increase in bulk is very rapid but it gradually slows down as the adult condition is approached. During this period

Fig. 73. — Development of Frog. *A*, early development of central nervous system of frog. *B*, closing of nervous system folds. *C*, later state with skin cut away to show complete separation of nervous system and a simple skeleton. Three gill slits are shown near mouth opening.

the animal may be starved and remain small, becoming a dwarf, or it may be abundantly nourished and grow to large size. Nevertheless, growth has its limits, except perhaps in the case of certain sponges and a few species of devilfishes. A mouse, for example, may be supplied with an unlimited amount of food yet it never grows to the size of a rat, though the bodily organization is practically the same in both.

Differentiation. — Development proceeds, as has been described, from a stage where no organs exist through a stage where they are but roughly outlined and only gradually reaches the point where they are in a completed functional condition. If the cells are examined during this period they also will be seen to progress from a condition where all appear to be essentially alike in form and structure. They usually move about to a greater or less degree in assuming their proper positions, and it is only toward the close of development that they assume the characteristic shape and organization of the various tissues. Development and differentiation thus proceed at an equal pace.

METAMORPHOSIS. — The process of development has been pictured as advancing by gradual stages from the egg to the adult. There are many animals, however, in which such is not the case. The young butterfly, for example, hatches from the egg as a crawling worm-like creature, the caterpillar or *larva*, that, after feeding on leaves and increasing in size, encloses itself in a web or at least becomes a quiet *pupa;* when certain complicated changes have ensued within the body, the pupal case bursts and a wholly different type of individual emerges fitted for a life on the wing and a diet of nectar. This marked change of form and function is known as a metamorphosis (Fig. 74). Fly larvae or maggots, the "wrigglers" of mosquitoes, the young of starfishes, sea urchins, crabs and worms are frequently so unlike the adults that it is only after the metamorphosis that their relationship can be determined.

Among the vertebrates, the frogs and toads undergo a complicated metamorphosis whereby the fish-like water-inhabiting tadpole becomes transformed into the air-breathing, four-legged and tailless land animal. In many eels the change from the transparent flattened larva to the round pigmented adult is likewise very marked. Finally, there are many larvæ, especially in the sea, whose life histories are unknown and whose structure is so unlike that of any known adult that their position in the animal kingdom is problematical.

CARE OF EGGS. — Among many of the lower animals, such as starfishes, sea urchins, and many worms, the eggs are laid in the water and are forthwith abandoned by the parent. On the other hand, the great majority of egg-laying or oviparous species insure the developing young against the attacks of enemies by providing them with some means of protection. The crabs, for example, attach the eggs to appendages of the body and fight off invaders, the spiders often carry their ova in silken cases, many animals construct brood pouches, and there are thousands of species that hide their eggs in safe retreats. Among many of the bees, wasps, and certain beetles not only are the eggs hidden but also a supply of food is placed within easy reach.

Many of the fishes, such as salmon and trout, bury the

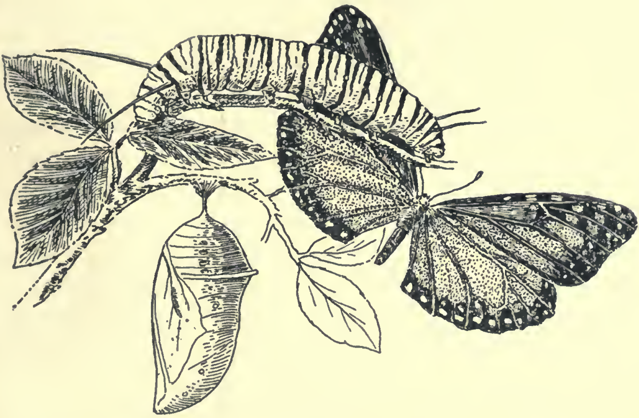


FIG. 74. — The Metamorphosis of the Monarch Butterfly.

eggs in the sand, others like the stickleback construct elaborate nests for them, the sea horses and related pipe fishes retain the eggs and young in folds of skin underneath the body, while certain other fishes attach their offspring to the skin or even carry them in the mouth. The eggs of frogs and toads are usually laid in water, though a few dry country species conceal them in folds of the skin on the back. The eggs of birds are usually placed in nests and the heat required for development is provided by the brooding parent. In the mammals, or hairy animals, the eggs are retained within the body of the mother.

Nourishment of Young. — Very little food yolk is stored in the eggs of many species of animals, and almost at the outset the young are compelled to forage for themselves. In other species, where the yolk is of greater amount and hatching accordingly is delayed, the struggle for existence begins at a somewhat later period. In either event, however, no parental care is exercised, and the newly hatched offspring are fully equipped for an active independent life. This, in large measure, continues to be the rule in numerous species where the young actually are under the care of the parents. Among the birds, for example, the parents normally supply some nourishment, but in the case of the ostriches, rails, plovers, ducks, quails and several related families, the young very early become independent in this regard.

In the mammals or hairy animals the eggs are retained in the body of the female, and — with the exception of the curious duckbill and the spiny anteater of the Australian region — the developing young are provided with special membranes and blood-vessels fitted for the absorption of food substances from the parent. Even after birth they are comparatively helpless, and are further nourished by milk developed in the glands of the mother.

Secondary Sexual Characters. — Among the lower animals a male usually can be distinguished from a female only by dissection or microscopical examination. The sex of the higher species on the contrary is generally associated with certain structural peculiarities known as secondary sexual characters. The males, for example, are of larger size than the females, or they may be characterized by highly developed tusks, horns, excessive growth of hair, brilliant plumage, spurs, combs, scent glands, or other organs that are developed in various regions of the body. The female often possesses highly developed organs for the protection and nourishment of the young, but aside from these characters her modification is usually less extreme than in the male.

In certain cases these secondary sexual characters are of evident use. Horns are of service to the male in defending the female or in battling for a mate. The brood pouches of many females, such as the opossum and kangaroo, serve to carry the young. Organs of scent, phosphorescent organs, and sound producing structures as in the katydid are believed to attract members of the opposite sex. But there are very many other characters of this class, such as the brilliant plumage of male birds and the colors of many insects, as well as spines, knobs, combs, wattles, etc., whose significance at the present time is an unsolved problem.

Body and Germ Cells. — As a result of the growth and differentiation of a sexually developed individual two classes of cells are produced. The first group comprises the reproductive or germ cells, which are protected and nourished by the second class, the body cells. This last named aggregate, forming by far the greater bulk of the individual, performs many duties, including food gathering, avoidance of enemies, and various activities in connection with the propagation and nourishment of the young. The germ cells, on the contrary, take no part in these purely individual processes, and are solely concerned with the perpetuation of the race.

Furthermore, it is important to note, both of these cell classes are equally the descendants of an original fertilized egg. The hen, by which is meant the cells of the body, does not *produce* eggs; it merely *lays* egg cells that during the course of development have become differentiated and set aside much as muscle or bone cells are differentiated and grouped into tissues. Each egg cell, when fertilized, produces in due time other eggs as well as the protecting body, and while the body dies after each period of sexual maturity, some germ cells persist from generation to generation.

Early History of Germ Cells. — Although the reproductive elements are held within the body of an animal, much like peas in a pod, this does not mean that during the months or years that they are thus imprisoned they lie dormant. As a matter of fact germ cells have a very definite development which begins at an early age and leads up to their completed form; and this history in its essential features is the same for both the sperms and the eggs.

In many animals the germ cells are recognizable in the gastrula stage or even earlier, though in numerous other species they are not distinguishable until a much later period. These original or primitive sex cells, as they are termed, as a result of repeated division (Fig. 75) become very numerous, and, closely packed together, may for a time cease to develop further. Sooner or later, however, they enter a growth period, during which time they increase in size, owing to the absorption of food (yolk in the case of eggs), and become, according to the sex of the parent, either sperm or egg mother cells. They now undergo two final reducing or maturation divisions that in three respects are of supreme importance. The maturation of the sperm cells will first be described.

Reducing Division. — It will be recalled that in the act of fertilization two nuclei, each carrying four chromosomes, in the species chosen as an illustration, fuse and the resultant cell thus contains eight. At each of the succeeding divisions each of these chromosomes splits lengthwise so that every cell of the body, including the germ cells up to the maturation divisions, possesses this characteristic number. At the beginning of the division of a sperm mother cell, eight chromosomes appear, but instead of splitting they unite or conjugate in pairs, one maternal with one paternal (Fig. 76). If the chromosomes that came in with the sperm at the time of fertilization be designated a, b, c, d, and those of the egg be designated as A, B, C, D, then the conjugation of the chromosomes is illustrated by Aa, Bb, Cc, Dd. A spindle forms and the chromosomes that have previously united in pairs separate without splitting and travel in opposite directions. This is known as the reduction division, since two cells are formed with only four chromosomes apiece instead of eight. Each of these cells divides by the usual process and the four that result undergo changes and

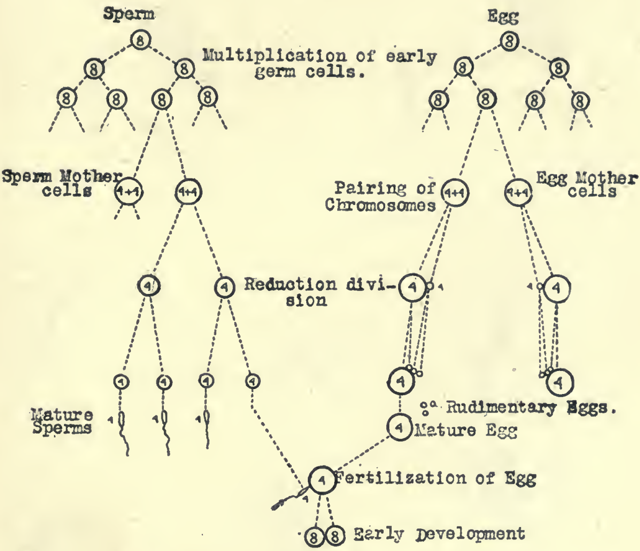


FIG. 75. — Diagram showing development of the germ cells.

become mature sperm cells. Each mature sperm thus has one half the usual number of chromosomes that characterizes the cells of the body. The egg cells undergo a similar reduction division, so that the union of a sperm with an egg produces the specific number, that is, eight. Were there no reduction in the germ cells a sperm uniting with an egg would produce a cell with sixteen chromosomes, and it is known from experiment that the development in such a case would be abnormal.

RANDOM ASSORTMENT OF CHROMOSOMES. — In the reduction division, as just described, the chromosomes are separated so that each resultant germ cell of the second order contains one member of each pair. But whether this member was derived from the sperm or the egg at the time of fertilization, that is, whether it is paternal

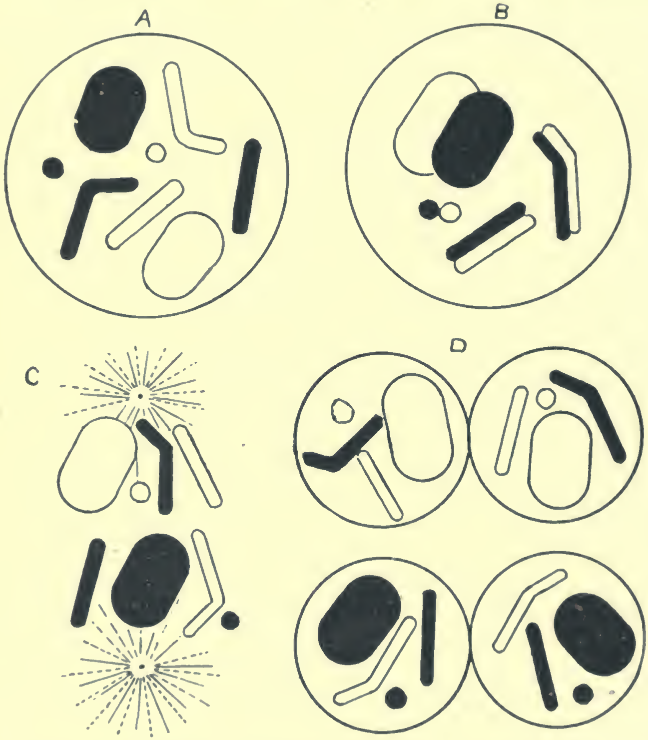


FIG. 76. — Diagram illustrating the reduction of the chromosomes. *A*, nucleus of sperm mother cell, with 8 chromosomes. *B*, pairing of chromosomes. *C*, division of sperm mother cell, showing 4 chromosomes passing into each daughter cell. *D*, four immature sperms, each with 4 chromosomes, resulting from two divisions of the sperm mother cell.

or maternal, is a matter of chance. In other words, the thousands of sperm mother cells produce, in the species under discussion, sixteen different types of sperm cells depending upon their chromosomes. If letters are used as in the preceding paragraph to designate chromosomes then two cells may be formed with paternal (a, b, c, d) and maternal (A, B, C, D) respectively, or these may exist in combination (A, b, c, d and a, B, C, D, etc.). With eight chromosomes sixteen combinations are possible; with forty-eight as in man the possible number runs into the millions. This random assortment, as it is termed, results in a wide variation as will be learned in a subsequent chapter and is of the highest importance in connection with the evolution of a species.

MATURATION OF THE EGG. — As a result of the accumulation of food substances during the growth period, each egg mother cell becomes a relatively large body; but while it is thus superficially unlike the corresponding small sperm cell its history during the maturation period is the same. It undergoes a reduction division and there is the same random assortment of the chromosomes, but the four cells formed as a result of the two maturation divisions are very unlike in size. This merely means, in the light of their subsequent behavior, that the three small cells without yolk (Fig. 75) and incapable of fertilization, are rudimentary eggs, while the remaining large cell alone is capable of development. Four functional sperms develop from one mother cell, while one functional and three vestigial eggs are derived from the egg mother cell.

DETERMINATION OF SEX. — Up to the present time it has been assumed that the number of chromosomes in the body cells of the male and female is the same, but at least one hundred species of animals are known where the male has one or at most a very few less than the female. This occasions a modification of the maturation divisions. Let it be assumed that the body cells of the female have eight chromosomes and the male seven (Fig. 77) — as actually happens in some species. The history of the maturation divisions of the egg is the same as that already described. In the male, on the other hand, the conjugation of the chromosomes results in three pairs and an odd or unpaired one (called a sex-chromosome) as though Aa, Bb, Cc and d were the combination. Upon their separation three chromosomes pass to one pole of the spindle and four to the other. The two cells thus

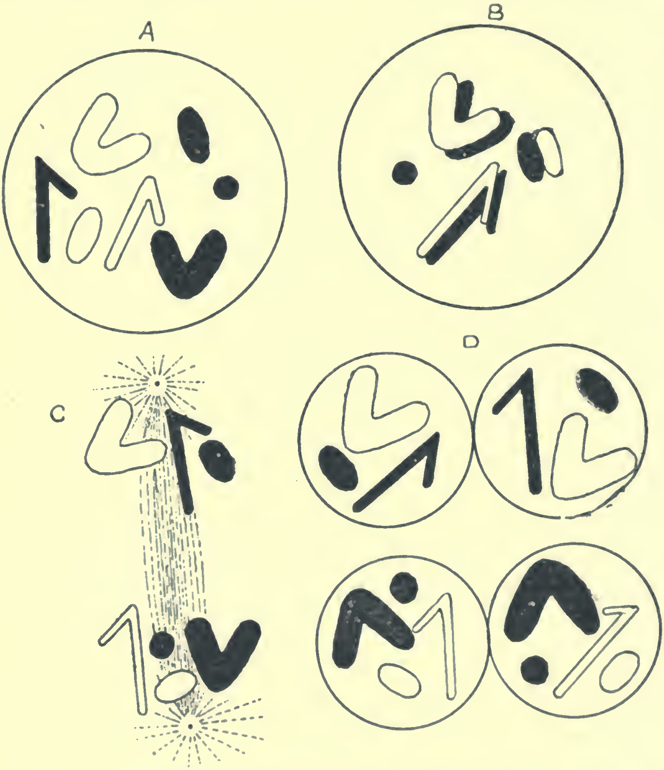


FIG. 77. — Diagram illustrating the determination of sex. *A*, nucleus of sperm mother cell with 7 chromosomes, pairing of 6 chromosomes with one odd (sex) chromosome. *C*, division of sperm mother cell showing 4 chromosomes passing into one cell and 3 into the other. *D*, second and last division of sperm mother cell resulting in two (as yet immature) female-producing sperms with 4 chromosomes each and two male-producing with 3 each.

formed now divide and of the four sperm cells that are produced two contain the odd number and two the even one. If a sperm with four chromosomes unites with an egg, which invariably carries four, a female results; the fertilization of an egg by a sperm with three chromosomes gives rise to a male. There are thus male- and female-producing sperms, but only one type of egg.

In a number of other species there are differences between the shapes of the chromosomes and even in many animals where these are not apparent there is evidence derived from breeding experiments that here likewise a chromosome mechanism regulates sex.

CHAPTER XXVII

REPRODUCTION IN PLANTS

Sexual and Asexual Reproduction. — In the preceding chapter it has been shown that animals have two types of reproduction — sexual and asexual. Plants also exhibit both types. It is proper at this point to re-emphasize the fact that while both methods secure the perpetuation of the race and may also serve to multiply it, one of them — the asexual — merely reproduces the individual without essential change, but that the other — the sexual — not only produces a new individual but also endows it with characters from both parents. In this way it may and usually does happen that the new individual is not exactly like either parent.

Types of Reproduction in Plants. — Since plants exhibit a far greater variety in the details of reproduction than animals it follows that no one example will suffice to give an adequate picture. Moreover, although our chief interest is with Seed Plants, it is quite impossible to understand the significance of their reproductive processes without some knowledge of the evolutionary states through which they have passed and which are still exhibited by the lower orders of plants. For this reason this chapter will deal in order of development with the following five types of reproduction: (a) By resting spores and swimming spores among the lowest plants — Algæ and Fungi; (b) By simple types of sex cells — or gametes — in the same lower plants; (c) By alternation of a sexual and an asexual generation — in Mosses and Ferns; (d) By seeds in the higher plants; and (e) By various sorts of purely vegetative division of plants, such as bulbs, cuttings, grafts, buds, etc.

Asexual Reproduction in the Algæ. — There are many plants of much simpler organization than the Flowering Plants, the only ones with which most persons are at all familiar. The lowest and simplest plants belong to the Algæ. These plants are typically aquatic; they have simple bodies, of no very high degree of specialization, and simple methods of reproduction. Some of the lowest do not have any sexual method at all. Two or three examples will make this clear.

Oscillatoria (Fig. 78) is an alga of blue-green color found in shallow temporary pools, in lakes and streams of stagnant water, about the outlets of sewers and other similar places where the water contains considerable amounts of filth. Its habits of life are, however, not the immediately interesting subject, but its method of reproduction. As the illustrations show, a single plant consists of a simple row or filament of short cylindrical cells placed with their flat surfaces in contact. A careful inspection will fail to reveal any essential difference among the cells, except that the terminal ones have their free end rounded out instead of flat. Any cell or group of cells may be detached from the others without making any difference in their development. Each one goes on manufacturing its food and growing independently of the rest. As each cell grows it reaches a point when division occurs, making two out of it. This increases the length of the filament. Any disturbance, such as frequently occurs in the water in which it grows, may break the filament into two or more pieces. Obviously in this plant there is no real distinction between growth and reproduction. Any cell division may accomplish either or both. If the pond dries up the plants are dried also. Fortunately the protoplasm is able to endure such treatment without killing all of the cells, though most of them do not survive. Those which do live need only that the necessary heat, light, and moisture be again furnished them to begin their life processes just where they had left off. Presumably they never become so entirely dry as to stop *all* metabolism.

Nostoc (Fig. 79) is another blue-green alga related to Oscillatoria. It carries on its work and growth in much the same manner but shows two interesting advances in

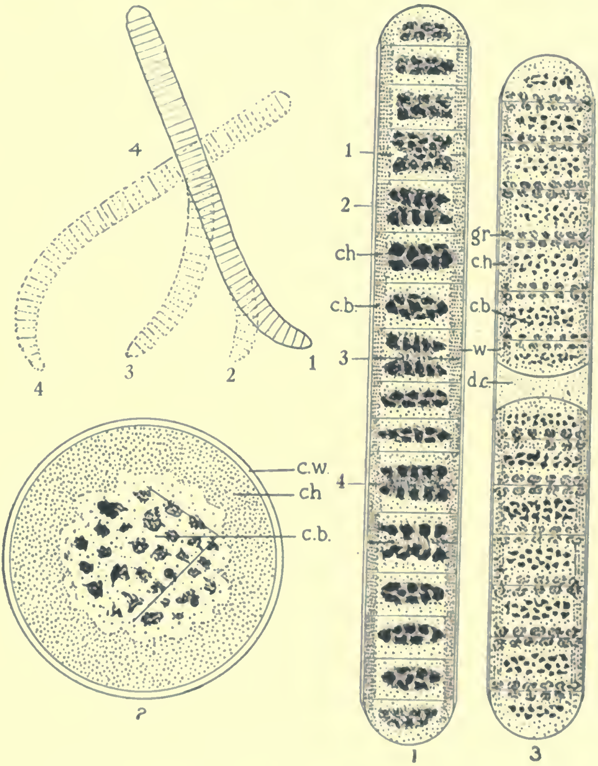


FIG. 78. — Oscillatoria. 1. A short section of a filament showing cells (1, 2, 3, 4) in process of division. *c.b.*, the central body corresponding to the nucleus of higher plants; *ch*, the chromatophore or region of the cytoplasm in which the bluish-green coloring matter is located. 2. A single cell on a larger scale seen from the end. Labels as in fig. 1. 3. A filament in which one cell has died creating a weak place at which the filament will break. This is the usual way in which this plant multiplies the number of filaments. 4. A single filament drawn at 5-minute intervals to show the amount and type of movement. 1, 2, 3, 4 in fig. 4 indicate successive positions.

its methods of reproduction. In the first place not all the cells are alike. Examined at a favorable period in its development three sorts of cells will be found. The larger number of cells are of the ordinary vegetative type which go right along performing their work of food manufacture,

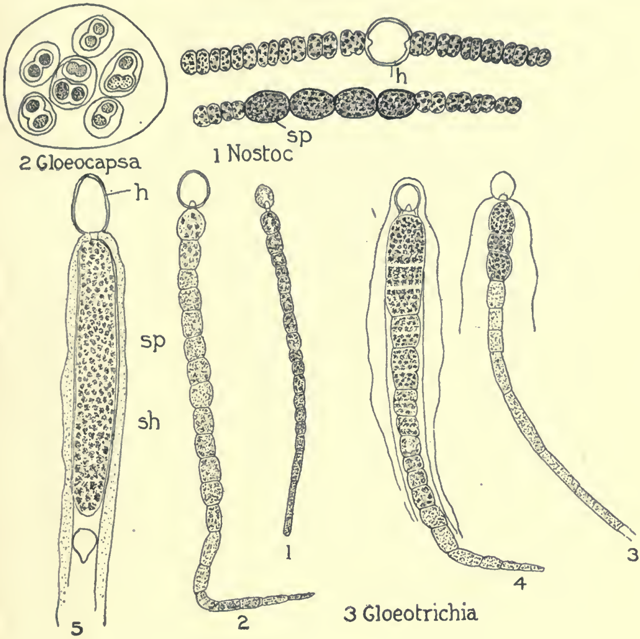


FIG. 79. — Other Blue-green Algæ. 1. Nostoc filaments showing dividing cells, heterocysts, *h*, which serve to break the filaments into sections and so multiply their number, and enlarged spore cells, *sp.*, stored with abundant food and surrounded by a firm wall for protection during the resting period. 2. Gloeocapsa, a simpler form which forms small irregular groups of cells instead of filaments, the whole enclosed in a mass of gelatinous wall material. 3. Gloeotrochia, a somewhat more complicated type with very large spores, *sp.*, formed by the union of several adjacent cells. The heterocyst forms next to the spore and so serves to detach the spore from the filament. The several figures show various stages in the growth of a filament.

growth, and cell division. At intervals in the filament are to be seen *a second type* of cells which are larger, have thick walls and very scanty cell-contents. Some of them will appear to be entirely empty. These cells (*heterocysts*) have the function of breaking the filament into shorter sections. As division of cells progresses a filament becomes longer and longer. But here and there some cell turns into a heterocyst. This sort of cell is attached loosely to the ordinary cells on either side of it with the result that a slight disturbance, such as that due to bending to accommodate growth, may easily break the filament. The *third type* of cell is also considerably enlarged but instead of being empty it is densely filled with protoplasm and stored food. Its walls also become thick and so changed chemically that they resist drying. These are called *resting spores* because they do not divide until after the other cells in the filament have dried or frozen. This kills the *ordinary cells* but does not kill the resting spores. On the reëstablishment of growing conditions the latter resume growth and cell division and make new filaments. In this plant there is seen to be a distinction between growth and reproduction. Cell division produces growth but does not of itself bring about reproduction. The differentiation of some cells to form heterocysts does however reproduce or multiply the number of plants during the growing season. The differentiation of the resting spores takes care of reproduction following unfavorable weather conditions. Obviously this arrangement has certain distinct advantages to the plant for it makes more certain that the filaments will be broken frequently and that reproduction will occur after drought.

Ulothrix (Fig. 80) is a simple filamentous green alga found in fresh water streams and lakes. Each filament is attached at one end to a stick or stone and free at the other end. The basal attaching cell is specialized for the purpose and the tip cell is rounded or sometimes pointed. The remaining cells are at first all similar. Each makes its own food, grows, and divides. When the filament has reached a suitable stage of development there occurs a differentiation among the cells. A few merely cease to grow, but most of them develop a number of small motile reproductive cells. This is brought about by a series of divisions of the nucleus until there are about 8 (or sometimes 16) in each cell. The cytoplasm then divides up into an equal number of portions, so that each nucleus is surrounded by a small amount of individualized cytoplasm. Next each of these units undergoes a process of

FIG. 80. — Ulothrix. *A*, part of a vegetative filament one of whose cells is undergoing division. *B*, a filament in which the cells are dividing to form four large swimming spores. *C*, a single swimming spore drawn to a larger scale. *D*, a swimming spore beginning to develop. *E*, a further stage of development. *F* and *G* smaller swimming spores developing into new filament.

rounding up into a sort of egg-shaped body. At the smaller end the cytoplasm puts forth fine cilia — two in number — and these new cells begin to move about inside the old cell-wall. Presently they break through the wall and escape into the water. They now begin a series of rapid swimming movements and eventually each one contacts with a suitable object to which it becomes attached by the ciliated end. The cilia are then withdrawn and thicker blunter protrusions of the cell body are extended over the substratum. They seek out and make use of its irregularities of form to secure a firm hold. The protrusions become covered with a cellulose wall at the same time that the whole cell is forming its wall. When attachment has been completed the cell begins to elongate and presently divides. The two new cells remain joined and make a little two-celled filament. A continuance of cell division elongates the filament until it presently reaches a degree of maturity when it will in its turn produce motile reproductive cells. On account of their number and movement these are called *swarm spores* or sometimes *zoöspores*.

Œdogonium (Fig. 81) is a somewhat more highly developed green alga than Ulothrix but will serve to illustrate the same phenomenon of reproduction by non-sexual swarm spores. It too is attached at the base and free at the apex. It grows by cell division. Occasionally (or frequently if the conditions are just right) some of its cells withdraw their protoplasm from contact with the enclosing wall and round up. Each cell then produces a single swarm spore. The old cell-wall breaks and the swarm spore escapes and swims about vigorously by means of a crown of cilia at the smaller end. It finally settles down in the same way described for Ulothrix and grows into a new filament.

Essentials of Asexual Reproduction. — Though there are a number of other different forms of non-sexual reproduction among the lower plants, it is probable that these illustrations will suffice to make clear its essential features. All agree in that the reproductive cells — whether they are just ordinary body cells or special swarm spores — have arisen through ordinary cell division and have identically the same kind of nuclei. Each and every cell of these plants, whether ordinary vegetative or reproductive cells, has the same number and kind of chromosomes. It naturally results from this that the successive generations are very similar indeed, no variations ordinarily occur excepting such as are due to the different environments under which the successive generations may

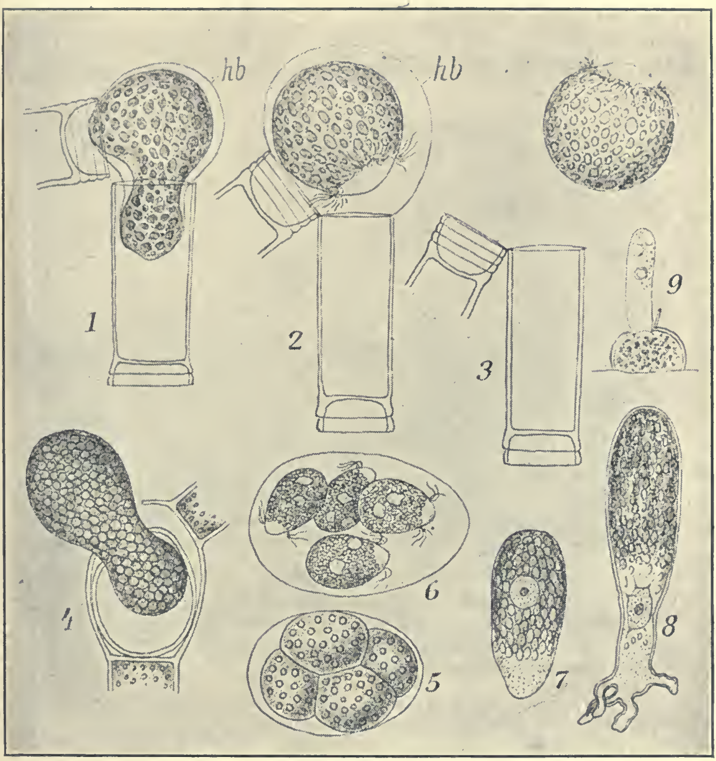


Fig. 81. — Œdogonium. 1, 2, 3, 4, showing the way in which the contents of a cell transform themselves into a swimming spore and escape from the old cell. 5, 6, show swimming spores formed from the fertilized egg shown in fig. 83. 7, 8, 9, show the germination of swimming spores to form new filaments.

grow. The advantage of this type lies in the extraordinary rapidity of multiplication enabling the plant to occupy all available space. It does not of itself give rise to any variation.

SEXUAL REPRODUCTION by means of Gametes — eggs and sperms. In most algæ and nearly all higher plants there is a sexual method of reproduction. Some plants have both methods. At this point it is necessary to define more precisely what is meant by sex. This can best be done by studying a simple form of it.

Ulothrix has also a sexual method of reproduction (Fig. 82). It is particularly suited to illustrate the *origin of sex*

FIG. 82. — Ulothrix, sexual reproduction. *A*, filament in which the cells are forming about 16 motile sex-cells or gametes. *B, C, D, E* show the gametes fusing in pairs. *F*, the resting spore developed from the fusion of the two gametes. *G*, the germination of the resting spore to produce a new filament.

because it is easy to observe that the swarm spores sometimes take part in sexual reproduction. It will be recalled that in Ulothrix each cell produces either 8 or 16 swarm spores. The more numerous ones are proportionately smaller. Sometimes they appear to be too small to produce a new plant alone and unaided; accordingly they fuse in pairs. The usual sex cells are produced in the same manner as the swarm spores but are still more numerous, 16 to 64 in number. These small motile cells are called *gametes* or *sex cells* and *always fuse in pairs* before growing into new filaments. From this it appears as if sex in its simplest form has originated by a change in the behavior of ordinary swarm spores and that the essence of the process is the fusion of two reproductive cells. It is an interesting fact that these gametes always show a decided preference for fusing with those from some other filament rather than with those from the same cell or filament. The precise chemico-physical relations at the bottom of this behavior are not yet known. That it is an advantage, however, is pretty clear, from the fact that so many plants and animals have evolved this method of reproduction. It certainly gives a greater opportunity for variation by bringing together the characters of two parents instead of one.

Œdogonium (Fig. 83) has a method of sexual reproduction in which the egg (i.e. female) gamete is very much larger than the sperm (i.e. male) gamete. A particular cell or cells in a filament swells up so as to become nearly spherical instead of the elongated cylindrical form found in the ordinary vegetative cells. Its contents then withdraw slightly from the cell-wall and round up to form an egg gamete. A spot on the wall softens and presently forms a perforation through which the sperm gamete can enter. In some other part of the same filament or, in some species, in another filament, some cell divides rapidly to form a number of very short cylindrical cells. In each of these the nucleus divides once. The cytoplasm is then divided between these two nuclei and each half becomes organized to form a sperm. When these sperms are mature they escape through the broken cell-wall and swim about by means of a crown of cilia at the smaller end. They are attracted to the perforation in the wall of the cell (oögonium) containing the egg, probably by means of some substance diffusing away from it and serving as a directive stimulus. This is a case of what was called a tropism in Chapters XII and XIV, where we learned that a variety of external conditions may act as

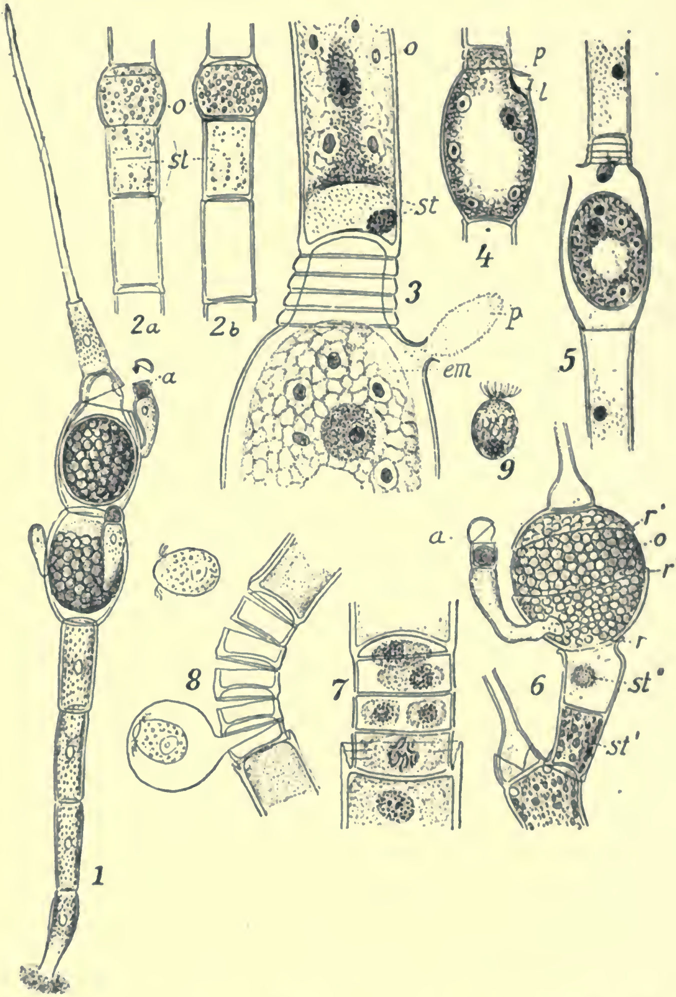


Fig. 83. — Œdogonium, sexual reproduction. 1. a filament with two enlarged cells containing the female sex-cell or egg. Attached to the side of the egg are small male plants, which in this species produce the male sex-cells or sperms. 2, 3, 4, show the development of the egg. 5 and 6 show the fertilization of the egg in a plant (Bulbochæta) related to Oedogonium. 7 shows the development of sperms in an ordinary filament, which in some species of Oedogonium may also contain egg cells. 8 shows small swimming spores which in this species develop the sort of small male plants seen in fig 1.

directive stimuli to cause whole organisms or their organs to move or bend in response to stimuli. The sperm finds the opening, enters, and fuses with the egg. As soon as this fusion has occurred a change comes about in the egg resulting in the formation of a membrane over its surface preventing the entrance of other sperms. This is a simple case of chemical regulation.

The Differentiation of Sex. — In Ulothrix we can speak of sex although there is no distinction between the sexes. Not only may the two fusing gametes come from the same individual but they are both motile and indistinguishable in every respect. In Œdogonium there is not only sex but two sexes, at least in respect to the gametes themselves. One is always small and highly motile, while the other is large, stored with food, non-motile, and remains in the cell where it was formed. In some cases there is a distinction of sex between the filaments such that one filament forms sperms only and the other eggs only. In still other species of Œdogonium the male filament is very small compared to the female. In these species there are also two kinds of swarm spores differing in size. The small ones produce male filaments and the large ones females.

Other illustrations of the same sort of differentiation of sex can readily be found among the Algæ and Fungi. Moreover, it is easy to extend the range of observation and find illustrations intermediate between these, so as to show that sex has arisen many times among plants through a change in the habits of swarm spores and that *two sexes* have been developed by a gradual loss of motion and increase in size and stored food by one gamete to develop an egg. Practically all the higher plants have sexual reproduction fundamentally like this but with added complications in the way the gametes are formed or in the sequence of development during the entire life cycle.

Alternation of Generations is found in some Algæ and Fungi, and is a regular part of the life cycle of all higher plants. It can be most readily understood by considering the life history of a moss and then comparing this with a fern.

Moss plants (Fig. 84) are green independent land plants capable of manufacturing their own food. Some

FIG. 84. — Mosses. 1. A male gametophyte with a cluster of antheridia in a rosette of leaves at the tip. 2. The antheridia with the enclosing leaves removed. 3. A female plant with a sporophyte attached to the right branch. 4. A group of archegonia from a tip like the one to which the sporophyte of fig. 3 is attached. When the egg in the base of the archegonium is ready for fertilization a sperm from an antheridial branch swims in the thin films of water that are present on the moss plants after rain or dew and goes down the long neck of the archegonium and unites with the egg. From this fertilized egg the sporophyte arises and remains attached by its foot, deriving all its water and salts and part of its food from the leafy gametophyte. 5. The upper part of the sporophyte, called the capsule, open and shedding spores.

time during their growth there develops, usually at the stem tips, a group of *sex organs*. The sort in which sperms are formed are called *antheridia*. Each one consists of a short stalk and body. The latter has an outside layer of protective cells and a mass of inner cells which form the sperms. Each sperm is a small motile cell swimming by means of cilia. The eggs are formed in organs called *archegonia,* shaped like long slender flasks. The accompanying illustrations will give an idea of their shape and structure. Essentially they consist of three parts: stalk, venter, and neck. The neck is long and slender with an outside layer of protective cells and a single axial row of cells known as the neck-canal cells. The enlarged middle part called the venter has one or more layers of protective cells on the outside. The row of neck-canal cells is continued down into the venter by two cells known respectively as the *egg* cell (at the bottom) and the ventral canal cell. When the egg is ripe the ventral and neck-canal cells die and turn into a sort of mucilage or jelly, which swells and forces the top off the neck. This substance oozing out into the water directs the sperm to the open neck. When one finds its way down the neck and fuses with the egg a fertilization membrane is formed about the egg and the mucilage hardens and blocks the passage.

An Extra Generation. — It is proper at this point to call attention to the striking peculiarity of these higher plants. In the plants we have been discussing heretofore a fertilized egg generally develops again into the sort of plant which produced it. But here there is a *regular alternation of two sorts of plants in the life cycle.* The fertilized egg remains in the venter of the archegonium and begins to grow and divide. Eventually this young plant, which we call an *embryo,* ruptures the wall of the enclosing structure and pushes up into the air. When it is mature it is found to consist of three parts. At the bottom is a sort of foot embedded in the end of the branch (Fig. 84.) which bore the archegonium. Above that is a slender stalk an inch or so long and bearing at its top an enlarged body known as the capsule. The foot is an organ which serves as a means of attachment and at the same time absorbs supplies of water and dissolved food from the original plant. The capsule at the top develops a multitude of small wind-borne spores. The stalk serves to lift the capsule up where the spores can be advantageously scattered. It should be noted that while this small attached plant is dependent on the first generation, it becomes green as soon as it is pushed out of the enclosing structure and is exposed to light. It can, therefore, manufacture a part at least of its carbohydrate foods.

Gametophyte and Sporophyte (Fig. 84). — In the above account it is to be recognized that a green independent moss plant produces the gametes (eggs and sperms) and that the fertilized egg grows into a small plant which in respect to water, salts, and part of its food is *parasitic* on the first and which produces air-borne spores which grow into the gametophyte or sexual generation. The first stage is called the *gametophyte* because it produces gametes. Reproduction is brought about by the regular alternation of these two generations. Every alternation of generations in the higher plants involves essentially this same cycle.

Ferns show the same alternation of generations as do mosses. There is, however, this striking difference, — the fern plant familiar to everyone is the sporophyte (Fig. 85) generation. The gametophyte (Fig. 86) generation is so small — a quarter of an inch or less in diameter — that it is ordinarily overlooked except by those who know about it and especially look for it. Another important difference is that, whereas the moss sporophyte is small and attached (parasitically for all its water and part of its food supply) to the green gametophyte, the fern sporophyte is proportionately very large, green, and therefore independent.

The Structure of Ferns. — For present purposes it is necessary to consider a few of the details of structure. In the first place it is clear from the most casual observation that the fern is a much larger and more efficient plant than the moss. It has large leaves and an ample root system. By cutting sections of these organs and of the stems a corresponding complexity and efficiency of organization is revealed in their inner structure. The spores, with which we are chiefly concerned, are commonly produced on the backs of the leaves. The accompanying

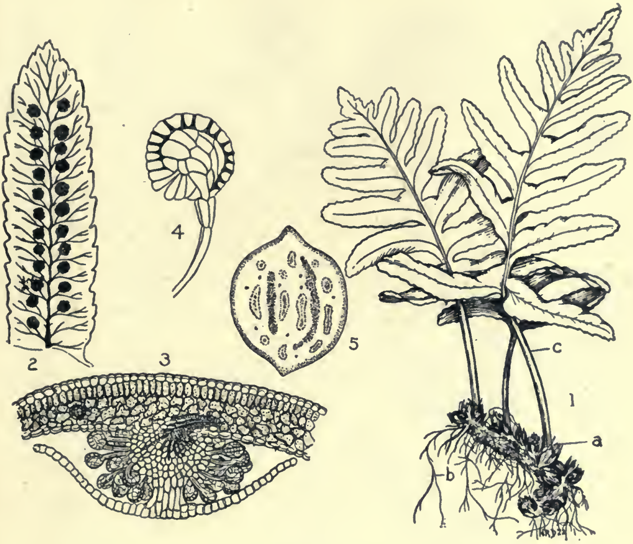


FIG. 85. — The Sporophyte or a sexual plant of the fern. 1. a whole plant showing (*a*) the stem, (*b*) the roots, and (*c*) the leaves. 2. the back of a leaflet showing clusters of sporangia and the branched "veins" through which water and dissolved food are transported. 3. a section through a cluster of sporangia on a different sort of fern with a flap-like cover or indusium. 4. a single sporangium showing the stalk and the ring-like "annulus" around the rim, made of thickened cells, whose function is to open the sporangium and discharge the ripe spores through the mouth-like opening at the left. 5. a cross section of the stem showing two dark bands of strong stiffening tissue and several round or oval bundles of conducting tissues.

illustrations show various details of spore production. At present we are concerned only with the facts that the spores are all alike and that they fall on moist soil, where they give rise to the small but green and independent gametophytes. The details of structure of the latter are also shown in the illustrations.

HETEROSPORY is a term used by botanists to signify that a plant produces spores of two different sizes (Fig. 87). In most ferns the spores are all alike in size and give rise indifferently to gametophytes of either sex or sometimes

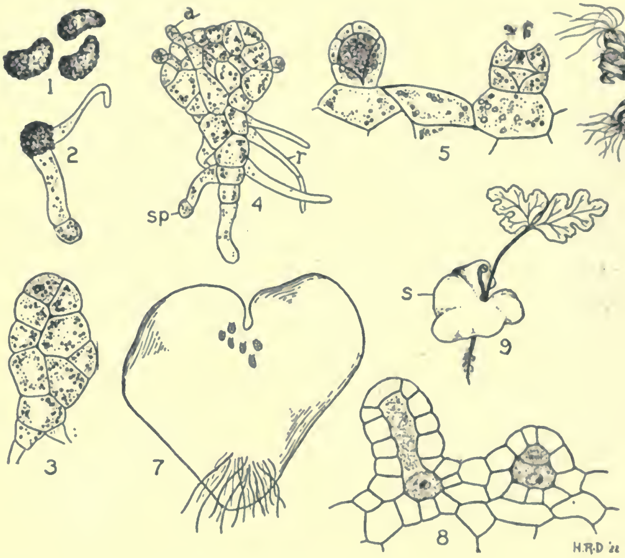


FIG. 86. — The Gametophyte or sexual generation of the fern. 1. spores. 2. a germinating spore with a slender rootlet and a thicker branch which will develop later into a flat sexual plant such as 3 and 4. 4. a sexual plant with antheridia (*a*), and rootlets or rhizoids (*r*). At (*sp*) the spore is shown from which the whole has developed. 5. a part of a male sexual plant with two antheridia showing the structure and method of discharging the mature sperms. 6. mature sperms. 7. a female gametophyte with several female sex organs (archegonia) on the under side and with a cluster of rootlets. 8. a younger and older archegonium with an egg ready for fertilization in the base of the older one. 9. a female sexual plant (*a*) with a young sporophyte still attached to it.

of both sexes. There are a few ferns, however, in which a *small spore* is produced in one kind of sporangium and gives rise to a *male gametophyte* so small that it can all be retained within the original spore wall. In these ferns the other kind of sporangium produces a few — sometimes only four — large spores. They are eight to ten

FIG. 87. — Selaginella. *A*, a branch showing the leaves arranged in four rows and the branches tipped with cones or strobili. *B*, a sporangium-bearing leaf from the cone with a microsporangium filled with the small sort of spore or microspores. *C*, a sporophyll or sporangium-bearing leaf with a megasporangium containing four large or megaspores. *D*, and *E*, showing comparative size of microspores and megaspores. The latter are from 8 to 10 times the diameter of the former and consequently from 500 to 1000 times as large in contents.

Coulter, *Plant Structures*. Appleton.

times the diameter of the small spore and consequently contain from five hundred to a thousand times (i.e., 8^3 or 10^3) as much substance. When they germinate they develop into small *female gametophytes,* which are almost wholly enclosed within the spore wall (Fig. 88). This differentiation of spores in respect to size and the retention of the gametophytes within the spore wall led

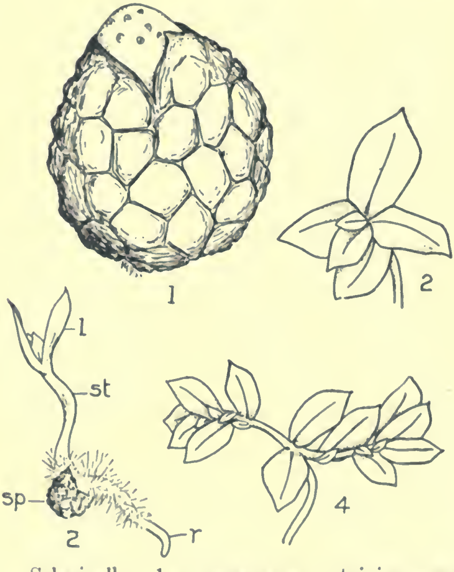


FIG. 88. — Selaginella. 1. a megaspore containing a mature full-grown female gametophyte with several archegonia exposed through the ruptured spore coat. 2. a young sporophyte which has developed from an egg fertilized in such an archegonium as shown in the preceding figure. Note that this young plant remains attached for a considerable time to the female plant and draws its food from the supply originally stored in the large spore. (*sp*) the old spore, (*r*) the first root of the new sporophyte, (*st*) and (*l*) the young stem and leaves. 3 and 4. older stages of the young plant. (Reproduced by permission from drawings by Professor Campbell.)

to the further development, along the same lines, of the pollen and seeds of higher plants.

REPRODUCTION BY SEED is a specialized development of the alternation of generation. If one examines a flower (Fig. 89) it will be found to be composed of an outer covering of sepals and petals, which may be brightly colored, constituting a protection to the enclosed organs during development and a means of attracting insect visits after the flower opens, and, inside, stamens and pistils. Examination of the pistil shows that within it are the rudiments of seeds, called ovules. At the top of the stamens are enlargements called anthers. Inside them are small bodies known as pollen grains. In appearance they resemble the spores of the fern and are in fact, as we shall presently see, only a modification of them.

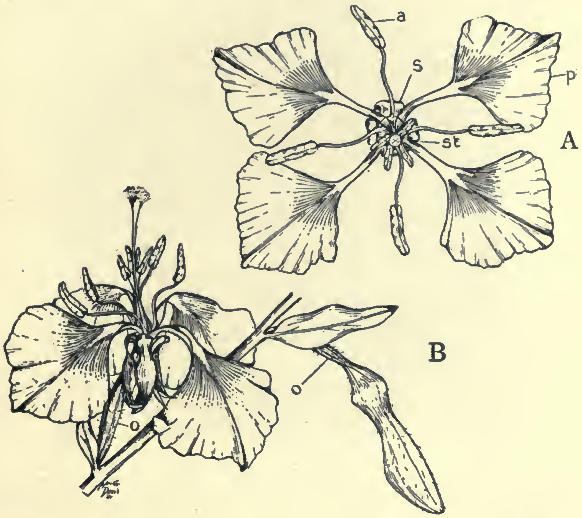


FIG. 89. — Parts of a Flower (Clarkia elegans). A, an open flower showing (*a*) anthers, (*p*) petals, (*st*) stigma; B, open flower and unopened bud, parts lettered as above in open flower. Bud covered by sepals (*s*) and below the open flower the ovary (*o*), which contains the ovules.

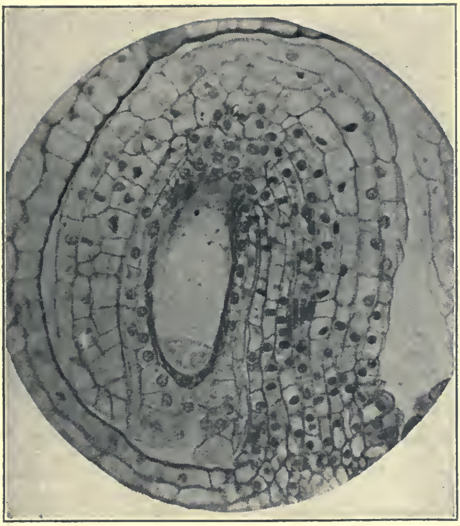
It is well known to almost everyone that in seed reproduction it is necessary for the pollen to be placed on the tip of the pistil, called the stigma, in order that fertilization may eventually result and seed be produced. The details which underlie this process are practically unknown to the layman and need to be carefully studied in order to understand reproduction in flowering plants.

THE OVULE AND FEMALE GAMETOPHYTE (Fig. 90). — The ovule actually corresponds to the organ (sporangium) on the back of a fern leaf in which the spores are produced. When the development of the ovule is carefully studied it is found that at a certain stage there is developed a spore mother cell and that it undergoes two successive divisions exactly comparable to those described in Chapter XXVI for the maturation of the animal egg, and

A

FIG. 90. — The Ovule and Female Gametophyte. A, shows a cross section through the base of the pistil of a lily flower. There are three cavities, in each of which are two vertical rows of ovules. The figure shows six ovules, each containing a nearly mature female gametophyte.

which will be presently described for plant pollen. These two divisions result in four spores, only one of which survives and matures. The other three remain small and are eventually crushed and destroyed. The one functional spore develops into a small *female gametophyte* without ever being shed from the ovule. It is the fact that the spore is not shed on the ground as it is in the ferns, and that the gametophyte is small enough to be retained in the ovule that makes possible the seed. When the enclosed and parasitic female gametophyte is full-grown it consists of only seven cells. At one end is the egg cell and two associated cells; at the opposite end are three vegetative cells which ordinarily are of negligible value; in the middle is a single large nucleus which was formed by the fusion of two, one of which came from the egg group at one end and the other of which came from the



B

B, a single ovule showing the outer coverings or integuments and the female gametophyte in the middle. The latter shows in this single section only 4 of the seven cells actually present.

opposite group of vegetative cells. This single large double nucleus is called the primary *endosperm nucleus.* It plays a very important part in the development of certain seeds of economic value and must be fully understood here if what is to be said later in respect to certain phases of heredity in corn is to be understood.

THE ANTHERS AND MALE GAMETOPHYTE (Fig. 91). — Turning our attention now to the anthers it will be found that a comparable development goes on there. A considerable number of spore mother cells develop in the cavities of each anther. Each single one undergoes the processes of reductional division and produces four spores, just as each sperm mother cell in the animal produces four sperms. The spores which develop in the anther also begin to grow and usually contain two or three cells at the time they are shed and carried by wind or insect to the tip of the pistil. Here they produce elongated protrusions of their walls called *pollen tubes,* which bore their way down through the tissue to the cavity of the pistil where the

Fig. 91. — The Pollen. This figure shows a cross section through the anther at the top of a stamen. There are four cavities in which thousands of pollen grains are formed. Each pollen grain is a microspore when first formed but usually has germinated to form a two-celled male gametophyte before it is actually shed and carried to the tip of the pistil. (See Fig. 92)

ovules are, and enter a minute opening in the ovule, known as the micropyle, and eventually reach the egg inside. In the meantime the pollen grain has completed its growth into a *microscopic male gametophyte.* It is so reduced in fact that it normally consists of only three cells. One of these is the so-called tube nucleus which appears to direct the action of the pollen tube and the other two are sperms.

Fertilization, Embryo, and Endosperm (Fig. 93). — When the two sperms are discharged from the pollen tube into the female gametophyte inside the ovule of a Flowering Plant, one fuses with the egg to fertilize it, and the other unites with the primary endosperm nucleus. From the fertilized egg develops the young embryo sporophyte plant. The endosperm nucleus now consists of three fused nuclei and the process by which it is formed is often referred to as "triple fusion." It is sometimes called "double fertilization" on account of the fact that one of the cells taking part is a sperm. It grows and divides to

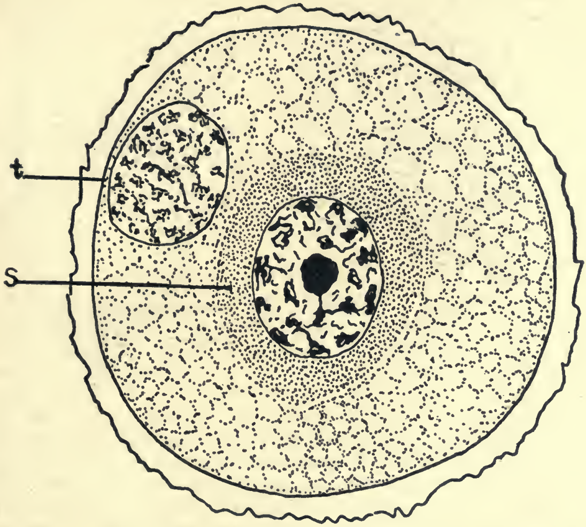


Fig. 92. — Male gametophyte or pollen grain at time it is shed from anther. (*t*) tube nucleus; (*s*) sperm mother cell which will divide to form the two sperms.

produce a special and peculiar tissue called *endosperm*. In some seeds there is very little development of endosperm while in others, like corn, there is a large development so that the larger part of the mature seed consists of endosperm.

The Seed is the matured ovule containing a young plant and a store of food (Fig. 94). The embryo plant has been derived by cell division, growth, and differentiation from the fertilized egg in the same manner that the animal arises from a fertilized egg. Since the development of the animal embryo has been adequately described in the last chapter it is unnecessary to repeat the story here. In the development of endosperm there is cell division and

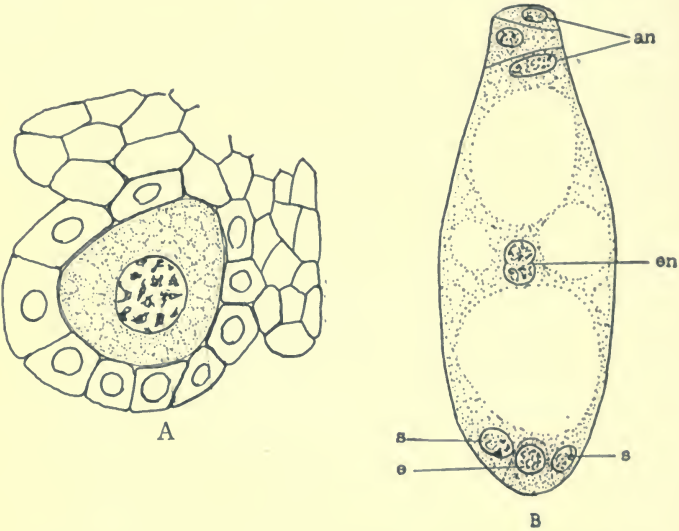


FIG. 93. — *A* is a young ovule with the megaspore mother cell. *B* shows the mature female gametophyte which develops from the megaspore; at one end are the egg, *e*, and two other cells called synergids, *s;* in the middle are two nuclei in the act of fusing together to form the endosperm nucleus; and at the other end are three cells which ordinarily take no further part in the development of the seed. When the pollen tube reaches a female gametophyte one of its sperms unites with the egg and gives rise to the young plant or embryo, the other unites with the endosperm nucleus and may give rise to a special tissue called endosperm, which when present contains the food supply for the embryo.

growth but little differentiation of cells beyond that involved in food storage. Wherever abundant endosperm is developed its cells are used to store a supply of starch or other food for the young plant. In pines and similar plants there is no endosperm and food is stored in the large female gametophyte. In Flowering Plants wherever endosperm is imperfectly developed, e.g., the pea, food storage occurs in the seed leaves or cotyledons of the embryo plant. The tissues of the ovule continue growth along with the young plant and become differentiated to form a hard coat which serves to protect the embryo.

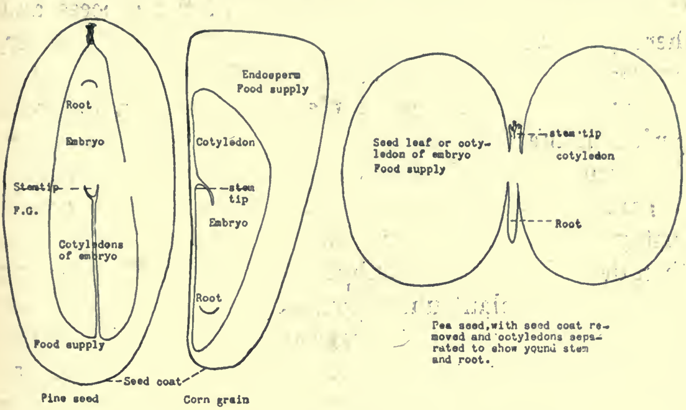


FIG. 94. — The Structure of Seeds. The diagrams show three types of seed. (1) Pine seed in which the embryo is located in the middle of the large female gametophyte and has most of the food stored in the gametophyte and some in the embryo; (2) the corn grain which has food stored largely in the cells of the endosperm; and (3) the pea seed, in which there is nothing left either of the female gametophyte or of the endosperm, has the food stored in the much enlarged seed leaves or cotyledons. Note also that the embryo of the pine has several cotyledons of which the diagram shows two, one on either side of the stem tip; that the corn embryo has but one very large cotyledon or seed leaf and that the stem tip occupies an apparently lateral position; and finally that the pea has two large lateral cotyledons and a terminal stem tip.

DORMANCY OF SEEDS. — The seed differs from most parts of the plant in that it can become air dry without injury to the protoplasm of its cells and then resume growth when placed in a suitable temperature and provided with sufficient water. This is a very important circumstance for it enables a plant to survive long-continued unfavorable conditions for growth or to be carried long distances without injury. Seed Plants have thus a great advantage over Ferns, Mosses, and the lower plants which have less effective means of reproduction.

The Chromosome History in Plants and Animals. — Since the plant chromosomes behave in almost identically the same manner as those of animals there is no necessity to restate the facts, aside from the opportunity it affords to reiterate the essentials of the process and thereby fix them more firmly in mind. It should, however, be remembered, in connection with this statement, that the reduction divisions of plants occur at a different period in the life history (Fig. 95). In animals reduction occurs during the preliminary stages of the formation of gametes, i.e., eggs and sperms, but in plants it occurs just previous to the formation of spores. The spores then develop into gametophytes, large or small according to the sort of plant under consideration. When mature the gametophytes form the eggs and sperms but, of course, no reduction is necessary at this point because it has already taken place in the formation of the spores. The matter may be put another way thus: In the case of the animal the gametes have the reduced number of chromosomes. Consequently the fertilized egg will have the double number. Since the animal body develops from the fertilized egg by ordinary cell division every cell of the animal body will also have the double number. In the plant the gametes also have the reduced number and the fertilized egg the double number. The fertilized egg grows into the sporophyte plant by cell division and every cell has the double number. Reduction occurs with the formation of spores and therefore the gametophyte has the reduced number. From this it will be seen that there is an extra generation — the gametophyte — in the plant life history which has nothing exactly corresponding to it in animals.

Reduction and Segregation of Chromosomes in Plants (Fig. 96). — This process is most frequently studied in the anther because there are many spore mother-cells giving an opportunity to see many different

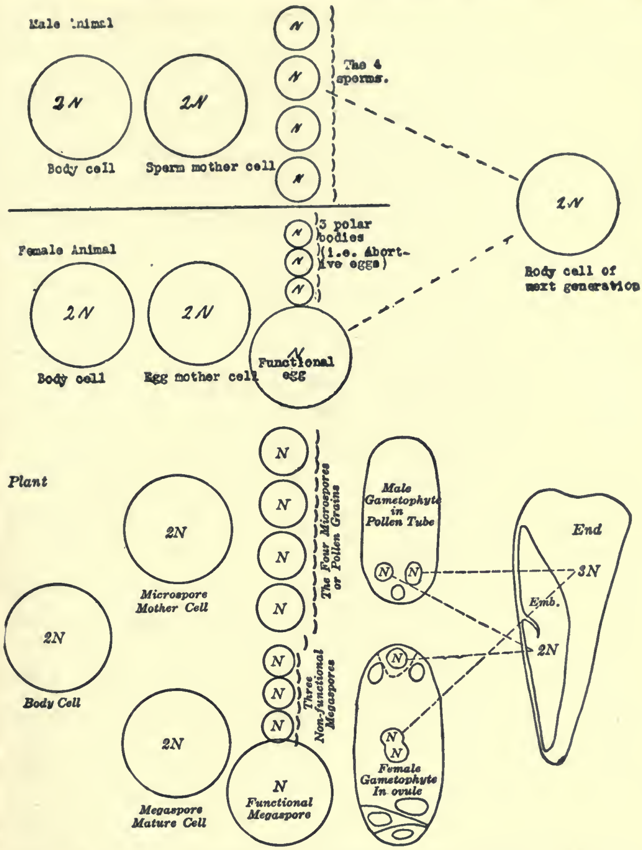


FIG. 95. — The Life-Cycles of Plants and Animals Compared. The diagrams are largely self-explanatory and show that the animal and higher plant both originate by the union of a sperm and an egg, thereby doubling the chromosome's number so that each cell has n pairs of chromosomes. When the animal forms its gametes the members of each pair separate from one another and go to opposite poles of the spindle. This results in reducing the number by half and further provides that each gamete has but one chromosome of each pair. Fertilization again unites a sperm and an egg and doubles the number again. In the plant the history is the same in so far as the cycle up to reduction is concerned. The reduction divisions give rise to spores instead of gametes, and spores develop into microscopic gametophyte or sexual plants in the higher plants which in turn produce the gametes. One sperm fuses with the egg to produce the new plant and the other in many plants unites with the endosperm nucleus to produce the endosperm, a part of the seed peculiar to certain flowering plants such as corn.

stages in each microscopic section. In each spore mother-cell the chromatin net resolves itself into chromosome threads. These then conjugate side by side. The paired chromosomes next shorten and thicken. By the time they are mature a spindle has been formed, which in plants has blunt poles and lacks *centrosomes* such as are always present in animals. Each chromosome pair has

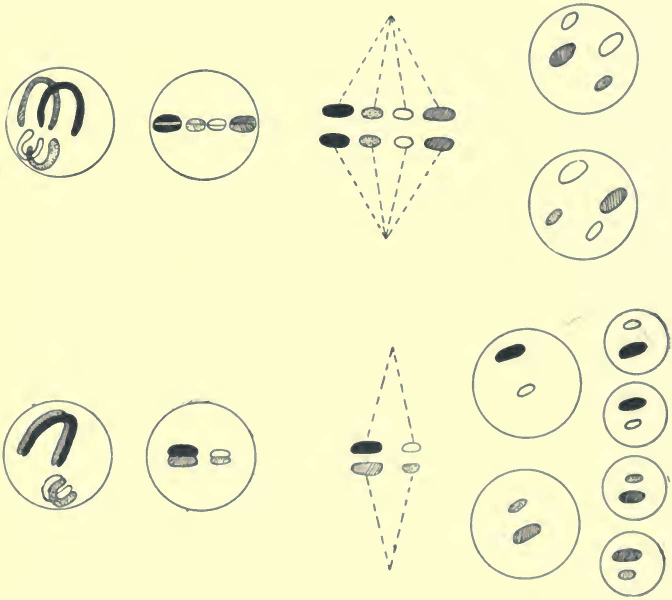


Fig. 96. — Cell Division and Reduction Compared. Cell division occurs regularly in growth, its essential feature is the longitudinal splitting of each individual chromosome so that one-half of each goes to each pole of the spindle and thus provides that the two new cells shall be exactly like each other and exactly like the one from which they have arisen.

In reduction division the members of each chromosome pair, first join side by side and then arrange themselves on the spindle in such a way that one goes to each pole, thus segregating them from one another. Since the pairs are arranged on the spindle in a chance manner it follows that this not only reduces the number of chromosomes that go to the spores but it also provides the means by which new assortments arise so that the spores produced by a plant will contain all the possible assortments of chromosomes.

one chromosome derived originally from each parent. The one from the original pollen parent is called paternal, and the one from the original seed parent maternal. The members of each pair are very similar though the different pairs differ much from one another. When the paired chromosomes arrange themselves at the middle of the spindle it is a matter of chance whether the maternal or the paternal one is turned toward any particular pole. Next the members are drawn apart along the spindle fibres. This separation of the respective maternal chromosomes from their paternal fellows is known as *segregation*. It is also spoken of as *reduction*. Both features are important. Reduction in number to one-half keeps the chromosome number constant, generation after generation, and segregation gives the spores a new assortment, a matter of great importance in heredity.

Vegetative Reproduction is very common in plants. There are many ways of accomplishing it, according to the structure of particular plants. A potato, for example, produces underground stems which become enlarged and filled with stored food, chiefly starch. When the plant matures and dies they are either harvested by man for his own use or remain in the ground, in the case of wild plants. In either event they will begin to grow on the resumption of favorable weather and soil conditions. New shoots will be put out from the leaf axils, popularly called eyes, and roots from the basal portions of the shoots, thus giving rise to new plants. Bulbs put out side branches which develop new bulbs that are used to start new plants. Rootstocks of Iris are merely prostrate stems. They may be divided and used to start new plants because each piece will produce new roots and shoots. Dahlia roots may be used in the same way. A twig of a willow may be cut and stuck into moist soil where it will put out roots and grow into a tree. A twig of a peach tree may be cut and grafted into another tree where it will not only continue growth but also unite its tissues with those of the plant to which it has been grafted. A bud cut off and inserted in a slit through the bark will grow in a similar manner.

In all these and other vegetative methods of reproduction there is one common fact. A piece of the plant consisting of more or fewer ordinary cells is detached to continue its growth elsewhere. These cells arose through ordinary mitotic cell division and so in respect to their nuclei are exactly like all the other cells of the plant. No reduction or segregation of any kind has occurred. Whatever assortment of chromosomes the original plant has in its nuclei, that identical assortment will be found in the detached portion. The new plant is to all intents and purposes merely a part of the old. All the navel orange trees of California, now running into hundreds of thousands, have been derived in this manner from two original trees brought from Brazil. That they are not all exactly alike and equally fruitful is due to another cause which will be explained in a later chapter on variation.

SECTION 9

HEREDITY

Gregor Mendel, the Austrian monk, who first correctly stated the first two laws of heredity.

CHAPTER XXVIII

MENDEL'S LAWS

VARIATION. — Children never resemble either parent exactly in all particulars and it is very doubtful whether any single character is an exact duplicate of that of either parent. Such "*differences among individuals related by descent*" are called *variations* by the biologist. The student should note that the differences between an oak and a man are not included in this definition because these two organisms are not nearly related by descent.

PURE LINES AND HYBRIDS. — In preceding chapters the student has learned that there are two sorts of reproduction found among both plants and animals; viz., sexual and asexual. In all asexual methods there is *only one parent* and the successive generations are all alike (Chap. XXVII). Moreover, when the two parents are germinally alike or when the sperm and egg are regularly produced by the same individual, it is clear that sexual methods will produce pure lines. But when the two parents belong to different species, races, or varieties the offspring will receive a different contribution from each and consequently will not be pure bred and will not belong to a pure line. The breeding together of such different parents (indicated in this book by X) is called a *cross* and the offspring is said to be *hybrid.*

MODIFICATIONS. — In any pure line there is always some variation among the various individuals. For example, two beans from the same pod belong to the same pure line because beans are ordinarily self-pollinated. Nevertheless they would scarcely ever weigh precisely the same nor when planted produce plants exactly alike.

In many cases the variation might be known to be due to soil or climate or some other environmental factor. In any event the variations would not be transmitted to their offspring. This type of variation is called *modification*.

Mutations. — Even in the purest races or in pure lines variations sometimes occur which are transmitted to succeeding generations. They are known as *mutations*. A not uncommon illustration of mutation is the appearance of a white-flowered plant in a pure line with colored flowers. If self-pollinated such white plants almost invariably breed true generation after generation irrespective of the climate or conditions of cultivation.

Recombinations. — When parents differ in several characters the hybrid offspring usually exhibit some of the characters of each parent and also lack some from each one. Variations of this sort due to recombination of characters are neither modifications nor mutations.

Heredity is the process which is responsible for the particular combination of transmissible characters possessed by any organism. It should be noted that the definition makes heredity responsible for the differences between parents and offspring as well as for their resemblances. Probably an illustration will make this clear. When a pure brown-eyed man marries a pure blue-eyed woman the children all have brown eyes but if these brown-eyed offspring marry blue-eyed mates approximately half *their* children will have blue eyes and half brown eyes. The process of heredity is equally responsible for both results.

Mendel's Discovery of the Laws of Heredity. — Although the fact of heredity has been known for two thousand years or more the laws have only recently been discovered. The first two of them we owe to an Austrian monk, Gregor Mendel, who experimented with garden peas and published an account of his work in 1865, in which he made the first statement of what we know today as: (1) the Law of Segregation, and (2) the Law of Reassortment. His momentous discovery was almost wholly neglected by his own generation and only brought to the attention of the world in general in 1900 when his paper was unearthed by three European botanists (de Vries, Correns, and Tschermak) who were also attempting to discover the laws of heredity.

THE LAW OF SEGREGATION

A Simple Illustration. — Although Mendel worked with peas this law can be more readily understood by studying a different experiment (Fig. 97). When a red-

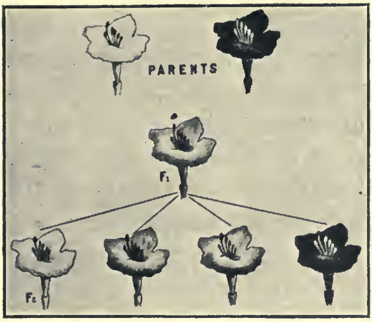


Fig. 97. — Diagram to show the results of crossing a red four o'clock by a white one. The upper row shows the red and white parents. The second row shows that the first generation hybrids are all alike and pink in color. The third row shows that when these pink hybrids are self-pollinated or bred with one another a second hybrid generation is produced which consists of one-fourth white flowered plants like one grandparent, one-half pink hybrids like the first hybrid generation, and one-fourth red plants like the second grandparent.

Morgan, Sturtevant, Muller, Bridges, *The Mechanism of Mendelian Heredity.*

flowered four o'clock is crossed with a white-flowered one the hybrid offspring, called the F_1 generation, are all pink-flowered. If these hybrid pinks are self-pollinated their offspring, called the F_2 generation, consists of three classes: one-fourth are red, like one of the grandparents; one-half pink, like the hybrid F_1 generation; and one-fourth white, like the other grandparent. The reds and whites breed true in successive self-pollinated generations but the pinks are always hybrids and always produce 1 red; 2 pink; 1 white when self-pollinated.

THE PURITY OF GAMETES. — At the time Mendel worked with his peas no one knew the structure of cells so he was compelled to formulate a purely hypothetical explanation in order to understand why the grand-parental types appear in a definite ratio in the F_2 and later generations along with the hybrids. His explanation applied to the four o'clocks would be as follows: (1) The red parent and the white one each transmits to the pink hybrid through their respective germ cells some sort of a determiner for flower color, whose interaction produces a pink color; (2) When the pink hybrid forms its germ cells or gametes the two determiners are separated and any particular gamete may receive either the "red" determiner or the "white" one but not both. (3) Hence some gametes are pure for red and an equal number are pure for white. (4) The chance combinations of equal numbers of "red" and "white" gametes will produce one-fourth red x red, (pure red), one-half red x white, (hybrid pink), and one-fourth white x white (pure white) combinations.

THE RECOMBINATION RATIO, 1:2:1 can be readily understood by examining the accompaning diagram.

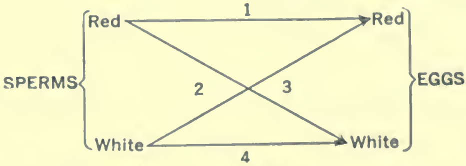


FIG. 98 is a diagram showing possible combinations of red and white sperms with red and white eggs to produce the 1 : 2 : 1 ratio.

The possible combinations are four. Combination 1 occurs one time in four and produces pure red. Combinations 2 and 3 both produce red x white hybrids or pink, and constitute half the offspring. Combination 4 produces pure white and occurs one-fourth of the time. This may be formulated in general terms by saying that the F_2 recombinations will result in 1 first grand-parental type to 2 hybrid F_1 types to 1 second grand-parental type. It is commonly referred to as the 1:2:1 ratio.

THE BEARERS OF HEREDITY ARE CHROMOSOMES. — In the preceding paragraph it has been assumed that the germ cells or gametes receive some sort of determiners now known as *factors* or *genes* which they pass on to the offspring. It is now desirable to inquire whether there is any mechanism suitable to perform this function. The reader should now recall that it has been shown in chapters XXV–XXVII that (1) The gametes are the sole contribution of the parents to the offspring, (2) That the egg is often a thousand times larger than the sperm, but that their nuclei are approximately equal, (3) That the chromosomes are the only parts of the nucleus which maintain a continuous identity. The large size of eggs is due to their having much more cytoplasm than the sperm and, usually, to this being stored with abundant food for the young organism. The sperm lacks this almost wholly, but is yet equally potent in heredity. It seems reasonable to think, therefore, that at least the chief part of the hereditary units called *genes* are contained in the nucleus. If that is so they must also be contained in the permanent part of it, the chromosomes. In fact this is known to be true, but its demonstration involves a knowledge of facts with which the student is not yet familiar.

THE CHROMOSOMES CONTAIN THE GENES. — The student is now asked to recall what he has already learned in Chapter XXV about the behavior of chromosomes. There it was shown that in ordinary cell division each and every chromosome splits lengthwise into two exactly similar halves, one of which goes to each of the new nuclei. This involves a similar splitting of every gene in the chromosome and insures that the two new cells have exactly the same number and kinds of chromosomes. It also follows that every cell in the body of a plant or animal has exactly the same equipment of genes (i.e., hereditary units). But since these chromosomes are present in pairs, one member of each pair having been derived from each of the organism's parents, there are actually two genes present for every separately heritable character, and moreover these paired genes are in opposite members of the same chromosome pair.

Segregation of Chromosomes and Genes. — In the reduction divisions which precede the formation of spores in plants and gametes in animals the first event of importance for the present discussion consists in the members of each chromosome pair placing themselves side by side in the process called *synapsis*. After a series of developments (which do not concern us at the present moment) each chromosome pair finally arranges itself on the nuclear spindle. The second significant step is that the two members of each pair separate or *segregate* from one another and go to opposite poles. This separation of the maternal chromosome from its paternal mate also separates the genes which they contain. Hence if the maternal chromosome of a hybrid pink four o'clock which contains the gene for red flower color goes to one pole the paternal chromosome containing the "white" gene goes to the opposite pole. This behavior of the segregating chromosomes thus does two things. First it insures that the spores or gametes produced will get only one of the pair of genes (red or white in four o'clock for example) and not both of them. In the second place it produces the two kinds of gametes in equal number. As we have already seen this is precisely the sort of mechanism required to produce the 1:2:1 ratio in F_2.

Dominance and the 3:1 Ratio. — In the four o'clocks the hybrid between red and white is pink and so is readily distinguished from either parent race. In many crosses this is not the case. When a tall pea is crossed with a short one the hybrid is as tall as the tall parent and ordinarily indistinguishable from it. In such cases "tall"

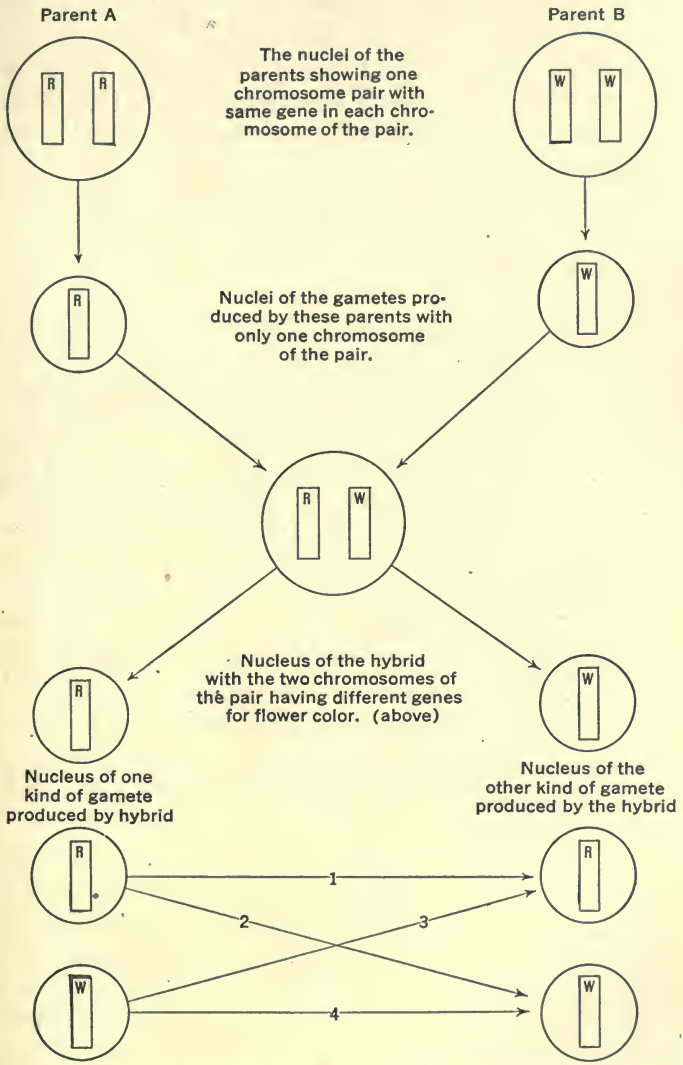


FIG. 99. — A diagram to show the segregation and combination of chromosomes in hybrid pink four o'clocks.

is said to be *dominant* to "short" and "short" *recessive* to tall. When the tall hybrids are self-pollinated they produce an F_2 generation which consists of 3 talls to 1 short. Obviously this result is due to the fact that the pure talls and the hybrid talls look alike. If each tall plant is self-pollinated and its seeds sowed separately, it is found that two-thirds of them are hybrids (i.e., their seeds produce both talls and shorts in a 3:1 ratio) and one-third are pure talls (producing only talls). The 3:1 ratio is therefore only a special case of the 1:2:1 ratio and really consists of one-fourth pure dominants (i.e., tall): two-fourths hybrid dominants: one-fourth pure recessives.

THE LAW OF SEGREGATION. — Heredity in a simple cross between two individuals involving a single pair of characters may be summed up in the following statement or law:

The paired genes which are responsible for the character difference segregate from one another in the reduction divisions of hybrids and thereby give rise to equal numbers of gametes pure for one or the other gene; and these gametes then combine by chance at fertilization to produce the F_2 or second hybrid generation, which will consist of approximately one-fourth of the individuals pure and like one grandparent, one-fourth pure and like the other grandparent, and one-half hybrid, which half will always be like the first hybrid generation and either like one grandparent or intermediate between the two grandparents.

THE RELATION OF GENES TO CHARACTERS. — Though the language used in speaking of genes and characters is such that the student might readily gain the impression that a particular gene is the sole cause of a corresponding character, this is far from the truth. A moment's consideration will show that a four o'clock flower cannot have a red color unless many genes have first wrought their coöperative effect to develop the plant and flowers. All that is really meant in the case under discussion by the expression "gene for red" is that red flowers are produced by a combination of genes that differs, in respect to a single pair of genes, from that which produces white. Thus this single gene is responsible for the *difference* between red and white but it is not by any means *solely* responsible for red or white flowers.

Are Genes the Sole Bearers of Heredity? — This question will receive adequate answer in later chapters but it seems desirable to point out here that the present state of knowledge of heredity recognizes only two means of transmitting characters from parent to offspring. The great majority of characters which have been investigated belong to the class which are transmitted through genes in the chromosomes. A very few characters in plants, having to do with the green color, are now known to be transmitted from the ovule parent directly to the offspring by means of the chloroplasts which are contained in the cytoplasm of the egg. There are many popular ideas about the influence of the mother on her unborn child which, if true, would not fall in either of these two classes. Most of these beliefs are obviously fanciful and have no basis in fact at all. All such ideas as that the mother can control the moral or intellectual character of the child by directing her own thoughts along similar lines are in all probability mere figments of the imagination.

Are Acquired Characters Inherited? — An acquired character is one which the organism has acquired during its own lifetime as a result of its own activities or the action on it of external influences. The chief difficulty in answering the above question lies in distinguishing genuine acquirements. So long as one experiments with characters about which there is no doubt the answer is always in the negative. For example the small feet of the high-class Chinese woman are certainly acquired. Her immediate ancestors and her remote ones have regularly bound up their feet to keep them small. But if any one in the series does not have her feet bound they are not small. Clearly this sort of an acquired character is not inherited. But if a trained trotting horse begets other fast trotters it is often popularly supposed that they have inherited the effects of the parent's training. It is far more probable, however, that they have merely inherited a *similar ability to be trained.* In any event the biologist has not yet, notwithstanding long-continued and painstaking experimentation, been able to produce any results which are not readily explicable either on the basis of the chromosome mechanism or on some organ or substance contained in the cytoplasm of the egg. Certain facts are, however, known about the structure and metabolism of cells which might offer an explanation in the event that the inheritance of a genuine acquired character should ever be established.

CHAPTER XXIX

THE LAW OF INDEPENDENT ASSOCIATION

The Independence of Characters. — For the sake of simplicity in the discussion of Segregation our attention has been confined to a single pair of characters and their corresponding genes. Of course the two parents often differ in respect to several character pairs. What is true, however, in respect to one pair is also true of any other pair. In order to illustrate the independence of characters in expression and in heredity at least two character-pairs are necessary. If a pure tall white-flowered pea is crossed by a pure short purple-flowered one the hybrid offspring are all alike and all tall and all purple-flowered. In this it is to be noted first of all that neither parent has dominated over the other as a whole. The hybrid has inherited its height from one parent and its flower-color from the other. If a tall purple is crossed by a short white the hybrid is again tall purple. In this case it resembles one parent exclusively. From the two experiments it becomes clear that the expression of particular genes depends on their own powers and not on which parent they have been derived from.

The Combinations of Independent Characters in F_2. — If the hybrid tall purple peas discussed above are self-pollinated to produce a second hybrid generation it will be found to consist of approximately 9 tall purple; 3 tall white; 3 short purple; 1 short white. It is to be noted that two of these combinations are the same as the grandparents and two are new combinations. The result is the same, whether the tall purple hybrids have been produced by crossing tall whites by short purples or tall purple by short white. Thus not only do these pairs of genes for tall-short and purple-white express themselves independently of one another, but also they recombine in F_2 independently of one another.

THE MECHANISM OF REASSORTMENT is the same as that involved in the segregation of a single pair of genes. It merely adds to the segregation of one pair the simultaneous segregation of one or more additional pairs. The diagrams show how this is accomplished.

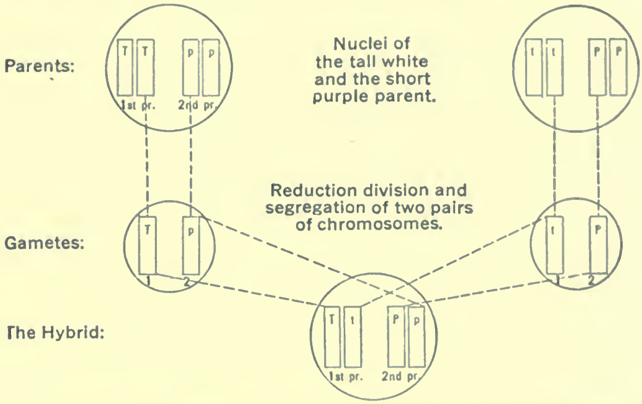


FIG. 100 is a diagram of reduction divisions of the tall white and short purple parents, etc.

THE CHROMOSOMES OF THE TALL PURPLE HYBRID. — The pea has seven pairs of chromosomes, only two of which are concerned with the present experiment. All further mention of the other five pairs will therefore be omitted. When the reduction division occurs each pair segregates (as shown in the diagram) so that the gametes receive only one member of each pair. The gamete of the tall white thus receives one chromosome containing the " Tall " gene T and another containing the " white " gene p. Similarly the gamete of the short purple receives one chromosome with the " short " gene t, another with the " Purple " gene P. These are the only kinds of gametes these parents can form. Since there is only one kind of gamete formed by each parent only one combination can result: viz., that shown in the diagram for the nucleus of the hybrid. In one pair one chromosome has the gene T and its mate the gene t. In the other pair, one has the gene P and the other the gene p. This sort of difference in the chromosome pairs is characteristic of the nuclei of all hybrids. Always one or more chromosome pairs have at least one gene in one chromosome different from the corresponding one in its mate.

THE GAMETES OF THE TALL PURPLE HYBRID. — The reduction divisions in the tall white and short purple parents produce only one kind of gamete for each because the members of each chromosome pair are exactly alike. In the Tall Purple hybrid more than one kind of gamete is formed, because in the segregation of its two chromosome pairs different genes go to the opposite poles of the spindle. Furthermore, it has been noted in previous chapters that it is apparently wholly a matter of chance which way a chromosome pair lies on the nuclear spindle, and therefore also a matter of chance to which pole either of its members goes. The diagram shows the two ways in

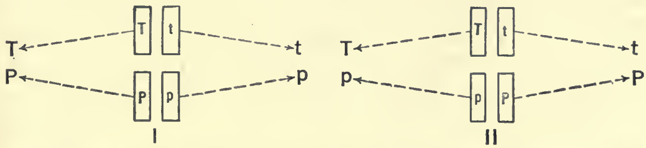


FIG. 101 is a diagram of two ways of arranging chromosomes of the tall purple hybrid on the spindle.

which these two chromosome pairs may be arranged on the spindle of the reduction division of the hybrid in reference to one another.

Position I produces two kinds of gametes TP (Tall Purple) and tp (short white). Position II similarly produces the gametes Tp (Tall white) and tP (short Purple). Since one position on the spindle is just as likely as the other, it follows that four kinds of gametes are produced in equal number.

THE COMBINATION OF THE FOUR KINDS OF GAMETES.— Since the hybrid can produce four kinds of sperms and four kinds of eggs, it is apparent that it can give rise to as many kinds of descendants as there are possible combinations of gametes. The diagram (called a Punnett square after the man who suggested its use) allows one to determine readily what combinations are possible and in what ratio each will occur. Along the top of the diagram are written the four kinds of eggs and along the left side the four kinds of sperms. In the sixteen squares are written the various combinations which four kinds of sperms can make with the four kinds of eggs.

Sperms \ Eggs	TP	Tp	tP	tp
TP	TT PP (1) Tall Purple	TT Pp (2) Tall Purple	Tt PP (3) Tall Purple	Tt Pp (4) Tall Purple
Tp	TT Pp (5) Tall Purple	TT pp (6) Tall white	Tt Pp (7) Tall Purple	Tt pp (8) Tall white
tP	Tt PP (9) Tall Purple	Tt Pp (10) Tall Purple	tt PP (11) short Purple	tt Pp (12) short Purple
tp	Tt Pp (13) Tall Purple	Tt pp (14) Tall white	tt Pp (15) short Purple	tt pp (16) short white

FIG. 102 is Punnett Square showing recombinations of the gametes of the tall purple hybrid.

THE 9:3:3:1 RATIO. — It was stated in a previous paragraph that there would be four combinations of characters in the second hybrid generation when the tall purple hybrids are self-pollinated and that they would occur in the ratio 9:3:3:1. These four types can be readily identified in the diagram. Every one which has either one or two "Tall" genes *T* will be tall, and likewise everyone with one or two "Purple" genes *P* will be purple. Thus, Nos. 1, 2, 3, 4, 5, 7, 9, 10, 13 are all Tall Purple, and are nine out of the total of sixteen. Similarly, Nos. 6, 8, 14 are Tall white and are three out of sixteen. Nos. 11, 12, 15 are short Purple and three out of sixteen. No. 16 is short white. This ratio is readily seen to be a general one for any two independent dominant characters.

GENOTYPES AND PHENOTYPES. — This diagram also makes clear another important fact. There is only one plant out of sixteen which is white and short. It has both recessive characters, and is pure (*ttpp*) for both. The three short purples, however, are not all alike. No. 11 is pure for both characters (*ttPP*) but both 12 and 15 are pure only for short (*tt*) and hybrid for purple (*Pp*). The same difference is to be noted among the tall whites and tall purples; only one of each group is really pure, the others being hybrid for one or both characters. From this it appears that there are more combinations of genes than are recognizable from the appearance of the plants.

In order to distinguish the combinations or genes from the combinations of characters biologists give them separate names. Any particular *combination of genes* is spoken of as a *genotype,* whereas any *combination of characters* is called a *phenotype,* that is to say, visible type. There are shown in the Punnett square 4 phenotypes or visibly distinguishable types (i.e., Tall Purple, Tall white, short Purple, and short white), but there are nine genotypes or combinations of genes, as follows: (1) *TTPP* (No. 1), (2) *TTPp* (Nos. 2 and 5), (3) *TtPP* (Nos. 3 and 9), (4) *TtPp* (Nos. 4, 7, 10, 13), all of which look alike and are tall and purple; (5) *TTpp* (No. 6), (6) *Ttpp* Nos. 8, 14), all tall and white; (7) *ttPP* (No. 11), (8) *ttPp* (Nos. 12, 15) all short purple; and (9) *ttpp* (No. 16) short white.

The Law of Independent Assortment of Genes and Characters. — *When two parents which differ in respect to two different character-pairs are crossed the hybrid will exhibit both dominant characters irrespective of which parent contributes them.*

When the hybrid forms its gametes the independent genes, which are in separate chromosome pairs, segregate and form four kinds of gametes.

At fertilization the four kinds of gametes unite to form nine different genotypes or combinations of genes, and when both character-pairs show dominance four different phenotypes or combinations of characters.

CHAPTER XXX

LINKAGE PHENOMENA

THE THIRD LAW. — Limitation of Independent Assortment. In the last chapter it was shown that many character-pairs assort themselves independently of one another. But since this independence is due to their respective genes being carried in different chromosome-pairs it is clear that there can be no more independent pairs of characters than there are pairs of chromosomes. For example, there are seven pairs of chromosomes in peas. Mendel found just seven pairs of independent characters, nor has the extensive work since his time discovered any more. This fact is also true of all other plants and animals so far studied. It may be stated as a third law of heredity: *The number of pairs of characters which can at the same time assort independently in any organism is equal to the number of chromosome pairs in its cells.*

THE FOURTH LAW. — *Characters whose genes are located in the same chromosome are linked in heredity.* Both the third and fourth laws are obvious consequences of the behavior of the chromosomes. Since these chromosomes are definite in number and maintain their individuality, the total number of characters must be assorted in an equal number of linked groups. That this is actually true is being abundantly proved by investigations with both animals and plants. Groups of linked characters are already known in several plants, including the sweetpea in which the phenomenon was originally discovered. Linkage is also known in several animals, including man.

THE VINEGAR FLY. — Investigations in heredity have probably made greater progress in the last dozen years or so than in all previous time. This has in large measure been made possible through the use of the vinegar fly, Drosophila. This insect (see Fig. 105) is small and breeds readily in captivity. It mutates (see p. 350) frequently and its life is short. In a little over ten years more generations of this fly have been reared and carefully observed under the microscope than there have been generations of men since the dawn of recorded history.

The nucleus (Fig. 103) of the cell of the vinegar fly is almost ideally suited for studies in heredity. In the first

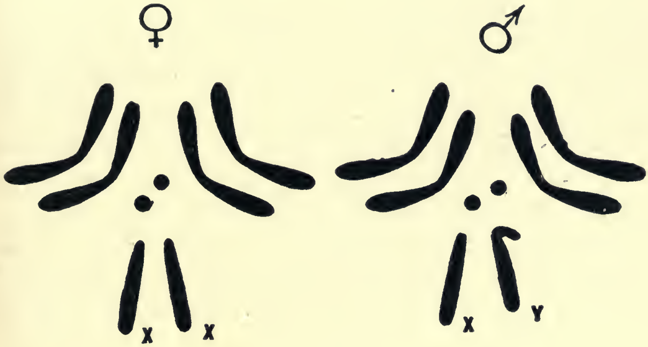


FIG. 103. — The Nuclei of the Cells of Vinegar Flies. The figure to the left shows that the female has 4 pairs of chromosomes in each cell nucleus and that the members of each pair are visibly alike. The right-hand figure shows that the male has three pairs like those of the female but that the members of the lower pair are visibly different from one another. So far as investigations have gone up to the present the one with the hook (the Y-chromosome so-called) carries no genes or hereditary factors. In certain abnormal flies it is entirely missing and that apparently without making any essential difference in heredity.

Morgan, Sturtevant, Muller, Bridges, *Mechanism of Mendelian Heredity.*

place it has only four pairs of chromosomes and hence can have only four groups of linked characters. In the second place, its chromosome pairs can be distinguished from one another by their form and size. This has been one of the means by which it is possible to tell in which chromosome pair the genes for the different linkage groups of characters are located. The first pair are straight rods, the second and third ones are bent rods, and the fourth pair are small round bodies.

The Sex Chromosomes of Drosophila. — In the female the two members of the first pair of chromosomes are indistinguishable and are called X chromosomes. In the male, one of these chromosomes is slightly different from its mate. One of them is like the pair in the female and is in fact an X chromosome. The other one is called the Y chromosome, and is not known to carry any genes.

The Determination of Sex. — When the vinegar fly forms its eggs, the two X's segregate from one another along with the members of the other three pairs so that every egg receives one X. In the male the X segregates from the Y so that one half the sperms receive an X and the other half receive a Y. There are thus two kinds of sperms and but one of eggs. If an X-containing sperm fertilizes an egg a female results (i.e., XX), but if a Y-containing sperm fertilizes it a male (XY) results. This general method of sex-determination appears to be common among insects, birds and mammals, including man.

Linkage in Vinegar Fly Crosses. — Many hundreds of experiments have been carried out in studies of linkage with this insect, so that there is now a very large body of data, whereas our knowledge of this phenomenon is far less complete in respect to any other animal or plant. For this reason the following paragraphs will deal with vinegar fly crosses with the understanding that the principles developed are in general applicable to other animals and plants.

The Back Cross is a method of breeding in which the first generation hybrids are mated to pure recessives instead of to one another. It is much used in analyzing the genetic composition of hybrids because it gives simpler results than mating hybrids with one another, in that the recessive parent, being pure, produces only one kind of gamete. Moreover, since these gametes have only recessive genes they will not obscure any dominant genes of the hybrid with which they unite. The back cross is thus particularly well suited for studying linkage phenomena. The next paragraph will show how it works in crosses involving independent characters.

Back Cross involving Independent Characters.— When the hybrid tall purple peas discussed in the preceding chapter were mated to one another or self-pollinated the second hybrid generation consisted of four phenotypes in the ratio of 9:3:3:1. If this same hybrid is back-crossed to the double recessive, short white, the same four phenotypes will be produced but in the ratio 1:1:1:1. The table shows why this is so.

Four kinds of eggs which are produced in equal numbers by the tall, purple hybrid.

		TP	Tp	tP	tp
1 kind of sperm of short white	tp	Tt Pp Tall Purple	Tt pp Tall white	tt Pp short Purple	tt pp short white

Fig. 104. — Punnett Square (showing results of back-crossing a tall purple hybrid to a pure short white).

Linked Characters in the First Hybrid Generation behave just like independent characters, in that it makes no difference from which parent the dominant characters come. For example, (1) if a long-winged gray-bodied fly is mated to a vestigial-winged black-bodied one the hybrid offspring will all be gray-bodied and long-winged because these two characters are dominant (Fig. 105). (2) If the same two character-pairs are introduced into the cross by mating a gray-bodied vestigial-winged fly with a black-bodied long-winged one the result will still be gray-bodied long-winged hybrids, just as would be the case if the experiment concerned independent characters (Fig. 106). Although Gray Long x black vestigial and Gray vestigial x black Long give identical first gen-

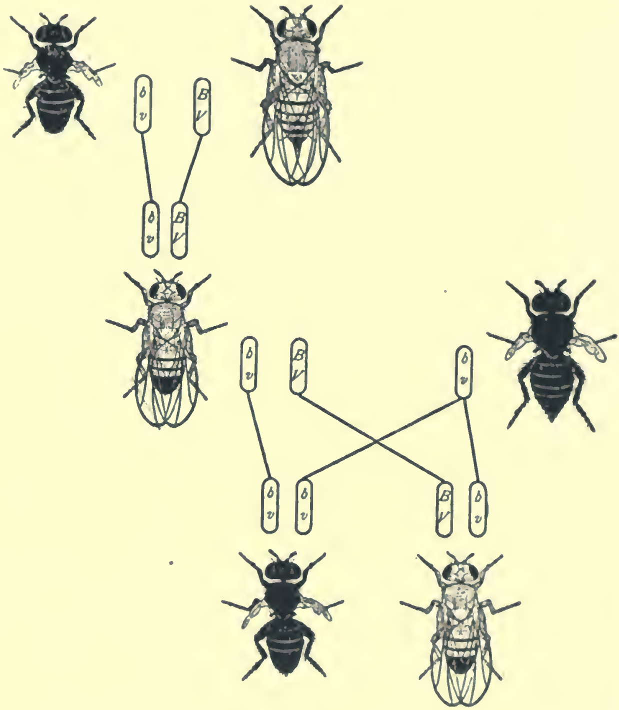


FIG. 105. — Illustrating the Behavior of Linked Characters in the vinegar fly. A black-bodied fly with vestigial wings is mated to a gray-bodied fly with long wings. The first hybrid generation is long-winged and gray-bodied. When this is bred to a black vestigial fly (i.e. back-crossed to the double recessive type) the grandparental types appear in the second hybrid generation. In the chromosome diagrams the gene *b* for black body is contained in the same chromosome with the gene *v* for vestigial wings so that the two remain linked together throughout all the cell divisions of growth and through the reduction divisions which produce the gametes, and therefore reappear together again in the second hybrid generation. The same is also, of course, true for the dominant genes *B* for gray body and *V* for long wings.
Morgan, *The Physical Basis of Heredity.* Lippincott.

eration hybrids, these hybrids do not (as hybrids with independent characters do) give the same phenotypes in the second hybrid generation either when back-crossed or when mated with one another, as is set forth in detail in the next paragraph.

BACK-CROSSING LINKED CHARACTERS. — If the long-

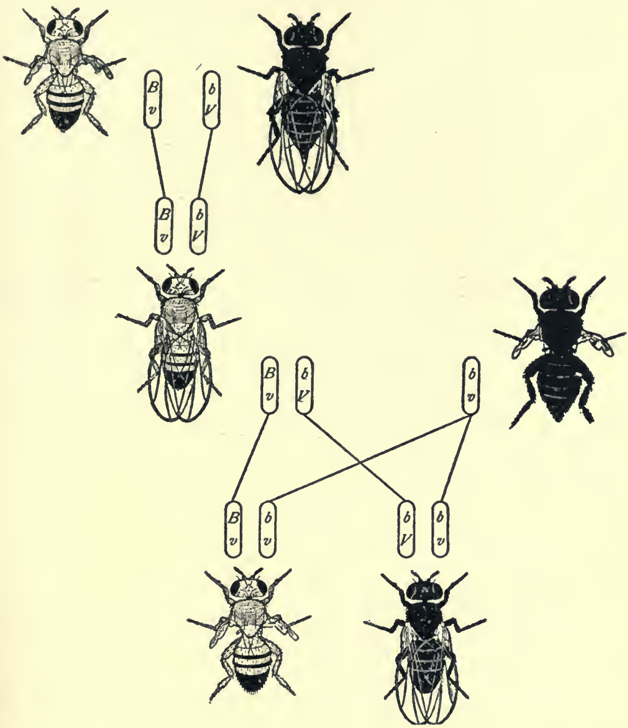


FIG. 106. — The Cross Between Vestigial Gray and Long Black. The symbols used in this diagram are the same as those in the last one. However it should be noted that in this cross each parent contributes one dominant gene, whereas in the last, one parent contributed both dominants. In this case the first hybrid generation will show both dominants and so, therefore, resemble one parent in respect to body color and the other in respect to wing length. As the diagram shows this does not involve any disturbance of the linkage since the grandparental combinations of genes and their corresponding characters reappear again in the second hybrid generation.
Morgan, *Phys. Basis.*

winged gray-bodied hybrid male flies from the first type of cross, where the two dominant characters (i.e., Gray and Long) came from the same parent, are mated to double recessive females (i.e., black vestigial) there will be just two types of offspring; viz., Gray Long and black vestigial like their grandparents. If free assortment had occurred there would have been in addition recombination classes: viz., Gray vestigial and black Long and all four classes in equal numbers, as was explained in a preceding paragraph for the pea cross.

If the second (2) type of gray long hybrid males are crossed to black vestigial females they produce also only two classes of offspring: viz., Gray vestigial and black Long like their grandparents and no recombination classes.

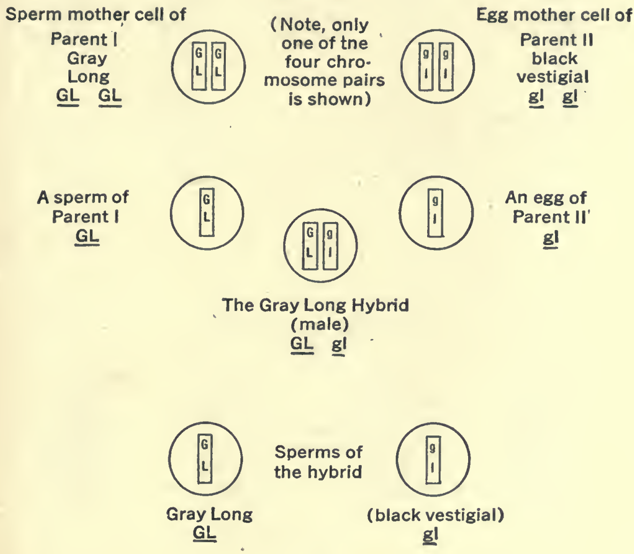
In both experiments there is a total failure to produce the recombination classes to be expected according to the law of free assortment. In other words, the characters that went into the cross together have stayed together or show complete linkage. The accompanying diagram and those in the next paragraph show why these results are obtained.

Sperms of the two sorts of gray long hybrids.

Case (1)	Gray Long sperm	×	*black vestigial egg*	=	Gray Long F_2
	black vestigial sperm	×	" " "	=	black vestigial F_2
Case (2)	*Gray vestigial sperm*	×	" " "	=	Gray vestigial F_2
	black Long sperm	×	" " "	=	black Long F_2

THE SEGREGATION OF LINKED GENES. Since it has already been shown that genes which are in different chromosome-pairs assort independently it is evident that characters which do not assort freely must be in the same chromosome-pair. The accompanying diagrams (Fig. 107a and b) show the locations of the genes for vestigial wing and black body color in the second chromosome-pair and the way they are distributed by segregation in the two crosses under discussion.

THE STRENGTH OF LINKAGE. In the last paragraph male hybrids of the vinegar fly were back-crossed to *female recessives* because the linkage of genes in the chromosomes of male vinegar flies is complete, i.e., there is never any separation of the genes in the same chromosome, and consequently the characters that originally



A

FIG. 107. — (*a*) Showing the segregation of linked genes in gray long hybrid of type GL gl.

went into the cross came out together again without fail in the second hybrid generation. This peculiarity of linkage in male vinegar flies, viz., that linked characters never separate, is not true for the female hybrids or for males of all species of animals. By mating a *female* (Fig. 108) hybrid Gray Long vinegar fly of type (1) (i.e., the offspring of Gray Long and black vestigial) with a double recessive (i.e., a black vestigial), male, all four phenotypes occur in the second hybrid generation, but they do not occur in the 1:1:1:1 ratio to be expected in the case of free assortment. If a female hybrid of type (2) (i.e., offspring of gray vestigial by black long) is mated to the double recessive (i.e., black vestigial) male,

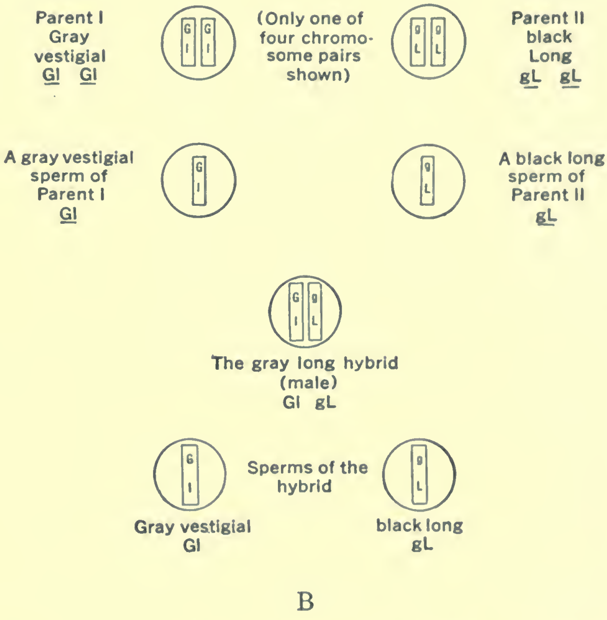


FIG. 107. — (*b*) Showing the segregation of linked genes in gray long hybrid of type Gl gL.

the same four phenotypes occur but the ratios are again different. In the first case there are about five times as many Gray Long and black vestigial flies (i.e., grandparental combinations) as there are Gray vestigial and black Long or recombination classes. In the second case there are also about five times as many grandparental types (i.e., this time Gray vestigial and black Long) as

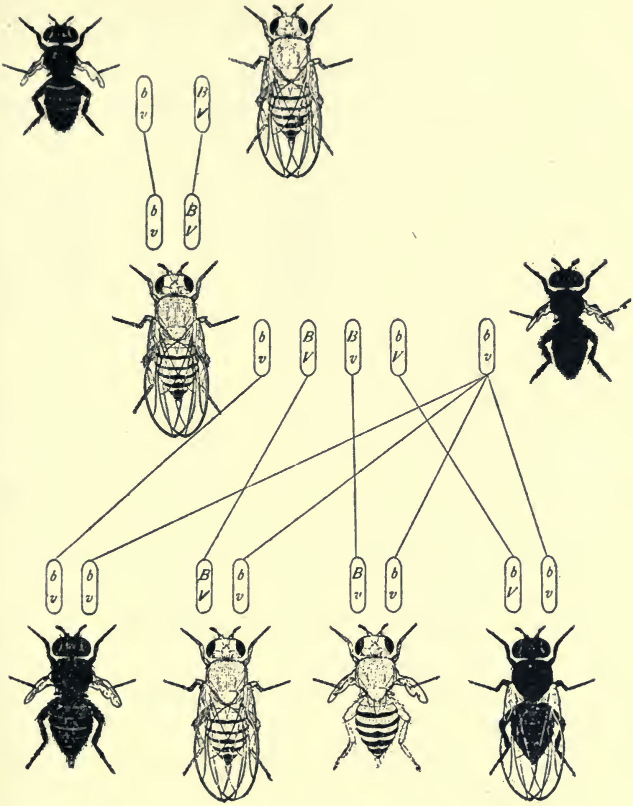


FIG. 108. — Crossing-Over in a Cross Between Black Vestigial and Gray Long. This experiment is like the last two except that in this case a female hybrid is bred to a double recessive male. The second line shows that four kinds of eggs are produced as if free assortment had occurred. The difference lies in the fact that there are many more eggs with the original combination of genes than with the recombinations as is shown by the fact that in the second hybrid generation there are about five times as many grandparental types as there are recombination types. Crossing-over of genes in the vinegar fly has occurred up to the present only in the female and not in the male. Hence female hybrids are used when it is desired to demonstrate crossing-over and males when linkage only is to be shown.

Morgan, *Phys. Basis.*

recombination types. Other characters show the same sort of phenomena but the strength of linkage varies with the particular characters.

Crossing-over is the technical name given to the breakage of linkage between characters whose genes are carried in the same chromosome-pair. In the preceding paragraphs the characters, black body and vestigial wings, were shown to be linked and during the formation of gametes usually to remain together, but to separate in a certain proportion of the gametes. Since linkage is due to the genes being in the same chromosome it is evident that there must be some means by which a gene may be exchanged from one chromosome to its mate.

The Mechanism of Crossing-over. In a very early stage of the reduction divisions in the mother cells of gametes in animals (and spores in plants) the chromosomes are drawn out into slender threads. At this time they become associated side by side throughout their entire length in the process called synapsis. They become so closely twisted about one another that it is difficult to distinguish one from the other. During their later development they become much shorter and thicker. It is supposed, and there is much indirect evidence to prove, that while they are twisted a part of one may come to replace a corresponding part of its mate. The diagram (Fig. 110) shows how crossing-over affects the position of the black and vestigial genes in a pair of chromosomes of a hybrid vinegar fly.

The Fifth Law of Heredity may be stated as follows: *Linked genes may cross-over from one chromosome of a pair to its mate by exchange of corresponding segments of the paired chromosomes.*

The Sixth Law states that *the genes in a chromosome are arranged in linear order.* This law rests on the fact that there is a definite percentage of crossing-over between any two pairs of genes and that it is greater the further apart they are. This is, of course, obvious from the diagram, for the farther apart the genes are the more chances there are that a break will occur between them.

SEX LINKAGE. Since the sex of an individual in many animal species is determined by its chromosomes it would naturally be expected that some characters would be

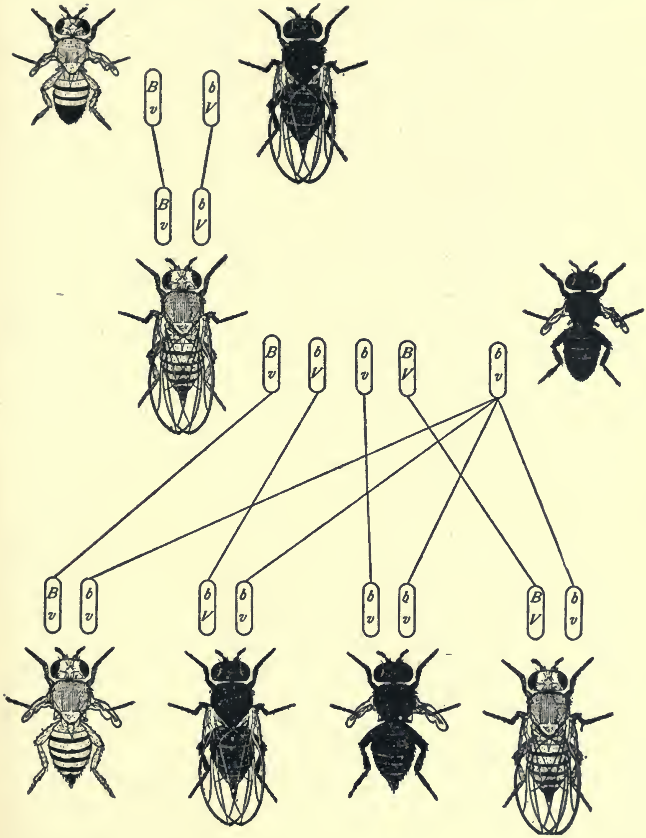


FIG. 109. — Crossing-Over in Cross Between Gray Vestigial and Black Long. The symbols and results are the same as in the last diagram except that the genes are linked differently. The second hybrid generation shows again about 5 times as many grandparental types (i.e. this time gray vestigial and black long) as recombination types.
Morgan, *Phys. Basis.*

linked in the sex chromosome. This is in fact true and we may now proceed to examine this matter more closely. Since the vinegar fly has 2 X's in the female and one X and one Y in the male, it is evident that the female can be pure (i.e., have the same genes in both chromosomes)

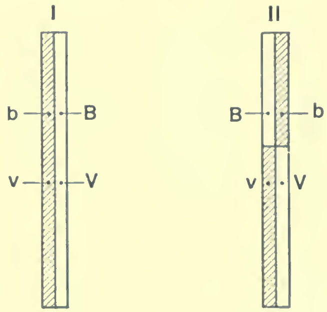


Fig. 110. — Diagram to show crossing-over of genes. I shows the arrangement of genes in the 2nd pair of chromosomes of the hybrid before crossing-over has occurred. II shows the recombinations after crossing-over has occurred. Segregation of the chromosomes in I will give gametes like the parents; of the ones in II will give recombinations. In this particular instance crossing-over occurs in about 17 % of the gametes. B = gray body; b = black body; V = long wings; v = vestigial wings.

for genes carried in the X chromosomes, but that the male cannot, because he has only one X and the Y has not been shown to carry *any* genes. An illustration or two will make the matter clear.

Red-eyed Female X White-eyed Male Fly (Fig. 111). — The gene for eye-color in this cross is located in the X chromosome. Red is dominant to white. The red-eyed female produces eggs all of which have one X chromosome containing the gene for red-eye. Half the sperms have an X with the gene for white-eye and half have the Y chromosome. When " white " X-sperms fertilize the " red " X-eggs, red-eyed females result; because the red is dominant to the white. When Y-sperms fertilize " red " X-eggs, red-eyed males result, because the only X present has a " red " gene.

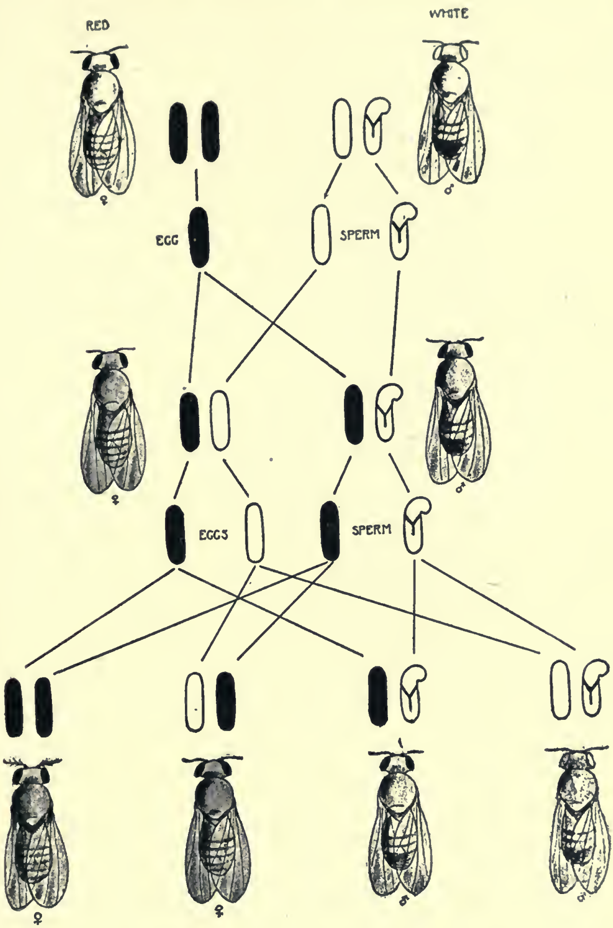


Fig. 111. — Sex-Linkage. A cross involving the genes red and white eye, which are located in the sex chromosomes. The X-chromosomes of the female parent are colored black to indicate the presence of the gene for red-eye and the X-chromosome of the male left white to indicate the white gene. The Y-chromosome of the male is also left blank because it does not contain either gene. The diagram shows that the first generation males and females are both red-eyed because each receives a gene for red-eye. In the second generation all females are red-eyed since they have either one or two chromosomes with the red gene whereas only half the males receive the chromosomes with the red gene. The other half receive a chromosome with the white gene and are white-eyed.

Morgan, Sturtevant, Muller, Bridges, *Mechanism of Mendelian Heredity.* Holt.

Red-eyed hybrid females X red-eyed males. If the hybrid red-eyed females of the last paragraph are bred to their red-eyed brothers (or any other red-eyed males) all the daughters are red-eyed because they receive a dominant " red " X from the father and either a " red " or a " white " X from the hybrid mother. Half the sons are red-eyed because they receive a " red " X from their mother along with the inactive Y from the father. The other half of the sons are white-eyed because they receive a " white " X from their mother and an inactive Y from the father. The accompanying figure (111) should make this point clear.

RED-EYED MALE X WHITE-EYED FEMALE. — Reference to Fig. 112 shows that the hybrid daughters here receive a " white " X from the mother and a " red " from the father, and are therefore red-eyed. Sons receive a Y from father and a " white " X from mother and are therefore white-eyed. If these white-eyed males are bred to their hybrid red-eyed sisters half the daughters are red-eyed hybrids and half are pure white-eyes. Likewise, half the sons receive a " red " X from their hybrid mother and a Y from their father and are red-eyed, and half receive a " white " X from the mother and a Y from the father and are white-eyed.

SUMMARY OF PRINCIPLES OF HEREDITY.

1. The first law or principle states that the genes for parental character-pairs segregate in the hybrid.

2. The second principle goes a step further and states that each pair of characters may segregate independently of other pairs.

3. The third principle is that independent segregation is limited to pairs whose genes are in separate chromosome-pairs.

4. The fourth principle is that characters whose genes are in the same pair of chromosomes will be *linked,* i.e., tend more or less strongly to remain together in heredity.

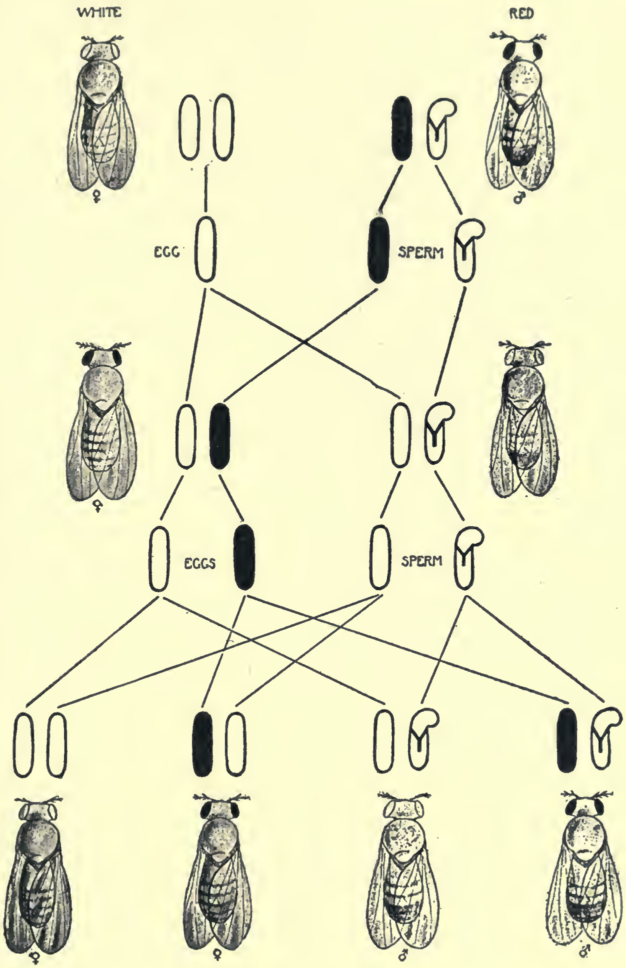


FIG. 112. — Sex-Linkage. White-eyed female by red-eyed male. The symbols used are the same as in the last figure. The results are somewhat different although the principles involved are identical. The first generation females are red-eyed because they receive a red gene from their father. The males are white-eyed because they receive a white gene from the mother and only an inactive Y-chromosome from the father. The results in the second generation are explained in the same way.

Morgan, Sturtevant, Muller, Bridges, *Mechanism of Mendelian Heredity.*

5. The fifth principle is that the crossing-over or exchange of corresponding parts of homologous chromosomes causes the breaks in linkage of characters.

6. The sixth principle asserts that by comparing the percentages of crossing-over it is possible to show that the genes are arranged in the chromosomes in *linear* order.

7. Since sex in higher animals is determined by the chromosomes, characters whose genes are located in the sex chromosomes show sex linkage.

CHAPTER XXXI

THE CHARACTER EXPRESSION OF GENES

THE DIFFERENTIAL GENES OR FACTORS. — In a preceding chapter it was shown that no character is ever the result of the activity of one single gene or factor alone. (Page 357). Nevertheless it is true that whether a particular character of a plant or animal *appears or not* often depends on the activity of one or a relatively few genes, which may, therefore, be called *differential genes* or factors. All the examples which have been used thus far in this book have depended for their *final* expression on some *one* factor. The real situation may possibly be made clearer by the relations existing in the vinegar fly in respect to eye-color. About twenty-five different modifications of eye-color in this fly have already been studied. Many genes, of course, interact to produce the natural wild type with red eye. The other colors are due to a *change* in some single gene for each but not always the same gene or even one in the same chromosome.

THE RELATIVE POSITION OF GENES. — It has already been shown that the two differential genes responsible for a pair of contrasting characters are carried in the same chromosome-pair, the one in one chromosome and the other in its mate, and so show segregation. Moreover, the genes are arranged in linear order so that corresponding genes lie at exactly the same relative positions in their respective chromosomes. This, however, fails to explain fully the hereditary behavior of many characters, as, for example, eye-color in vinegar flies. A red-eyed fly (Fig. 113) crossed to either a white-eyed or a cherry-eyed fly shows the ordinary segregation in the second hybrid generation into red and white or red and cherry, as the case may be. A white-eyed fly crossed to a cherry-eyed fly similarly gives white and cherry in the second generation. Since any two of these genes (red, cherry, white and also eosin) for eye-color may pair with one another they must

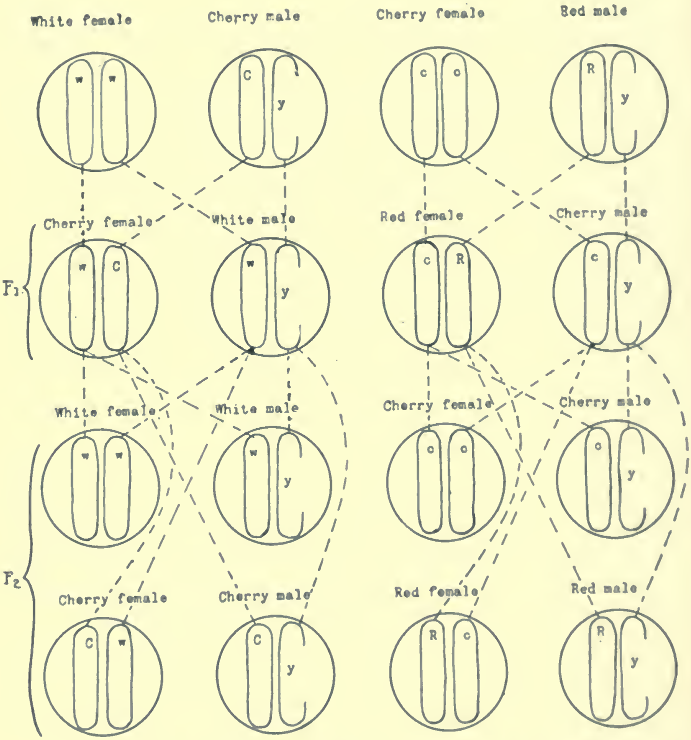


FIG. 113. — Multiple Allelomorphs. Cherry is a modification of the same red gene which when modified in another way produces white eyes. It is also known to undergo still another mutation which gives rise to eosin eyes. The diagram shows the behavior of the sex chromosomes in which these genes are contained in the two crosses white female by cherry male and cherry female by red male. They should be compared with the cross between a white female and a red male in the last chapter. From an examination of these diagrams it will be observed that any two of these genes will pair with one another because they all occupy the same relative position in their respective chromosomes. Such a system of several genes able to pair with one another constitutes a system of multiple allelomorphs.

all be located in the same relative position, but of course any particular chromosome can have but one of them. Thus we have in such a case a system instead of a pair of genes, all due to different changes of the same gene.

MUTATIONS OF GENES. — If the wild red-eyed vinegar fly is actually the original type it is clear that all other eye-colors have been derived from it by a change or *mutation* of some one or more of the genes concerned in the production of red. In the mutations which have given rise to white, cherry, and eosin we have seen that the mutation occurred at the same locus or position in the chromosome. Other eye-colors, e.g., vermilion, have arisen by mutation of other genes in the same chromosome-pair. When white-eyed males and vermilion-eyed females are crossed the F_1 males are vermilion, like the mother, and the F_1 females are red, because they receive the normal red gene corresponding to white from the mother and the normal gene corresponding to vermilion from the father. An inspection of the accompanying figure (114) will show that they are hybrid for both genes, white and vermilion, and therefore have red eyes, because the normal genes are both dominant. *Mutations of genes* always *precede* and are in fact the *cause* of *mutations* in *characters* of plants and animals.

THE GAMETIC RATIOS OF HYBRIDS. — The reader already knows that the hybrid between parents differing in a single pair of genes and characters produces just two kinds of gametes, and further, that the hybrid between parents differing in respect to two pairs of genes produces four kinds of gametes in equal number, provided the genes in question are in different pairs of chromosomes and hence not linked. It is easy to go a step further and generalize this. If parents 1 and 2 differ in respect to the independent genes a and a' and b and b', the hybrid has the genotype aa', bb' and can produce equal numbers of gametes ab, ab', $a'b$, $a'b'$. Now suppose a third pair of genes *c* and *c′* to be involved. The *ab* gametes can then be either *abc* or *abc′*; i.e., there are twice as many kinds of *ab* gametes as before. The same thing is true for the other kinds. Thus each additional pair of characters and genes for which a plant or animal is hybrid doubles the number of different kinds of gametes it can

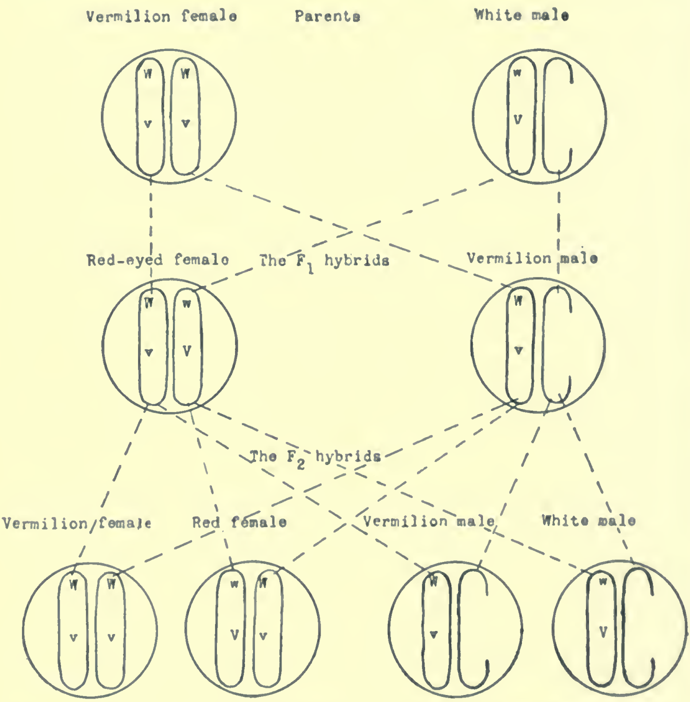


Fig. 114. — Red-Eyed Hybrids produced by crossing white-eyed and vermilion parents. The F_1 male is vermilion because he receives his single X-chromosome from his mother. The F_1 female is red-eyed because she receives an X-chromosome with the normal red factor V from the father and another with the normal red factor W from the mother. The results of interbreeding the F_1 males and females is shown in the lower row of the diagram.

produce. Or, in general terms, an organism hybrid for n pairs of independent genes and characters can produce 2^n kinds of gametes.

THE NUMBER OF GENOTYPES IN THE SECOND GENERATION is constant for any particular type of mating and *depends,* of course, *on the number* of kinds of *gametes* which the first generation hybrid can produce.

Here only back-crosses and interbreeding can be considered. The first is so simple as barely to need mention, for if n kinds of pure gametes are mated to one kind of sperm (or egg) (and a pure recessive can form only one kind) they will of course give rise to n different combinations of genes or genotypes and all will occur in equal numbers. In interbreeding the matter is not quite so simple but is easily understood in the following way: Parents a x a' produce the hybrid aa' and it produces gametes a and a' which combine in the second generation genotype combinations $1aa$; $2aa'$; $1a'a'$, i.e., 3 genotypes. If a second gene and character difference b-b' is added genotype aa may become $aabb$, $aabb'$, or $aab'b'$, i.e., is multiplied by 3. The same thing is true for the aa' and $a'a'$ genotypes, hence adding another gene and character difference in the hybrid multiplies the number of F_2 genotypes by 3. Stated generally, a hybrid involving n pairs of independent characters and genes forms 3^n genotypes in the second hybrid generation by interbreeding.

THE PHENOTYPES OF THE SECOND GENERATION. — Two independent pairs of genes assort in the reduction divisions of the hybrid so as to give four kinds of gametes and these unite by chance to produce four phenotypes in the second hybrid generation. If the genes are linked two phenotypes may be missing altogether, or when crossing-over occurs, appear in greatly reduced numbers in comparison with ratios expected in independent assortment. It is now possible to consider a second reason for variation from the usual ratios of independent assortment. The ratios discussed in previous paragraphs are those which occur when a character difference depends on a *single* differential gene, but there are many character differences which depend on more than one differential gene. It is to be emphasized that the chromosome mechanism distributes these genes in the usual way and gives rise to exactly the same number and kinds of genotypes as in other characters, but that the number and kind of phenotypes vary with the way in which the particular genes express themselves. The following paragraphs illustrate common types of interaction of genes:

Complementary Genes are such that the presence of both is necessary to produce the character. There are two sorts of white corn each of which has one of the complementary genes necessary to produce red corn. When they are crossed the hybrid is red and the F_2 consists of 9 red to 7 white. This result can be readily understood by considering the combinations of genes in the second generation. If we suppose that the one white parent carries the genes *A* and *b* and the other carries the genes *a* and *B*, both dominants being necessary to produce red color, we can account for all the facts. The hybrid then has the genotype *AaBb* (since one parent is supposed to be *AAbb* and the other *aaBB*). The hybrid produces four kinds of gametes *AB*, *Ab*, *aB*, *ab* in equal numbers. These recombine according to Law 2 to give 9 *AB*; 3 *aB*; 3 *Ab;* 1 *ab* (see Punnett square, Chap. XXIX). The 9 *AB* are of course red; the 3 *Ab* are white like one grandparent; the 3 *aB* are white like the other grandparent; and the 1 *ab* is also white. The seven are white because they lack either one or both of the genes necessary to make red.

Supplementary Genes. — This name is given to genes which change or modify the characters produced by other genes but do not produce any visible effect of themselves. For example, if pure red corn is pollinated by a certain kind of white corn a purple hybrid is produced. The white carries a modifying or supplementary gene which changes red to purple, but produces no color in the absence of either of the genes for red. If this purple hybrid is self-pollinated it gives purple, white, and red phenotypes in the second hybrid generation. In this particular cross the red corn has the genotype *AA BB cc* (*A* and *B* being the genes which produces red) and the white one may have the genotype *AA bb CC* (in which *C* is the gene which changes red to purple). The F_1 hybrid is *AA Bb Cc* and produces gametes *ABC*, *Abc*, *AbC*, *Abc* which combine to produce F_2 of 9 *ABC*; 3 *ABc*; 3 *AbC*; 1 *Abc*. The 9 *ABC* are purple; the 3 *ABc* are red; the 3 *AbC* and the 1 *Abc* are white because they lack one of the genes for red.

INHIBITORY GENES are genes which prevent the usual action of other genes. If a certain kind of white corn is crossed with red corn the hybrid is white, notwithstanding that it receives both red genes from the red parent. There are several ways in which this may happen of which one of the simpler will be explained. The red parent has the genotype *AABBii* and the white parent *AAbbII* which gives the hybrid the composition of *AA Bb Ii*. It produces gametes *ABI*, *ABi*, *AbI Abi*, and they recombine to produce a second hybrid generation of 9 *ABI;* 3 *ABi;* 3 *AbI;* 1 *Abi*. All those with *I* are white because this gene prevents the formation of red, and *Abi* is white because it lacks *B*. There are therefore 13 white to 3 red in the second hybrid generation of this cross. Other crosses can be made with different kinds of whites but all containing *I* which will, of course, give still different phenotype ratios in F_2.

CUMULATIVE GENES are those which produce different intensities or amounts of the same character according to how many of them are present. A very simple case of this was described in the four o'clock where the red parent has two "red" genes *RR* and the white has two corresponding genes *rr*. The hybrid has only one red gene (*Rr*) and is only about half as red (i.e., pink) as the red parent. A certain red-grained wheat crossed with a white gives a half-red hybrid. When the hybrid is self-pollinated it produces a second generation of plants in which there are six shades of red besides white. Without going into detail it may be said that this result depends on the fact that the red grandparent has three pairs of genes for red and all are practically equivalent. They recombine in the second generation so that some plants have 6 red genes, some 5, some 4, some 3, some 2, some 1, and some none, thereby giving rise to as many color types. The way this works out is shown in the accompanying Punnett square (Fig. 115).

	RED	REd	ReD	Red	rED	rEd	reD	red
RED	RED RED 6	REd RED 5	ReD RED 5	Red RED 4	rED RED 5	rEd RED 4	reD RED 4	red RED 3
REd	RED REd 5	REd REd 4	ReD REd 4	Red REd 3	rED REd 4	rEd REd 3	reD REd 3	red REd 2
ReD	RED ReD 5	REd ReD 4	ReD ReD 4	Red ReD 3	rED ReD 4	rEd ReD 3	reD ReD 3	red ReD 2
Red	RED Red 3	REd Red 3	ReD Red 3	Red Red 2	rED Red 2	rEd Red 2	reD Red 2	red Red 1
rED	RED rED 5	REd rED 4	ReD rED 4	Red rED 3	rED rED 4	rEd rED 3	reD rED 2	red rED 2
rEd	RED rEd 4	REd rEd 3	ReD rEd 3	Red rEd 2	rED rEd 3	rEd rEd 2	reD rEd 2	red rEd 1
reD	RED reD 4	REd reD 3	ReD reD 3	Red reD 2	rED reD 3	rEd reD 2	reD reD 2	red reD 1
red	RED red 3	REd red 2	ReD red 2	Red red 1	rED red 2	rEd red 1	reD red 1	red red 0

FIG. 115. — The F_2 of a Certain Wheat Cross where the red parent (*RREEDD*) differs from the white one (*rreedd*) in respect to three separate and independent pairs of genes, all of which are capable of producing some red color. The F_1 is about half as red as the red parent. When this half-red hybrid (*RrEeDd*) is self-pollinated it produces the genotype combinations shown in the Punnett square. Note that since each of the genes *R*, *E*, and *D* are equivalent and their effects cumulative, there will be 1 plant with 6 doses of red, 6 plants with 5 doses, 15 with 4 doses, 20 with 3 doses, 15 with 2 doses, 6 with 1 dose, and 1 with no red, i.e. white.

Summary. — 1. The number and kinds of gametes produced by a hybrid depends on the number of differential genes involved in the cross and on whether any of them are linked in the same chromosome-pairs.

2. For any particular type of mating (i.e. back-cross or interbreeding) the kinds and ratios of combinations of genes (i.e., genotypes) which occur in the second hybrid generation depends on the ratio and kinds of gametes formed by the first generation hybrid.

3. The ratio of phenotypes in the second hybrid generation depends on the way in which the individual genes express themselves as well as on the ratio of gametes produced by the first generation hybrid.

4. The comparatively simple ratios to be expected according to the laws of Mendel (i.e., 1st and 2nd Laws) are very often greatly modified by (1) linkage and crossing-over, and (2) the way in which the genes express themselves.

CHAPTER XXXII

PLANT BREEDING

The History of Plant Breeding. — There is no record of when men first began to attempt to improve plants. Wherever the explorer goes among savage and primitive peoples he finds them using plants of some sort as food. He often finds some plants cultivated and they are likely to be better than the wild ones. It seems probable that conscious choice of better plants for seed in many cases came soon after man realized the efficiency of cultivation. Certain it is, that most important crop plants had not only been improved by the time at which there is the earliest historical trace of them, but also that this improvement had happened so long before, that it is a matter of difficulty even to trace their original source. For example, it is only a few years ago that wheat was found growing in the natural wild state in Palestine, although it had been in cultivation before the dawn of history.

During the last 200 years the attempts to breed better plants have been numerous and sometimes strikingly successful. It is, however, only within the last twenty-five years that sufficient knowledge of the laws of heredity has been available to put plant-breeding on a scientific basis that enables it to proceed confidently and rapidly toward its desired ends. Every civilized government now employs numerous plant breeders. Scores are working in experiment stations, schools, and commercial seed establishments.

The Economic Importance of Plant Breeding. — In the United States the National Government, through the Department of Agriculture, and the various states through their experiment stations and colleges of agriculture, expend large sums of money on plant breeding. These facts are well known and sometimes form a basis for unfounded criticisms because comparatively few people realize the value in dollars and cents of this work. As a matter of fact the expense is a mere trifle compared to the returns. A few years ago Mr. Luther Burbank placed on the market a new potato. It was estimated that when it had come into general use it had *increased the value* of the annual potato crop by an amount greater than the entire cost of running the U. S. Department of Agriculture for one year. Just before the Great War the Marquis wheat, produced by Dr. Charles E. Saunders, Dominion Cerealist, had come into general cultivation in the areas of Canada and the Dakota region of the United States which are suited to it. It is a very interesting fact that the increase in yield due to its introduction in these areas is almost exactly the same as the amount of wheat which the two countries could spare for export to our allies. What the lack of this additional wheat would have meant, the reader can readily judge for himself. Its mere monetary value to the producer was more than a hundred million dollars. When Professor Roberts of Kansas isolated his Kanred wheat he added to the annual income of every Kansas owner of a 160-acre wheat field enough money to buy a new automobile and that without the least increase of labor.

The Problems of Plant Breeding are as various as the desires of men. Increase of yield is one of the most frequent. It is often desirable to extend the range over which a crop can be grown and so it becomes necessary to produce a new variety that will thrive under the new conditions of greater cold or higher temperature, drier or wetter soils, more or less sunshine, etc. In many crops (e.g., apples, potatoes) uniformity of size and appearance is highly desirable. In oranges and grapes, seedless varieties are valuable as well as those high in sugar content. In corn the percentage of sugar, starch, protein, and oil are all important considerations for particular uses and the breeder strives to produce a race with the most suitable composition for each. The following paragraphs will furnish concrete examples of how the breeder has solved some of these problems:

The Methods of Plant Breeding naturally vary according to the problem, but may be grouped under two general heads, *selection* and *hybridization*. The student will understand from his previous studies that some kinds of plants are naturally self-pollinated and so exist in "pure lines" ready for the breeder to identify and select, while others are naturally cross-pollinated so that populations of them consist of many and usually all possible genotypes. Some plants are self-sterile and so cannot be self-pollinated, thereby increasing the labor of breeding them. Furthermore, it frequently happens that it is necessary to cross two species or varieties in order to bring together the desired combination of characters, self-pollinate or interbreed the hybrids, and choose from among the recombinations in F_2 and later generations the ones that are desired.

Pure Line Selection. — Wheat is naturally self-pollinated but is occasionally crossed in the field. A field of most commercial varieties is likely to consist of a mere mechanical mixture of numerous different pure lines. One method of improving it is, therefore, to make a very careful and complete study of the growing grain in order to choose the best plants. These are then harvested separately. The seeds of each plant will ordinarily be pure and constitute a pure line. These pure seeds are sowed the next year in the testing plot, one row to each collection of seed, for comparison and selection of the best pure lines. The next year samples from the best pure lines are sowed in larger plots for more accurate comparison. It requires about five years of testing in this way to make a final selection. It was in this way that Professor

Roberts isolated the Kanred wheat, which has proved to be so superior to the wheats previously grown in the Plains region.

Improving Indian Corn. — No crop is more important in the United States than maize or Indian corn, or has received more attention at the hands of the breeder, both amateur and professional. It is believed that this plant probably originated in Mexico. In any event, there were already many varieties in cultivation among the American Indians when white men first made its acquaintance. These varieties have since then been increased and improved until now there are excellent varieties adapted to almost every purpose and to almost every sort of climate or soil within the range of the plant. Corn is naturally wind pollinated, and therefore, usually crossed. Accordingly, most corn plants are hybrids. They can be reduced to a pure condition by artificial self-pollination, but this impairs the vigor of the plant so greatly as to make the method impracticable except for special purposes. In practice, the breeder, to begin his work, either selects directly a number of good plants from the variety he wishes to improve, or else he first crosses two presumably suitable varieties and selects desirable plants from their offspring. Whichever way the first selection is made the chosen plants are isolated in a separate breeding plot, so as to be protected from pollen of other varieties, and allowed to pollinate one another. The best plants are again chosen and the process repeated. Eventually, a relatively uniform race is secured, but it is not, of course, pure. What has actually happened by this method of selection is to make the race relatively pure for certain characters (whatever may be desired), and hybrid for many others in order to maintain the necessary vigor of the plant.

Breeding Cotton. — The most valuable parts of the cotton plant are long silky hairs attached to the seeds inside the cotton " boll " or seed pod. These hairs vary in number, length, and strength. It is desirable for most purposes (e.g., automobile tire casings) to have them as long, strong, and flexible as possible. Cotton in nature readily crosses, so that pure seed can be produced only by guarding against cross-pollination. The method of accomplishing this is both unique and effective. In certain isolated valleys of the arid southwestern United States cotton can be grown by irrigation and can easily be kept pure provided only one variety is grown in each valley. Growers in a valley agree on a certain strain and then prevent by law the planting of any other kind. Selection for improved seed is then made in isolated breeding places until a suitable variety has been secured, and then only pure seed is sown in the valley. It remains pure merely because it has no chance to cross.

Seedless Oranges illustrate a sort of plant breeding which can only be practiced with perennial plants which can be multiplied in asexual ways by grafts, cuttings, etc. All the Washington navel oranges in California are descended from two trees originally brought from Brazil. Just as these first seedless oranges originated from seeded varieties by mutation, so they in their turn have produced many new strains from bud sports. By a bud sport is meant that a mutation occurs in the cells of a bud, and the bud in turn grows out into a branch showing this mutation. Whenever a new and better mutation is observed it is multiplied by taking buds from the mutated branch to graft into seedlings. Aside from mutations, plants of this sort do not change (except in response to the environment) and no special care is necessary to keep them pure. Some trees are more productive than others, however, and are now used by the up-to-date nurseryman as the source of his buds.

Disease Resistance has been found to be a heritable character in many species of plants. Two illustrations will show how this can be made useful in combating loss from disease.

A few years ago the cabbages grown extensively in Wisconsin were nearly wiped out by a soil fungus. Professor Jones observed in a field that one plant seemed not to have been injured. He saved seed from it and planted them in the infected soil and again saved seed from the most resistant. In this way he bred a race sufficiently resistant to make it profitable to grow cabbages again in that region.

When the southern watermelons were attacked by a wilt fungus, Dr. W. A. Orton of the U. S. Department of Agriculture, crossed them with the citron, which is unpalatable but is resistant to this wilt. The hybrid offspring were self-pollinated and from among this progeny he eventually selected new combinations which are resistant to wilt, and taste like watermelons, and in addition stand shipping better than the original melons.

Frost Resistance. — Some years ago an unusually cold winter killed large numbers of orange trees in the Florida orchards. The loss was so severe that growers hesitated to invest again. The problem was eventually solved by Dr. W. T. Swingle of the U. S. Department of Agriculture who crossed the cultivated oranges with the hardy Chinese wild species, Citrus trifoliata. Selections from the numerous and varied recombinations of F_2 and later hybrid generations have yielded varieties not only well adapted to stand the cold in the original citrus belt but even to extend it nearly four hundred miles to the north.

Summary. — Plant breeding consists in:

1. Isolating already existing pure lines in self-pollinating species.

2. Selecting suitable hybrids from populations of naturally crossed species and interbreeding them until they form pure or approximately pure lines.

3. Crossing species, varieties, or races to recombine the desired characters from each in the second hybrid genera-

tion, from which selections may be made and purified by further inbreeding or self-pollination.

4. The selection and propagation by asexual methods of desirable branches which have arisen by vegetative mutations or bud sports.

The characters with which the plant breeder works are mutations, and not mere modifications, or are recombinations of mutant characters. They may be either old but unnoticed characters or new ones produced by recent mutations, since all heritable characters have originated at some time by mutation.

CHAPTER XXXIII

ANIMAL BREEDING

Reproduction in Higher Animals. — Whereas the plant breeder has a considerable range of reproductive processes at his disposal and can often choose the one best suited to his purposes, the animal breeder is limited to a single one. There are two sexes in all higher animals, so that every individual has two parents and is therefore likely to be hybrid for a number of genes and their corresponding characters. If the breeder makes a cross between the purest of races he cannot expect the hybrids to be all alike, as he could if dealing with self-pollinated plants, because the parents are probably never exactly alike in all their genes.

On Interbreeding. — Since there are always two sexes the breeder of higher animals cannot self-fertilize his first generation hybrids but must mate them with one another. In some species of animals it is possible to mate brother and sister without ill effects, while in others this does not appear to be practicable. In any event the breeder comes as near self-fertilization as the nature of the species makes advisable in order to come just as near to breeding a "pure line" as possible. In actual practice this never produces an absolutely pure race no matter how long the pedigree. On the other hand, races are often pure for individual characters which are reproduced generation after generation with remarkable fidelity.

On the Effects of Selection. — It must be clear from the reader's present knowledge that recombinations (page 36) are continually occurring in respect to some characters in animals. Some of these may be slightly better and some worse than the parental combinations. For this reason continuous selection of the best offspring of each generation to become the parents of the next is always necessary to secure any improvement or even to avoid degeneration of the stock. It appears to be true that animals are especially rich in *supplementary genes* (page 386) which modify the quantitative extent of a character. Since these are numerous there is excellent opportunity for continued selection to isolate genotypes with more and more of these genes in both members of the chromosome-pairs and so increase the quantitative expression of the character. Of course selection is usually equally effective in the opposite direction.

Inheritance of Coat-color in Guinea Pigs. — These small animals are much used for experimental work in biology on account of the satisfactory way in which they endure captivity. Two characters of their hair will serve as illustrations (Fig. 116) of the fact that many traits in animals behave in strict accordance with Mendel's laws of segregation and independent assortment. A smooth-haired black guinea pig crossed to a rough-haired white one gives hybrid offspring with rough black hair. When these hybrids are interbred they yield a second hybrid generation of 9 Black Rough; 3 Black smooth; 3 white Rough; 1 white smooth. Hair color in many other animals behaves in essentially the same way, although there are often more pairs of genes involved and so the results are less simple.

Inheritance of Hooded Pattern in Rats. — In an extensive series of experiments with rats Professor Castle showed that a pattern of the coat color can readily be modified by selection. If a pure colored race is crossed with one having a colored patch or hood over the head and shoulders the hybrid offspring are all fully colored (Fig. 117). When the hybrids are interbred the second hybrid generation shows 3 colored to 1 hooded. The hooded ones are, of course, recessive and pure for the "hooded" gene. They do not, however, breed wholly true to type, for their descendants show various degrees of "hooding." By selection for several generations it is possible to breed a nearly white or nearly full-colored race. This result is now generally believed to be due to the selection of modifying factors which extend the size of the hood.

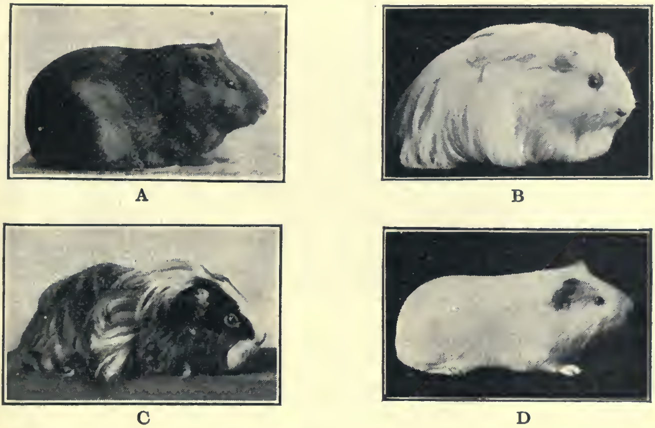


FIG. 116. — Results of a Cross between two varieties of guinea-pig differing in the two unit-characters, color and length of fur. Fig. *a*, a colored and short-haired guinea-pig. Fig. *b*, an albino and long-haired guinea-pig. The F_1 young were colored and short-haired like the parent shown in Fig. *a*. Fig. *c*, a colored and long-haired guinea-pig, one of the new F_2 varieties. Fig. *d*, an albino and short-haired guinea-pig, the other new F_2 variety. The two other F_2 varieties were like the grandparents, Fig. *a* and *b*.
Castle, *Heredity and Eugenics*. Harvard Press.

LETHAL GENES IN YELLOW MICE. — There is a type of yellow color characteristic of certain strains of hybrid mice. When these hybrid yellow mice are interbred they should produce 1 pure non-yellow (e.g., black); 2 hybrid yellow; 1 pure yellow. As a matter of fact only two yellows (both hybrid) are born for every 1 non-yellow, but the missing pure yellows can be shown to have perished before birth. Such genes as this are called *lethals* and are of considerable importance. Care has to be taken by the animal breeder when selecting for certain desired combinations of characters not to include also lethal genes or others which unduly diminish the fertility or stamina of the race. There is actual record of a superior race of cattle which perished for this reason.

INHERITANCE OF WINTER EGG PRODUCTION BY FOWLS. — It has been found that the ability to produce many

FIG. 117*A*. — Inheritance of a recessive pattern of white spotting seen in "hooded" rats. The parents at the left are a homozygous hooded mother and a heterozygous "Irish" father (black with white belly). An entire litter of their young is shown at the right. Four are homozygous hooded like the mother, five are heterozygous like the father. Note fluctuations in both classes. Such fluctuations are found to be in part heritable.
Castle, *Heredity and Eugenics*. Harvard Press.

FIG. 117 *B*. — A Graded Series of Patterns Used in Grading the Coats in a selection experiment. By continual selection of the progeny of the offspring of the cross shown above, any of these types of patterns can be produced. This result is now supposed to be due to the modification of the effects of one main factor for "hooding" by numerous other factors which have the effect of modifying the extent of the white and colored areas.
Castle.

eggs during the winter months when eggs bring fancy prices is inherited and that it depends on two pairs of genes. This is an instructive case because it shows that the ability to lay eggs in winter is not an acquired character introduced by the kind of care taken of the flock. One of these genes is in the sex chromosome of which

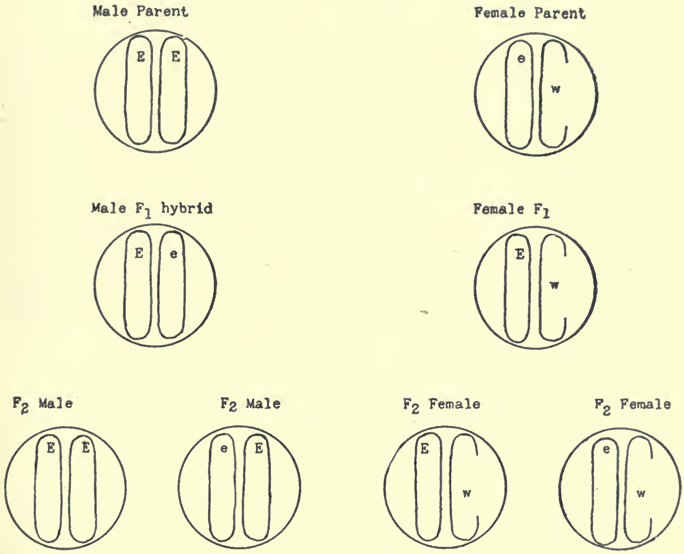


FIG. 118. — Inheritance of Winter Egg Production Through the Male. One factor for winter egg production is located in the sex-chromosome of fowls. The male has two sex chromosomes and the female one. The diagram shows that the purebred male transmits high egg-laying ability to all his daughters even when mated to a female without this factor (*E*). Half the F_2 females inherit high ability and half do not. All the males inherit the gene (*E*) but only half of them are pure for it (*EE*) and therefore suitable sires.

the male fowl has two active or Z chromosomes and the female only one active or Z chromosome and one inactive or W chromosome (Fig. 118). Hence every daughter receives an active Z from the father but only an inactive W from the mother. Since this gene for high egg-laying is in the Z chromosome, hens inherit this characteristic from the father and not from the mother. Manifestly the father never acquired the ability to lay eggs at any season although he can transmit to his daughters a marked ability to do so.

Inheritance in Dairy Cattle. — The ability to produce large quantities of milk and butter fat depends on the proper correlation of many structures and functions and is therefore not governed by a single pair of genes. It is nevertheless heritable, as is clearly shown by the superiority of certain breeds, e.g., Jerseys. In breeding for high milk production the breeder must keep all these things in mind. Merely to enumerate some of them will suffice to show the complexity of the problem. To turn food into milk as economically as possible certainly requires a good set of teeth, and a good digestive system, and a type of metabolism which turns foods into milk instead of into muscle or fat. That many of the genes which control these things can be assembled in one race is shown by the fact that the breeder has actually produced champion cows (e.g., Holsteins) which produce 30,000 pounds of milk per annum in place of the 3000–4000 pounds produced by the scrub cow. Here again it should be emphasized that high milk production is inherited from the male parent as well as from the female. It should be noted, however, that the advantages of a pure bred sire are not so great as in the example of the fowl just given, because there the gene for winter egg-production is sex-linked.

Inheritance of Speed in Horses. — Since speed is equally characteristic of both sexes, and since fast horses are usually descended from parents both of whom were fast, the inheritance of trotting ability has often been cited by the advocates of the inheritance of acquired characters as a case in point. If all cases were of this sort it would be extremely difficult to give an acceptable answer to this assertion, for it is an undoubted fact that fast horses often beget fast offspring. The crux of the question is whether it is the *effect of training* which is inherited or merely the *ability to be trained.* In view of the last two examples, the latter seems much the more probable. The effects of continued selective breeding are, therefore, to be ascribed to the gradual accumulation of numerous genes all of which contribute something toward speed.

THE VALUE OF IMPROVED BREEDS is out of all proportion to the cost of producing them. It costs little or no more to feed a thoroughbred than a scrub cow, but the quantity of milk and butter received may in extreme cases be ten times as great. It is certainly the duty, therefore, of individuals and governments to promote the breeding of superior stock, not only of dairy cattle and fowls but of many other domesticated animals; for what is true of milk, butter, and eggs is also true in general terms for beef, pork, and mutton, wool, hides, and silk.

SUMMARY. — The practical animal breeder has carried many species and varieties to a high state of perfection. Where the knowledge of the genes involved is sufficient, they appear to behave in the same manner as those with which we are acquainted in the experiment garden and breeding pen. The methods employed are either continued selection in a variety toward an ideal, or selection after hybridization. The results of selection in both cases appear to be best explained on the assumption of the gradual assembling of many favorable genes in a more or less pure genotype. The genes are probably so numerous that no "pure race" has yet reached a point where it is pure for every pair of genes. Consequently, it may be confidently hoped that continued breeding will improve even the best of breeds.

SECTION 10

EVOLUTION

CHAPTER XXXIV

EVIDENCES OF EVOLUTION

Evolution Defined. — For many centuries it was generally believed that every species of animal and plant was a special act of the Creator, and long ago was placed in its present perfected state and in the same locality it now occupies. According to this view a species is unchangeable. The fish is forever adapted for a life in the water, a mole for tunneling in the earth, and a bird for an existence in the air. This view of the organic world fails to take into account a large body of facts which is now thought to run counter to such a belief, and which is explained by the modern biologist on the principle of evolution. According to this doctrine, a species amid changing conditions is not fixed, but on the contrary is undergoing alterations from generation to generation. The changes generally are very slow and almost imperceptible during a brief period, but where the remains of countless generations have been preserved in fossil form during millions of years, the transformation is clear and unmistakable. It is also true that the further back the history of a species is traced the simpler the ancestral type becomes. In other words, if the geological record were complete it would be found that each of the thousands of species of animals and plants is the descendant of one simple form of life, or at most, of a very few. Evolution, therefore, is the derivation of complex, high, and specialized species from simple, low, and generalized ancestors.

Sources of Evidence. — This gradual change or evolution of living things is to the trained biologist an established fact. To him the evidence in support of such a belief is as convincing as that underlying the phenomena of gravitation and chemical affinity. As indicated in the foregoing paragraph, the study of paleontology, or fossil remains in the crust of the earth, is a most important source of information, but — contrary to the popular belief — it is by no means the only one. In addition to the proof furnished by (1) Paleontology, a wealth of evidence has been supplied by studies in (2) Classification, (3) Geographical Distribution, (4) Comparative Anatomy, (5) Embryology, (6) Artificial Selection, and (7) Genetics. These topics will now be considered in some detail.

Evidence from Paleontology. — It is often supposed that if all the fossils in the earth's crust could be studied, a fairly complete history of life could be written. Such, however, is not the case. All the animals and plants from the first appearance of living things down to perhaps fifty million years ago have disappeared completely. If they ever were preserved as fossils, these have been destroyed by heat, water, or other agencies. What exists at the present day is only a small fraction of the whole. Nevertheless, this remnant is highly illuminating and furnishes exactly those facts which are to be expected as a result of evolution.

Some of the best known and most striking examples of a long continued evolutionary history have been discovered in the United States. Approximately three million years ago, it is estimated, the climate of the country was similar to that in Africa at the present time. Tropical vegetation extended as far northward as the Canadian border, crocodiles inhabited the extensive marshes, while herds of camels, elephants, and rhinoceroses roamed the land. As time passed the temperature gradually lowered, the country became dryer, and large forested districts were changed into treeless plains. Amid these shifting conditions many animals and plants became extinct or migrated into more favorable regions. Others underwent changes and, being adapted to the new conditions, persisted. Most fortunately, the skeletons of many of these animals have been preserved, and from them it has been possible to trace the evolution of various species from the ancestral form down to the present day.

History of the Horse. — The first undoubted members of the horse family, which furnishes one of the best known examples of a long evolutionary history, appeared in North America as small animals, scarcely larger than a good-sized house cat (Fig. 119). In addition to several

Fig. 119. — Restoration of the four-toed horse; based on a mounted skeleton, sixteen inches high, in the American Museum of Natural History. (After C. R. Knight.)

other remarkable characters, they had four hoofed toes and a rudimentary thumb in each fore foot, while the hind foot lacked the great toe and the fifth digit was small and rudimentary. During the next million years, or perhaps a longer period, these ancestral forms gradually became larger and developed or evolved into (*a*) a relatively slow-going heavy type confined to the forests, and into (*b*) a graceful, light-bodied, swift, plains type.

The first form became extinct after undergoing certain changes, while the plains animal became differentiated into several distinct species. Some of these remained in North America and became extinct during the Ice Age. Others migrated into South America where they died out in very recent times. Still others travelled into the Old World and became the ancestors of the modern breeds. There were no horses in the New World when Columbus made his voyages.

Throughout this entire period the body was undergoing many changes. Among the most obvious were those affecting the feet. The middle digit gradually increased in size, while the others became rudimentary or dis-

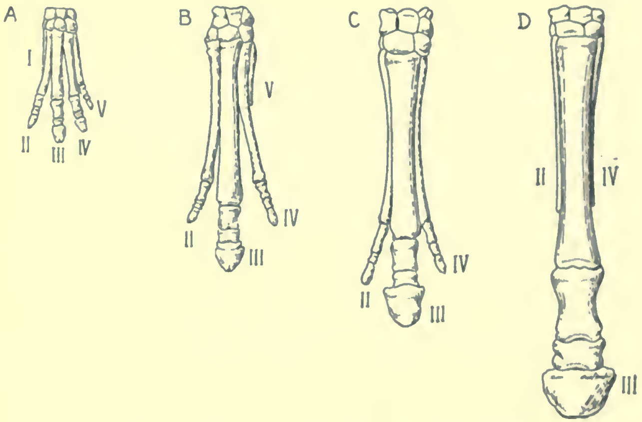


FIG. 120. — Evolution of the Hand of the Horse.

appeared completely (Fig. 120). The result is that the modern horse travels on the tip of a single (the middle) digit, the hoof representing the nail, while the "knee" is actually the wrist or ankle. The teeth also became modified, and as a result of these and other changes the generalized five-toed ancestor evolved into one of the most highly specialized of modern animals.

EVOLUTION OF CAMELS. — Although these animals are not included in the list of native North American species, the family actually passed through the greater part of its development on this continent. The earliest known ancestors were small animals, about the size of the average dog, with four hoofed toes on each foot. This type became developed into many species, some of which, like the graceful and swift gazelle camels and the excessively long-necked giraffe camels, became extinct. Others continued to exist, and migrating into South America, evolved into the llama, guanaco, alpaca, and related species. Still others crossed the ancient land bridge into the Old World, and became transformed into the modern type. Those remaining in North America died out long ago.

In addition to an increase in bodily size and several other characteristic features of the group, the digits disappeared with the exception of the third and fourth, the hoofs became reduced to small conical nails, and the weight of the body was supported by fleshy pads. All of these evolutionary changes are evidenced by a wealth of fossil remains, and the history of the camel is accordingly as well established as that of the horse.

It is important to bear in mind that geologists are agreed that the great rock masses in which these fossil horses, camels, and other animals are entombed form an unbroken series. The lowest strata were first formed, and the uppermost are the most recent. The paleontologist is equally positive that the fossils in the oldest deposits are the most primitive and generalized, and that the various species are more and more complex and specialized as the latest strata are approached. To the open-minded student of biology these facts present unmistakable evidence of the reality of evolution.

Classification. — The history of the camel family illustrates two important facts. In the first place the one- and two-humped camels, the llama, guanaco, and alpaca are the descendants of a common ancestor. Secondly, these are distinct species at the present time, owing to the dying out of the intermediate stages or connecting links. To express it graphically, the family history of the camel is a tree whose trunk is the ancestral stock, while the branches represent the evolution of the remote ancestor into different species. The greater part of this tree is dead, the tips of the branches, which correspond to the modern species, being the only living portion. Other families of animals and plants whose ancestral trees have been carefully followed into the earth, and the fragments of those which yearly are brought to light, all illustrate these same general principles.

In the attempt to classify these living species it was long ago discovered that resemblances and differences of structures are the only safe guide. Shape, size, color, and other superficial characters were used by the biologist a century or more ago, but they were found to be practically worthless. Various schemes of graphically representing relationships were also abandoned in favor of the tree-like branching plan, such as is used to illustrate the genealogy or relationship of various human families. In other words, the earlier scientists to whom evolution was unknown were driven to adopt a system of classification approximating that of the present day. Their work, however, was little more than an intellectual exercise, a pigeonholing of organisms for convenience only. To-day it remains a convenient system, yet at the same time it expresses the blood relationships of living things, and is one of the strong proofs that evolution has occurred.

The Modern System of Classification. — According to the present system of classification, a species is defined as an assemblage of similar animals or plants, which do not differ in size, shape, color, etc., beyond the limits of individual variation. Furthermore, these characters are inherited with but slight modification; and the group is not united with any other by connecting links. Now let this definition be applied to the group of cats. Among the domesticated animals there are many breeds, persian, maltese, manx, etc., but these do not constitute distinct species, since there are many intermediates. They are only varieties or sub-species developed during domestication from the wild or Pallas' cat of Africa.

The lion, tiger, ocelot, puma, etc., are structurally different from each other and are distinct *species*, and each inhabits a definite geographical area. Furthermore, each of these species, and nearly a hundred others, possesses certain anatomical characters in common, and accordingly they are united in a larger division, the *genus*. Other cat-like animals, belonging to other genera, are grouped with these into a *family*. The cat family, together with those of the dogs, hyenas, etc., are embraced in an *order*. This and several other orders of animals, all with hair, comprise the *class* of mammals. The several classes of backboned animals form the *phylum* of vertebrates. And, finally, the various phyla (sponges, mollusks, etc.) are subdivisions of the *animal kingdom*.

The plant kingdom is subdivided in the same manner. Every animal and every plant, which has been classified, occupies a definite place. If the work is accurately done its position indicates its nearest relatives, and the broader features, at least, of its evolutionary history.

Scientific Names. — The question is often asked, why is it necessary to use " jaw-breaking " scientific names? The answer appears when one talks about gophers, for example. In the Southern States the word refers to a tortoise, in California to a pouch-cheek, rat-like animal, in Idaho to a species of snake, and in Montana to a ground squirrel. Vernacular or popular names are therefore confusing, to say the least. The great work of the Swedish scientist, Linnæus, was the bringing of order out of this chaos by adopting names from a dead language, either Latin or Greek, and hence incapable of change.

Each species of animal and plant is given two names, one for the genus, the other for the species. The generic name of all cats is *Felis*. The specific name of the lion is *leo*, of the tiger, *tigris*, of the leopard, *pardus*, etc. The complete name of the lion is *Felis leo,* of the tiger, *Felis tigris,* etc. — names that are fixed and known by the entire scientific world. Every species, genus, family, and higher division of both the plant and animal kingdom has its own particular scientific name.

COMPARATIVE ANATOMY. — As indicated in a former paragraph, evidence from superficial resemblances between the various species of animals and plants is not a safe guide in classification. On such a basis the whale and fish would be close relatives. Actually, they are no more closely related than man and a shark. The resemblance is merely one of analogy, a similarity of form. Wings are analogous organs in birds and insects. In both groups there is a likeness of function, but structurally they are very different and only distantly related.

On the other hand, the wing of a bat and the arm of man present no analogies of either form or function. They are, however, fundamentally alike in structure (Fig. 121). Bone for bone, muscle for muscle, nerve for nerve, they are almost identical, the difference being merely those of proportion. Extending the comparison, it is found that the wings of birds, the paddles of whales, the digging arms of moles, the legs of horses, zebras, etc., present wide differences of form and function, and yet are structurally nearly alike. Other parts of the body illustrate the same fact. This deep-seated identity of structure is termed *homology,* and is interpreted as a sign of blood relationship. Just as the modern one-fingered horse has been derived from a five-fingered ancestor, so, it is believed, all of the backboned animals or vertebrates, with their various types of limbs, are the descendants of a remote ancestral species.

RUDIMENTARY OR VESTIGIAL ORGANS. — In the search for homologies among the various species of animals and plants, organs have come to light, especially among the higher species, which are of little or no use. In the modern horse, for example, two small splint bones occur just below the "knee" (Fig. 120). At the present time they are of no service, and represent the last traces of two fingers or toes which once were provided with hoofs and were functional.

In man there are not fewer than 170 vestigial organs. The appendix, for example, is a remnant, often a troublesome one, whereas in such animals as the rabbit and kangaroo it is of vital importance. There are also traces

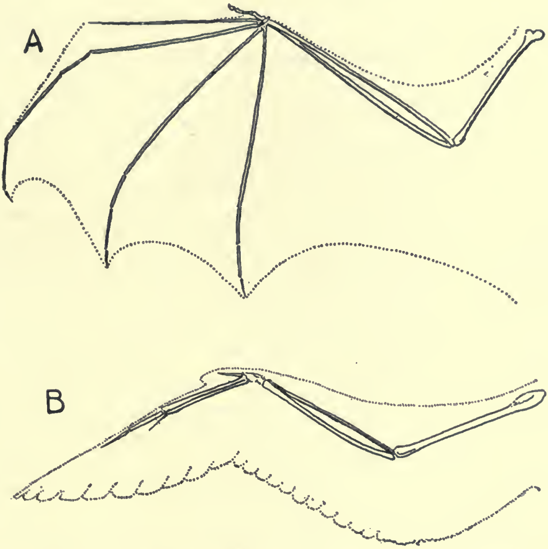


FIG. 121. — Homologous Organs: A, wing of bat; B, wing of bird.

of a tail with rudimentary muscles, muscles that once moved the ears and twitched the skin, a rudimentary third eyelid, such as one finds well-developed in the birds, and numerous other vestiges associated with the skeletal, muscular, and other systems.

Examples of this class of organs in other animals as well as in many plants could be multiplied to a great length. In every instance their presence can be explained on the assumption that each of these organs was functional in a remote ancestor. Indeed, they are definitely known to have been so in many instances. As the species evolved, the organ became less important, dwindled in size, and ultimately ceased to function.

Evidence from Embryology. — In a former chapter (XXVI) it has been shown that all of the many-celled animals develop from a single fertilized egg-cell whose divisions result in a blastula and still more complicated gastrula. This development is from a comparatively simple to a complex condition. This is also the history of life on the earth. The ancient simple species have evolved into the more or less complex descendants of modern times. Amœba, Volvox, and Hydra, respectively correspond to increasingly complex steps in the evolution of the animal kingdom. The corresponding stages — egg, blastula, and gastrula — are increasingly complex states in the evolution or development of an individual. The young stages in the growth of a higher species thus resemble the adults of lower species. Speaking broadly, life history parallels or repeats race history.

Development of Vertebrates. — This parallelism between life and race histories is further illustrated in a striking manner by the development of the vertebrates. The fishes, frogs, reptiles, birds and mammals all belong to this great group, and agree in the possession of a backbone, four limbs, a dorsal nervous system, and several other important features. The resemblances are presumably due to the fact that they are the descendants of a common ancestor; the differences are owing to evolutionary changes, fitting each species for a definite mode of life.

In its development each species travels essentially the same path, and for a long period the young can be distinguished only by an expert. Moreover, before definite classes assume the final adult and distinguishing characters they all develop gills in the throat region. Internally as well as externally, they bear a striking resemblance to fishes. In the fishes these organs persist throughout life; in the toad, lizard, robin, rabbit, and related species, this fish-like condition gradually disappears.

From their development, as well as from evidence supplied by comparative anatomy and fossil remains, it is very evident that modern vertebrates are the descendants of primitive backboned gill-bearing ancestors whose evolution has resulted in the thousands of modern species. Broadly speaking, each vertebrate, like other animals as well as plants, in its development as an individual repeats its ancestral history.

Geographical Distribution. — Although the broader features of the subject will be discussed in another chapter, the evidence supplied from this field in support of evolution demands a preliminary statement. In the first place, it is a most significant fact that although the animals and plants of oceanic islands are distinct, they nevertheless bear an unmistakable resemblance to those on the adjacent continent. In some instances, the islands, together with their imprisoned inhabitants, were cut off from the mainland by means of developing channels; in other cases they were populated by migrants. In either event, the isolated colonies underwent evolutionary changes and gradually became distinct. The longer they remained distinct the more unlike they became. The great differences between the animals and plants of Africa and Madagascar or between those of Asia and Australia, for example, are explained on the basis of a separation of great antiquity.

As a result of this evolution within a district, hedged about by barriers, several closely related species may evolve. Indeed it is generally true that the most closely related species are found in neighboring areas. For example, there are over four hundred species of humming birds, all confined to the New World; kangaroos of several species are peculiar to Australia, and the adjacent islands; the Old World monkeys are very distinct from those of the Western Hemisphere. Where related species are widely separated, as in the case of the family of camels, past migrations with the extinction of individuals in the intervening territory are responsible. In short, all of the facts of geographical distribution are satisfactorily explained by evolution. Otherwise they are a senseless jumble.

Artificial Selection. — That animals and plants are not rigidly fixed but on the contrary are capable of change is known to every breeder. (Chap. XXXIII) He decides upon some character — a special form, color, or quality — and selects those individuals which manifest it in the highest degree. The survivors in the selection process are then bred, the most desirable members are again selected and bred, and so on, generation after generation. "It would seem as if they had just chalked on the wall a form perfect in itself and then had given it existence."

The two hundred and more breeds of the domestic pigeon have been derived from the rock pigeon of Europe and Asia by artificial selection. The many varieties of domesticated fowls are the artificially selected descendants of the jungle fowl of India, which has been bred for more than three thousand years. Sheep, cattle, and hogs, pansies, tulips, dahlias, and many other cultivated flowers as well as numerous garden vegetables, are likewise greatly altered descendants of the original wild stocks. But while man is thus able to mold a species into many distinct varieties, there is a wide difference in one respect between his results and those obtained under natural conditions. If these domesticated breeds are allowed to escape and come into competition with wild species, they are usually exterminated. Evidently, the characters desired by man are not necessarily those that best fit their possessors to compete successfully with wild forms. There is, however, a general similarity between the artificial and natural production of species, as will appear in the next chapter. And furthermore, the evidence supplied by these breeding operations not only demonstrates that species are capable of change but also provides a clue to the method whereby species may have developed in a state of nature.

Genetics. — In recent years breeding experiments have been carried on by the trained biologist, not so much for the purpose of bringing to a high state of development some particular character in an organism as to determine the underlying causes of variations and the manner of their inheritance. This new science of genetics, as it is termed, is thus largely a study of heredity controlled and analyzed at every stage.

A species of animal or plant is selected for the experiment whose ancestral history or pedigree is well known. Its development, at least in a general way, is traced out, and the behavior and structure of the germ cells is determined with a high degree of accuracy. The different kinds of variations which occur during the course of the experiments are also recorded, and where these are inherited the mechanism determining their inheritance is analyzed by the most highly refined methods known to the scientist. The determination of sex, and the relation this phenomenon bears to heredity are also phases of the general subject of genetics. Paleontology, geographical distribution, classification, and the other sciences previously mentioned supply proof that evolution has taken place. Artificial selection demonstrates that evolution is still possible and can be guided by the breeder, and the results of studies in genetics have enabled the biologist to form a far clearer picture of the mechanism of evolution than was known in Darwin's time.

CHAPTER XXXV

THEORIES OF EVOLUTION

PRE-DARWINIAN SCIENCE. — Although Darwinism and evolution are popularly believed to be synonymous terms, the general notion is actually older than the Christian Era. In the writings of the Greek philosophers the idea is occasionally expressed, usually in very vague language unsupported by facts, to account for the origin and development of the universe, including the organic world. A notable exception appears in the case of Aristotle (384–322 B.C.). In the realm of biology he classified over five hundred animals, understood adaptation, recognized the meaning of physiological division of labor, studied embryology, and advanced the science of living things to the position it held for sixteen hundred years. Aristotle also believed that inorganic matter evolved into a soft mass, living but unorganized, from which higher species gradually developed as a result of an internal impelling force. In certain important respects his theory resembles that held by the modern biologist.

After the time of Aristotle, both science and the desire to find a natural explanation for the origin of things underwent a decline lasting until the 12th century. Toward the close of this period the writings of the Greek philosophers were translated by the Arabs, who, under their influence, founded the first universities that had existed for centuries. As a result of this intellectual awakening, a large number of students arose who profoundly influenced scientific thought, and directly or indirectly laid the foundations of modern science.

THE INFLUENCE OF DARWIN'S WORK. — During the four hundred years after the beginning of the revival of learning naturalists had accumulated a vast amount of unrelated information in many different fields, and had developed to a considerable degree the modern sciences of anatomy, embryology, physiology, geographical distribution, classification, and microscopy. In the more remote departments of history, language, religion, politics, etc., there was also a huge mass of unrelated observations, unrelated for the reason that the underlying fact of evolution had not been proved and accordingly was not generally considered to be even a remote possibility.

At the present time it is difficult to picture the influence upon human thought of Darwin's theory of evolution. His first work, "The Origin of Species," appeared in 1859. It was based upon more than twenty years of careful observation, was clearly and fairly presented, with proofs at every stage, and in the face of bitter opposition was accepted by the open-minded student. Under its influence very many questions of the most puzzling character were made plain, and the flood of light which was let in on the intellectual world at that period has increased with each successive year. The time was more than ripe for the fact of evolution to be recognized, and it is not to be marvelled at that Darwin is hailed as the greatest scientist the world has ever known.

Factors of Darwin's Theory. — The Darwinian theory of evolution, which is also termed Natural Selection or the Survival of the Fittest, involves several different factors. The first of these is (*a*) over-production. All animals and plants produce a far greater number of offspring than can survive, owing to lack of space or food. Since (*b*) the number of individuals remains about the same from century to century, it follows that (*c*) there is a struggle for existence. Furthermore, there is (*d*) variation (i.e., mutation) and (*e*) heredity. No two organisms are exactly alike, and many of these differences are transmitted from one generation to the next. The result is that some are better fitted to their surroundings than others, which results in (*f*) the survival of the fittest in the struggle for existence.

All these factors, with one exception, were recognized by several biologists before the time of Darwin. Indeed, Darwin's grandfather, Erasmus Darwin, specifically mentions them in his writings. The supreme work of the grandson was supplying the evidence for the survival of the fittest, which may be considered the cornerstone of the most generally accepted theories of evolution at the present time. These various factors will now be considered in more detail.

Overproduction. — "There is no exception to the rule that every species of organic being, animal or plant, naturally increases at so high a rate that if none were destroyed, the earth would soon be covered by the progeny of a single pair." If, for example, every human being were to come to maturity and were to breed at the average rate, the numbers of individuals would be doubled every fifty years. At the end of a few thousand years, if these conditions prevailed, there would not be standing room for the descendants. An annual plant producing two seeds only would have 1,048,576 offspring in twenty-one years if each individual attained maturity and reproduced. The conger eel lays 15,000,000 eggs each year, the codfish 9,000,000, the Virginia oyster not fewer than 15,000,000 on the average. If these were to come to maturity and breed, their progeny would fill the sea in a very brief period. This factor, therefore, in the theory of evolution is a generally recognized and firmly established fact.

Stationary Numbers of Individuals. — It is also well established that the number of individuals of the majority of species remains fairly constant over long periods. There may be an increase at one time and a decrease at another, but in the long run the average is approximately uniform. This is to be expected when it is remembered that every species of animal and plant is fitted to a definite set of conditions, and that within its range each species finds a limited food supply, enemies of many kinds, and unfavorable as well as favorable conditions of soil and climate. All of these agencies tend to hold the number of individuals at a given level.

THE STRUGGLE FOR EXISTENCE. — It is also manifest that since many more individuals are produced than can come to maturity, a struggle for existence is the inevitable result. Broadly speaking, this is a battle against the surrounding conditions, an effort, conscious or otherwise, on the part of the organism to place itself in the most favorable relations to the environment. In this combat animals play a more obvious part, but it is none the less true that plants are at war with one another, and victory comes to a very few. This struggle against unfavorable conditions presents a threefold aspect. The individuals of the same species may compete with one another. A plant may become overshadowed by its fellows and perish for lack of sunlight. A rat may fight with its own kind and even devour its young. Or members of one species may enter into competition with those of another. The eagle strikes down a fawn, and locusts consume the harvest crops. Finally, there is a continual striving on the part of an organism to withstand extremes of heat and cold, a lack or a superabundance of moisture, and other unfavorable physical features of its surroundings.

INTERRELATIONS OF ORGANISMS. — The environment of an animal or a plant is more than a simple mixture of light, heat, air, moisture, and soil, plus other organisms. These elements are parts of a complex system wherein a relatively small modification at one point may produce highly important changes in a distant and frequently unexpected quarter. In this, Nature resembles a pool where a pebble dropped into the depths causes far-reaching effects.

Darwin calls attention to the fact that bumble bees carry pollen from one clover plant to another, and the flowers thus fertilized bear seeds. Bumble bees are destroyed by mice, which in turn are eaten by cats. The more cats the fewer mice, and the greater number of bees and clover seeds. Earthworms, by tunneling the soil and carrying organic food from the surface into their burrows, are highly important agents in loosening up and fertilizing the soil. These animals, therefore, are an important factor in determining the size of crops and the number of human inhabitants in the region. The history of the rabbit in Australia, the potato beetle in Ireland, the codling moth, scale bugs, the water hyacinth, thistle, and of many other animal and plant pests, also illustrate how the balance of nature may be seriously destroyed by insignificant causes.

Variation and Heredity. — While it is true that organisms tend to resemble their parents, it is equally certain that they are rarely if ever their exact counterparts. In the human race, for example, there often are striking family resemblances and yet invariably individual differences in form and structure can be shown to exist. In some instances this unlikeness or variation is the result of exercise or some direct effect of the environment. An abundance or lack of nourishment, the exercise of a muscle, the effect of sunlight, and many other agencies may produce marked changes in an animal or plant during the course of its lifetime. Such effects, so far as is known, are not transmitted to the offspring; they are non-heritable variations or modifications. On the other hand there are differences of color, form, proportion, size, and thousands of other characters, known as mutations, which are transmitted from generation to generation. The part which the germ cells play in this process was entirely unknown in Darwin's time. Since his day a great amount of information has accumulated, and the method of the transmission of heritable variations is almost as well known as the structure of animals and plants. For the first time the biologist has reached the point where the mechanism of heredity is fairly well understood, and the causes and methods of evolution stand out in a clearer light.

THE SURVIVAL OF THE FITTEST. — This term signifies that in the struggle for existence among animals and plants those individuals with the greatest vigor, the keenest senses, the highest powers of speed, or those otherwise best adapted to their surroundings, are the ones which tend to outlast their companions. They accordingly are the ones most likely to produce offspring. And these individuals are likely to transmit the same heritable variations to some of their progeny, while the others less fit will die in the struggle. From time to time mutations occur in one or more individuals. Where these are beneficial the possessor is more certain to be preserved and to transmit this new character to some of its descendants. If the mutation renders an organism less fit, less able to withstand the rigors of its surroundings, it perishes. Nature thus continually puts a premium on the fittest individuals, while the imperfect ill-adapted ones are vanquished in the combat. The species is thus gradually changed or in other words it evolves "by the incorporation into the race of those mutations that are beneficial to the life and reproduction of the organism."

APPLICATION OF THE THEORY. — There is conclusive evidence that the excessively long-necked giraffe camels evolved from a relatively short-necked ancestor (see page 411). It is also highly probable that the modern giraffe likewise descended from comparatively short-necked deer-like progenitors. According to the theory of Natural Selection some of the individuals of this ancient stock possessed somewhat longer necks than their fellows. They were thus enabled to browse in their semi-arid surroundings on foliage out of reach of the others. This advantage, seemingly insignificant, nevertheless enabled more long-necked than short-necked individuals to come to maturity and reproduce their kind. New variations, in the form of mutations, appeared during the long history of the race. Where these resulted in longer necks than before they were incorporated into the race. The great height and exceedingly long neck of the giraffe is therefore not the result of one variation in the history of a deer-like ancestor. On the contrary the evolution of the species is the result of the gradual accumulation of many comparatively slight variations or mutations which not only modified the race in respect to the neck but enabled it to withstand the attacks of enemies and the severe conditions of its surroundings. This same line of reasoning is applicable in the case of every other species of animal as well as plant.

Sexual Selection. — In another connection (Chap. XXVI) it has been shown that, among many kinds of animals, marked differences exist between the males and females. The reason for this fact appeared to Darwin to lie more or less beyond the realm of Natural Selection, and was rather to be explained on the basis of Sexual Selection. According to this theory the males either engage in a struggle among themselves for a particular mate, or, among other species, they are chosen by the opposite sex. When a battle ensues it is a well known fact that in many instances those males with the greatest strength and the most highly developed weapons come off victorious and leave descendants. This is even more apparent among polygamous animals, where one male fights for the possession of several females as in the case of the fur seal, sea lion, domestic fowl, and several other species. In all of these cases there is a survival of the fittest, and at the present time this phase of sexual selection is explained on the basis of Natural Selection.

Among the birds, insects, the crabs and related species, where the male is often highly colored or distinguished by other secondary sexual characteristics, the female, according to the theory of Sexual Selection, is believed to choose a male whose beauty, grace or other conspicuous feature satisfies her esthetic sense. The survival of the fittest is thus determined by the female. As a matter of fact it has been shown that among many insects the wings may be dyed or even cut off without disturbing the mating instinct. The sexes are attracted by special odors, and not by color. Certain crabs, and related species, as well as the spiders, mate by means of the sense of touch. Among the birds the female usually pays no attention to the male who is "showing off." The remarkable bird-dances undergone by certain species occur after mating has already taken place. From these and many other examples, which can be cited, there is little evidence that the female chooses her mate. On the other hand it is not clear that such structures as the great tail of the peacock, the tuft of hair-like feathers on the breast of the turkey, the wattles, plumes, spines, knobs, and conspicuous colors possessed by the males of many species are of supreme importance in the life and death struggle for existence. In short, there is as yet no satisfactory all-embracing explanation of the significance of secondary sexual characters.

Lamarckism. — It is an uncontested fact that animals and plants are continually being molded under the influence of their surroundings. Food and climate are important agents in this respect. Exercise increases the size of muscles and disuse causes their shrinkage. Drugs, such as morphine and alcohol, modify the organism, and many other forces cause more or less extensive alterations. According to the French scientist, Lamarck (1744–1829) the characters or modifications thus acquired by the organism during its lifetime are supposed to be inherited by the offspring. This simple plausible theory was accepted by Darwin as a factor in evolutionary processes, and was likewise accepted as a matter of course by scientists and laity alike until recent years.

The long neck of the giraffe, according to the Lamarckian theory, is due to the fact that the deer-like ancestors stretched and so lengthened their necks to a slight extent. The immediate descendants inherited longer necks in consequence of their parents' activity. Generation after generation this process of stretching and transmitting the effects went on, and the increasingly long-necked species evolved into the modern giraffe.

Scientific journals and the public press recounted instances of the (supposed) inheritance of mutilations, the transmission of a powerful physique due to exercise, and implicitly or explicitly, the work of the schools, churches, asylums, hospitals, and other philanthropic institutions was based on the belief that the benefits conferred upon one generation are inherited by the next.

The New Lamarckian School. — Toward the close of the last century, Weismann challenged this theory of the inheritance of acquired characters, and demanded more conclusive evidence than had hitherto satisfied the scientific world. He also directed attention to the fact that a modification, such as a neck lengthened by stretching, can only be transmitted to the succeeding generation by means of the germ cells. And not only this, but the Lamarckian theory requires that precisely that portion of each germ cell which controls the development of the neck must be changed to the exact extent required for the inheritance of the modification. As a result of this challenge, old evidence was carefully scrutinized and found to be inconclusive. New evidence was sought, but without avail. To-day there are no known cases where definite, specific changes in an organism due to the influence of the environment on the body are inherited by the offspring.

There is evidence that the form, color, size, vitality, etc., of an individual may be modified by environmental influences, and the descendants of such parents may vary more or less widely from the normal type. For example, the size of seeds stands in close relation to the amount of nourishment received by the parent. If starved and highly nourished seeds are planted in the same environment they respectively produce small and large plants. It is important to note, however, that such effects pass away in a few generations. The germ cells have not been affected, and the modification is not inherited. The same facts have been shown to be true in the case of certain organisms subjected to different degrees of temperature, moisture, light, drugs, and several other modifying agents. The effects of the environment in such cases are not permanent, and hence are not heritable.

On the other hand it is beyond question that mutations do appear from time to time. It is also well established that this is due to the rearrangement of the hereditary chromatin in the germ cell. In some cases there is evidence that such changes are closely related to temperature — an environmental factor which thus appears to modify heredity. Since the germ cells are protoplasm, and protoplasm is capable of change, it may indeed be true that environmental influences have an effect. They are believed to have by the later Lamarckian school, but the question is as yet a hotly debated and unsettled one. Even if it were settled in the affirmative, however, it is probable that it would do no more than shed light upon the origin of heritable variations, and would in no wise unseat the theory of Natural Selection.

Orthogenesis or Determinate Evolution. — The evolution of the organic world may be compared to the growth of a tree, the tips of the branches corresponding to the modern species of animals and plants. And just as the tree is caused to grow by forces within it, so, a considerable number of scientists are convinced, living things are constrained by their structure or by internal or external forces or by these in combination to evolve along fairly definitely fixed paths. Such in general is the meaning of Orthogenesis.

According to the most extreme view, protoplasm is endowed with a peculiar force, which not only impels the organism to evolve in a definite direction, but also adapts it to its surroundings. A less radical position is taken by certain other scientists who maintain that at certain definite periods the structure of an animal or plant determines the general trend of evolution, after which the surrounding conditions mold the species to fit the environment. Several other theories, more or less Lamarckian in principle, have also been proposed as all-sufficient explanations of evolution, or as subsidiary theories to account for the orderly and seemingly predetermined course of species development.

At the present time the majority of biologists are agreed that heritable variations are to a certain extent limited, the range being determined by the structure of the organism concerned. As Huxley wrote, " whales never produce feathers, nor birds whalebone." Nevertheless, each species of whale, bird, or other species of animal or plant may vary in any one of thousands of different directions. Provided the mutation harmonizes with the environment, evolution may accordingly take place along any one of a multitude of different lines, and not along the limited number demanded by the usual theory of Orthogenesis.

CHAPTER XXXVI

THE RESULTS OF EVOLUTION

ADAPTATION. — The current of life, as it has flowed through the ages, resembles a mighty river, or better, perhaps, the slow-moving glacier, which at varying distances from its source breaks up or evolves into numerous branches. And in much the same manner that the glacier fits into the inequalities of its bed, the various species of animals and plants fit into or are adapted to their surroundings. This is the great outstanding characteristic of living things. Furthermore, adaptation does not stop with the organism as a whole. On the contrary, every system, organ, tissue, cell and the elements of the cell itself are all adapted parts of the vital machine. The results of evolution therefore are largely summed up in the one word, adaptation.

CONVERGENT ADAPTATIONS IN ANIMALS. — Viewed in its broader aspects, one striking feature of adaptation among organisms is the so-called convergence or parallelism of form. That is to say, many species of animals and plants, surrounded by essentially the same conditions,bear a superficial resemblance to each other. The whale for example has been called a fish since the days of Jonah. In reality this is a case of convergence whereby a hairy, warm-blooded vertebrate, or mammal, has evolved a form of body adapted for cleaving the water with the least possible resistance. Its resemblance to cold-blooded fish is entirely superficial. The same is true of the extinct fish-like reptiles, which long ago inhabited the sea.

Another familiar example of convergence occurs among the birds, bats, certain ancient reptiles and to a less extent among the flying squirrels, flying lemurs and certain species of lizards. Here again the wings and planes are adaptations with the same general function though the organs themselves are structurally quite different.

On the high seas many vertebrates, snails, crabs, shrimps, jelly-fishes and the young of many other equally distantly related species are transparent as glass, a convergent adaptation, enabling such animals to escape the notice of many sharp-sighted enemies. Numerous aquatic organisms are provided with oil and fat which decreases their specific gravity, or they are furnished with gas bags or feather-like outgrowths which prevent their rapid sinking. The heavy fore limbs of digging animals, the claws of those which climb, the long legs and tendency to go about on tiptoe common to many running species, the more or less blind and colorless condition of cave animals, the phosphorescent organs of numerous deep sea organisms and many other examples known to the observant student illustrate convergent adaptation.

Convergent Adaptations among Plants. — In the plant kingdom no less than among animals there are many examples of convergent evolution. Numerous species of widely different relationships have evolved the climbing habit, in the struggle for existence. By means of tendrils, holdfasts, or by twining about some support they are adapted to scale a wall or forest tree and expose their leaves to the light. In the most extreme case, certain palms, commonly known as rattans, form great festoons in tropical forests, and not infrequently attain a length of 600 to 900 feet, the greatest known length of any organism.

In the life of plants of arid districts it is of the utmost importance that the water absorbed by the roots be conserved as far as possible. To this end the leaf surface is greatly reduced, thus preventing rapid evaporation; and various species have evolved water storage tissue, giving the leaves or stems a thickened fleshy appearance. These are convergent adaptations characteristic of numerous desert plants the world over. Incidentally it may be said that as a result of this adjustment to the environment the agave, represented by such species as the century plant of this country, bears a close resemblance to the old world aloes, and the cactus closely duplicates the African spurges.

The plants of high mountains and of the treeless regions of the far north, where deep snows prevail throughout the greater part of the year, form low dense mats or carpets. Convergent adaptations appear in the case of many species where the over-lapping leaves chiefly rest on the ground and diminish the loss of heat, while the roots are generally loaded with starch and furnish the food necessary for the rapid growth of the plant during the short summer.

The plants adapted to an existence in water, or to the sandy stretches bordering the sea and the larger lakes, or to any other relatively large territory where essentially the same conditions prevail, possess certain features in common; but considerations of space prevent their detailed description.

Other Classes of Adaptations. — While the animals and plants of a given region, or in different districts where the same general conditions prevail, may manifest this convergence or parallelism of form, it is equally true that every species possesses its own particular adaptations which enable it to live amid surroundings more or less different from those of any other species. Indeed it is these minor adaptations which in large measure serve to distinguish one species from another. The relations of plants to their environment are usually less complex than in animals with highly developed nervous systems, sense organs, and active powers of locomotion. Accordingly, plant adaptations are less obvious and not generally so striking as those in the animal kingdom, though they are as universal and belong to the same general classes.

These lesser specific variations have been variously classified. According to one recent view there are five general categories: "(*a*) food-securing; (*b*) self-defense; (*c*) defense of young; (*d*) rivalry; (*e*) adjustment to surroundings."

Food-securing Adaptations. — Teeth are present in the great majority of the higher animals, and are variously adapted for seizing and killing prey or biting off vegetable material, or tearing through the protective husks and shells of nuts as well as for crushing or cutting the food preparatory to swallowing. So close is the form of the teeth related to their function that the paleontologist is frequently able not only to determine from a single tooth the relationships of the species but also to form a fairly clear picture of its food and feeding habits. The same principle applies to an almost equal extent in the case of birds. Certain parrots have a relatively long and curved beak adapted for digging up roots. Other species possess a heavier, shorter bill serving for the cracking of nuts and other thick-shelled seeds. The sparrows and other seed-eating birds have heavy conical bills, while those of the warblers and certain other insect-eaters are more slender.

In many of the lower animals, such as the insects and crabs and related species, the mouth is unprovided with teeth, and certain of the legs have become adapted to form cutting or piercing organs. The "bill" of the mosquito and the long proboscis of the butterfly are organs of this type. Finally, there are many attached or stationary animals, such as sponges, corals, numerous species of worms, barnacles, and various clams, which obviously must subsist upon food brought within reach. In the barnacles, numerous legs create currents in the water and grasp the food as it passes by. In most of the remaining species mentioned, myriads of cilia on the surface of the body drive floating nutritive particles into the mouth.

Plants Adapted to Absorb Gases, Water, and Salts. — Since these raw materials are absorbed through the leaves and roots it follows that the former must be properly exposed to the air and the latter to the soil. Leaves must not only absorb oxygen from the air and discharge carbon dioxid into it in the dark but they must also reverse this order in sunlight and absorb carbon dioxid and light energy and discharge oxygen. To do this efficiently requires many shapes and positions of leaves.

The roots likewise present a wide range of variation. Primarily they are adapted to absorb water and dissolved salts anywhere from the surface of the earth to a depth of at least seventy-five feet, in the case of certain desert species. At the same time it is highly important that they function as holdfasts to anchor the plant in a secure position.

In parasitic species, such as the mistletoe and dodder (Chap. XVIII) specially adapted roots serve to absorb nutritive materials from the host plant. In many lower species of plants, such as fungi and bacteria, the individual is fitted to decompose and absorb organic substances. Still other species, ranging from relatively simple to highly complex types, are adapted to an aquatic life where delicate tissues, few if any roots, but a highly developed absorbing body surface are the more general adaptations.

Insectivorous Plants. — Several species of flowering plants have been described which add to their customary food supply the digested remains of animals, chiefly insects, and in this way are adapted to a life in soils poor in nitrogen. In the pitcher plant, which affords a good example, the leaves are slender vase-shaped structures whose rims secrete a sweet fluid which slowly oozes down their outer surfaces. In the interior, immediately below the rim is a smooth slippery zone; beneath this there is a second zone provided with inwardly directed hairs;

while at the bottom of the urn or pitcher is a fluid containing a digestive enzym. If an insect, attracted by the nectar, attempts to crawl into the urn it slips on the smooth zone, falls into the liquid, and unable to escape by reason of the hairs, it drowns, is digested and absorbed. The Venus fly-trap of the southeastern part of the United States is another of these remarkable insect-trapping species. The terminal portion of each of its leaves is developed into two flat, highly sensitive lobes with numerous hairs located around their margins. When an insect settles upon this portion of the leaf the lobes close like the jaws of a steel trap and the captive is digested. This operation over, the lobes again open and the process is repeated.

This curious habit of ensnaring and digesting insects is common to several other species occurring in this and other countries. The interested student will find the subject entertainingly discussed in Darwin's " Insectivorous Plants."

Adaptations for Self-Defense. — Animals when in danger of attack take flight and escape by virtue of fleetness or the ability to hide, or they may defend themselves by means of claws, horns, teeth, and various other organs. The rabbit, for example, when in danger, dashes into its burrow, various species of birds escape into thick vegetation, certain fishes bury themselves in the mud, while hosts of insects, spiders, and crabs conceal themselves under sticks and stones and in other safe retreats. There are also many species whose protective covering renders them comparatively free from attack. The spines of many crabs, fishes, porcupines, the armor of the armadillo, the shells of clams and snails, are familiar examples of this. In several species an additional protection is afforded by poison, which in some of the sea urchins and fishes is situated in small cavities in or near the spines. Poison sacs are also a characteristic feature of many snakes, all of the spiders, centipedes, the stings of many insects, and the stinging cells of the corals, jellyfishes, and their numerous relatives. In several of the fishes (for example, certain of the eels and rays) there are electric organs sufficiently powerful in a large individual to paralyze a man temporarily. The devil-fishes, squids, and related species throw out an inky cloud when molested and escape amid the gloom. From such examples it is but a short step to those cases where protection is afforded to an animal covered with foreign substances, as described in the section on Protective Resemblances.

Defense of Young. — Adaptations used in the defense of the young are in most instances the same as those serving for self-defense.

Self-Defense in Plants. — Many species of plants, as well as numerous fishes, shrimps and other prolific animals, persist by sheer force of numbers. If a grass plant or so-called weed is destroyed by some enemy, enough remain to maintain the race. In numerous other species the presence of thorns on stem or leaf renders them comparatively free from attack. This is especially true of desert plants where, amid severe conditions, the number of individuals is relatively small and adaptations along the line of self-defense are of supreme importance. In the same or more favorable situations certain other species are covered with stiff prickles, or with stinging cells, as in the case of the nettle, or, as in the Jack-in-the-pulpit, are packed with needle-like crystals which insure them against the attacks of insects, snails, and other animals. Several species, such as the oxalis, develop acids in their tissues, while many others form unpleasant and even poisonous substances which probably enable such individuals to escape complete destruction.

Adaptations for Rivalry. — Battles among the male individuals of a species for the possession of a female occur in practically every class of animals from the crabs and insects to man. Furthermore, it probably is self-evident that the organs adapted for defence are chiefly concerned in this matter of rivalry. Among certain of the fishes, such as the salmon, trout, and stickleback, there are combats ranging from sudden rushes, without any material damage resulting, to bitterly contested struggles where death may result, teeth being the organs chiefly concerned. Many of the turtles, lizards, and crocodiles also engage in lively tilts during the breeding season, using teeth, claws, or beaks as weapons. Among the birds there are many species, chiefly those related to the pheasants and domestic fowl, where spurs and wings and beaks are at times used with deadly effect. Among the higher animals, especially those where one male strives to gain possession of several females, the struggles are even more severe. This is especially true of certain species of wild sheep and swine and of some of the deer and antelope tribe, where teeth and hoofs lay the vanquished low or drive him from the field.

Rivalry among Plants. — If anyone is in doubt as to the existence of rivalry among plants let him repeat the experiment of Darwin, in which a small plot of ground was cleared and a census taken of the large number of individual plants which germinated and of the small number which came to maturity. As in the case of animals the struggle for supremacy is most severe among the members of the same species, so that throughout its range many more individuals are born than are able to live and reproduce. But while it is true that only a limited number of offspring of a single species can live in one locality, this does not prevent members of other species from flourishing in the same region. A glance at the vegetation of any field or forest is sufficient to prove this fact. In either event, however, whether the rivalry is between the individuals of the same or different species, the ill-adapted die in the struggle. Just what adaptations are the most valuable aids in achieving success is difficult to decide. Obviously, a favorable location is of prime importance, and a vigorous constitution is scarcely less so. It is also very certain that mutations resulting in new and more favorable adaptations or in the increased value of already existing ones, are of the highest importance in perpetuation of the race.

Adjustment Adaptations in Animals. — In a broad sense every adaptation which enables an organism to maintain itself, beget young, and in some instances to care for them, is in the nature of an adjustment to the environment. The gills and fins of aquatic animals, the lungs and legs of land dwellers, the fur, shells, spines, scales, and other protective structures, digging, climbing, and flying organs, and innumerable other adaptations are in every instance of service to the species in adjusting it to the surrounding conditions. In many regions an animal's surroundings are subject to marked changes with periods of high and low temperature alternating. In such a location many animals undergo a winter or summer sleep (Chap. XXII). Where the conditions are less severe a considerable proportion of these same species, as well as numerous others, are active throughout the year. At the same time this last named class usually displays different degrees of activity in response to day and night conditions. The greater number of animals are active during the daytime, and sleep or remain comparatively quiet at night; other species reverse the process. In brief, every species displays a characteristic series of activities in response to heat, light, cold or moisture, or to the nature of its food supply, and is continually adjusting itself to the changing conditions of its environment.

Plant Adjustments. — Not only are plants and animals adapted to live in a definite territory, but also, within this range, they are continually undergoing minor changes which serve to adjust them to shifting conditions. Most plants, in moderate light, expose to the fullest possible extent their leaves and flowers to the sunlight, and some even shift their positions throughout the day as the direction of the light changes. On the other hand, where the light and heat are intense, as in the tropics or deserts, the leaves of many plants close and bend downward, thus escaping the danger of excessive illumination and evaporation. Other plants undergo somewhat similar nocturnal movements and prevent an undue loss of heat.

Another phase of adjustment appears in the case of those plants capable of existing amid markedly different surroundings. Individuals, even from the same parent, if grown in very moist habitats, differ materially from those in comparatively dry soil. Those of cold elevated regions are decidedly unlike their brothers of the lowlands. And furthermore, while these plants of the mountain top or cold countries die down in the fall, the very same plants in warmer regions, in many instances, may live for several years.

Every plant and every organ of the plant is thus a delicately adjusted mechanism under the sway of many controlling influences. Heat, light, moisture, soil conditions, gravity, etc., are continually stimulating the living material, which responds by molding its leaves, stems, or roots to harmonize with or fit into the shifting conditions.

Colors of Animals. — One of the most universal features of living things is their color. In many instances this obviously is an adaptation; in certain other cases its significance at the present time is by no means clear. The redness of the blood, for example, is seemingly an incidental result of its chemical composition, and is of no more use to the organism than color is to a brick or a ten cent piece. On the other hand, there are very many species where the color pattern is believed to be of the highest value in the struggle for existence. It may serve so to blend an animal with its surroundings that it escapes the notice of enemies, or it may enable it to steal unobserved upon its prey. In other animals it apparently is of service in giving warning to friends or, in still other species, to foes. And finally it may serve to reflect or absorb heat or protect the tissues of the body from injurious effects of the sun's rays. A few examples of these various classes of animal coloration will illustrate the various ways whereby it serves to adapt a species to its surroundings and the struggle for existence.

Protective Resemblance. — The color pattern of this class of adaptations enables an animal to escape recognition on the part of its enemies. It may be of a general character (Fig. 122), and harmonize the animal with the

Fig. 122.— The common Eastern quail, or Bob-white, *Colinus virginianus*. (Photograph by J. R. Slonaker.)
Kellogg and Doane, *Econ. Zool.* Holt.

color, as a whole, of the surroundings; or it may be more specific and cause the organism to resemble a leaf, pebble, or some other relatively small object. To the first class belong such animals as the polar bear, arctic fox and hare, whose white coats blend with the snow; or the brown tones of desert animals which harmonize with sandy wastes; or the greens, grays, and other tints of many insects, spiders, lizards, and birds, living among trees, grass, and other plants.

In the second class the color resemblance of an animal to a particular object is usually heightened by a similarity of form. The familiar walking-stick insect, and the caterpillars of many species of butterflies and moths closely resemble the twigs on which they feed. A considerable number of butterflies, katydids, and other insects bear a remarkable resemblance to leaves, duplicating even the worm holes and fungus spots. Numerous other insects closely resemble thorns, grains of sand, bits of earth and other objects. Every observant student of nature can add other examples to the list of this widespread type of adaptation.

Several animals are capable of altering their color with a change in the surroundings. Devil fishes, squids, many fishes, tree-frogs and lizards, are examples of this well-known class. Finally there are other species which gain additional protection by covering themselves with objects unappetizing to their enemies. Several crabs, for example, attach seaweeds to their backs, and thus concealed, escape danger. Other species travel about with clam shells held over their backs. In all of these and the other cases of protective resemblance it is difficult for human sight to recognize the presence of such animals, and it appears to be an equally assured fact that their enemies are likely to overlook them.

Colors of Physiological Value. — There are many animals whose bodies bear color-coats which may or may not be protective in the sense that they conceal them from enemies, but which nevertheless may serve to protect them from the injurious effects of the sun's rays. Many subterranean and wood-boring animals either throughout life or in an immature condition, are without pigment. In the case of the termites, or white ants, which serve as a good illustration, the winged or reproductive individuals are colorless up to the time when they are about to leave the nest to found new colonies. The color which then develops in the skin does not protect them against the attacks of enemies, but it does appear to screen the internal organs against sunburn or the injurious effects of light. Tan is a temporary protective coat, and the brown and yellow pigments which are permanent features of the skin of various races of men are protective adaptations of the same character. In several species of animals the nerves are more or less covered with pigment, while in others a heavy pigmented coat lines the visceral cavity. In many otherwise transparent marine organisms the eyes, and, in certain species, the reproductive organs as well, are coated with variously colored substances. In these and many other species, it is assumed that color screens are protective, or in certain instances they may absorb or reflect the light and thus keep an animal warm or cool.

Warning Coloration. — Many animals are so brilliantly and conspicuously colored that it appears surprising that they have escaped annihilation on the part of numerous enemies. The explanation, at least in certain definitely established instances, is that the color advertises the fact that they are dangerous on account of stings, poisons, or a nauseous flavor. For example, there is a gorgeously blue and red frog in Nicaragua which flaunts its colors in the brilliant sunshine comparatively safe from attack. Mr. Belt, who conducted the experiment, states that he offered one of these frogs to ducks and chickens, all of which refused it except one young duck which snatched it up, promptly dropped it, "and went about jerking its head as if trying to throw off some unpleasant taste." It has further been shown that the memory of such experiences endures for a very considerable period, and the victims cannot be induced to repeat the experiment.

The yellow and black banded bodies of hornets and wasps are also warning or signalling colors, reminding their enemies of danger ahead. The striking colors of certain butterflies, bugs, beetles, skunks and other animals with unpleasant odor or taste, bring sharply to the attention of some would-be assailant the penalty of an attack. It may indeed happen that an enemy may destroy a warningly colored animal, but it is also probable, as has been proven for a considerable number of species, that it will rarely repeat the operation. The destruction of a few individuals thus insures the race against continued attacks and enables it to persist.

MIMICRY. — If warning coloration is a valuable adaptation to one species of animal, it must follow that another

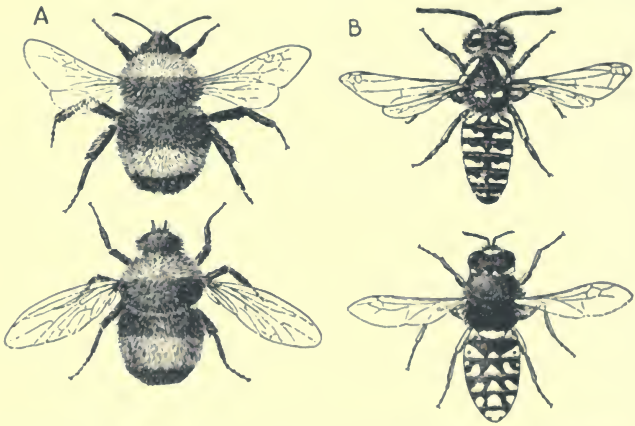


FIG. 123. — Mimicry. A, B, bumble-bee and wasp, mimicked by flies.

one which resembles it is likewise benefited. At least this is the general explanation of those cases where a harmless and inoffensive species more or less closely duplicates a nauseous one. Instances of this type of protective coloration are numerous among insects, and are also known to occur in several other groups. For example, there are several species of flies which so closely resemble honey-bees or bumble-bees that it requires close scrutiny to detect the fraud (Fig. 123). Some of the wasps are mimicked by beetles; certain conspicuously marked beetles, such as the potato beetle, are mimicked in turn by grasshoppers; a well known leaf hopper insect bears a striking resemblance to the powerful and aggressive leaf-cutting ant; and there are many spiders which significantly are very similar to the flies upon which they feed. Among the butterflies there are also many species which mimic distasteful ones, and a few which resemble bees or wasps.

Flowers and Insects. — Although plants in general do not possess as definite, or at least as remarkable adaptations as characterize animals, there are many species which prove an exception to the rule. This is especially the case with plants in relation to insects. As is well known, the great majority of flowering plants produce pollen and ovules whose union is necessary to produce seeds. The sex-cells may be the product of the same individual or more frequently of different plants. Furthermore, the pollen may be carried by the wind, as in the case of most forest trees and grasses, or it may be transported by insects. The wind-pollinated flowers are small, scentless, and inconspicuously colored. Those pollinated by insects are larger, conspicuously colored, and are frequently provided with nectar and distinctive odors. The presumption is that the flowers of the latter class are thus adapted to attract insects. This has actually been proved to be the case with many species.

In the first place it can easily be seen that bees, flies, butterflies, moths, and even humming birds, in their search for nectar, become more or less coated with pollen as they journey from flower to flower. It has been conclusively demonstrated that during these visits the pollen of one flower is dislodged in another. Moreover, it has been experimentally proved that the honey-bee is especially attracted by colors. Wasps have also been shown to be attracted by color, and it is probable that many other insects possess a color sense and are attracted by flowers in consequence.

It is also probable that odors attract insects. This is certainly the case with several species of plants related to the common skunk-cabbage, whose flowers possess a strong odor of decaying meat and are pollinated by multitudes of flesh-flies which crawl over them and even deposit eggs. Needless to state, the instincts of the flies in this case are faulty, since the young soon starve to death, while the plant profits by the deception and produces seeds.

In addition to alluring colors and scents there are many mechanical adaptations in flowers which further insure pollination. The nectar is usually located deep within the flower, so that to reach it the insect must inevitably brush against the pollen. In the Dutchman's pipe and related plants, there are inwardly directed hairs which prevent the escape of the visiting flies until they have coated themselves with pollen. With the withering of the hairs the captives escape to another blossom. The flowers of the sage are so adapted that the stamens are caused by the entering insect to bend down and dab a mass of pollen on its back. In the orchids, adaptations of this class reach a high degree of development. In addition to attractively colored footpaths up which the insect is invited to walk, there are delicately adjusted contrivances for attaching pollen to the visitor or for actually discharging it at its head. The details of the process, along with many other examples, are given in Darwin's work on the "Fertilization of Orchids."

SECTION 11

THE DISTRIBUTION OF ORGANISMS

CHAPTER XXXVII

PLANT DISTRIBUTION

THE FACTS OF DISTRIBUTION. — Almost everyone has travelled far enough to realize that the assemblages of plants and animals in different places are more or less different. The chief underlying causes of this fact become more obvious when distant areas are considered, as, for example, North America, South America, Asia, and Africa. If one were to find an area in each of these continents in which the conditions of soil and climate are so nearly the same that the same plants can be cultivated equally well in all, he would nevertheless find that the plants native in each area differ from those in all the others, but that there exists a large measure of superficial resemblance in the general appearance or aspect of the assemblages of plants. When the individual plants are considered it is found that the difference is much greater than the general appearance in the mass would suggest. From these observations we may deduce two conclusions: first that mere distance has something to do with the distribution of plants and second that similarity of habitat has a good deal to do with similarity of appearance in the mass. For example, if one of the supposed areas is a forested one it is quite certain that all the others will be also.

THE GENERAL CAUSES OF DISTRIBUTION are already familiar to the reader for he knows that organisms undergo mutations or heritable variations and that they are able to spread themselves over considerable areas either because they themselves are motile or because their seeds or spores can be carried by wind, water, or animals.

Moreover, he is aware that all organisms have various means of adjusting themselves to their environment. These three factors account in a general way for the fundamental facts of distribution, namely: (1) that there are different assemblages of organisms in distant regions, (2) that species are more or less widely distributed over the world, and (3) that plants and animals are aggregated into groups adapted to live under similar environmental conditions. Each of these factors may now receive a somewhat fuller consideration in order to see just how they actually work out.

Evolution and Distribution. — When new species originate by evolution it is probable that in the vast majority of cases they do so in one particular locality only. From this they spread more or less widely according to circumstances. In the great majority of cases they find *something* to prevent their spread over the *whole* world, from which it follows naturally that evolution tends to create diversity among the plants and animals of widely separated regions. It can be readily seen that this would be true even if all parts of the earth had been originally populated with exactly the same species; evolution of new and different species in regions distant from one another would in the course of time have given them widely different assemblages of plants and animals.

Migration and Distribution. — When new species of plants and animals have once evolved they spread gradually away from their place of origin. Some sorts of animals and plants are able to spread rapidly, as, for example, birds and dandelions. On the other hand angleworms and plants with large heavy seeds have in nature very much less efficient means of dispersal. From illustrations of this sort it is easy to understand that the means of dispersal govern in some measure the probability of a particular organism spreading to the limits of its possible range. However, it must be noted that even the organisms with the least efficient means of dispersal would ultimately occupy all suitable areas unless there were some actual barrier to prevent their reaching them.

ADAPTATION AND DISTRIBUTION. — Another fact of great significance is that plants and animals do not occupy all the areas which they can readily reach. A study of any area of a few square miles will ordinarily show that there are several different assemblages of plants within it, each occupying a habitat of a special sort. The plants in each of these, for the most part, could readily reach any of the others, and likewise in most cases they do so but do not establish themselves, because the environment is not suitable. For illustration, it is not unusual to find a lake, a stream, a plain, and a mountain within close proximity but without any tendency for the plants of the lake to spread to the mountain top. While the mountain and the plain are not so different as the mountain and the lake, yet each is likely to have a distinctive assemblage of plants and to show little tendency for this difference to be lessened by migration from one habitat to the other. This sort of phenomenon shows that some plants are adapted to live under one set of conditions and not under others. The same thing is true of animals but to a lesser extent on account of their greater independence of certain features of the environment. A polar bear would probably find no insuperable *physical* obstacle to prevent his migration from Alaska to Panama but he would almost certainly find the conditions there so little adapted to his fur-clad body and habits of life that he would lead a sad life of no long duration. Nor would the cougar of the Mexican jungle find himself better situated should he perchance migrate to the polar bear's arctic home.

FLORAS AND FAUNAS. — In order to enable us to speak accurately the biologist has coined two words to express the assemblage of plants or animals characteristic of a particular region. All the plants found native in Maine or California, the United States or Europe constitute the *flora* of that region. The animals native to a region considered all together constitute its *fauna*. A particular species of plant or animal may occur in the flora or fauna respectively of many regions and be associated with a different set of other species in each. This illustrates the universal fact that the range of any particular species is distinctive of it but rarely corresponds accurately with the ranges of other species with which it may be associated.

VEGETATION. — When one speaks of the flora or fauna of a region he refers to the actual species inhabiting it, but when he speaks of a forest, prairie, or desert he refers not to the species constituting this assemblage of plants but to the general appearance or aspect of the region. As a matter of fact very different assemblages of species may combine to produce forests of very similar appearance. Pine forests occur in Maine, Michigan, and California, for example, which look much alike but which have few species in common, and no one species of pine is found in all. Any of these would have still fewer species identical with a pine forest in Europe or Asia and probably would not have a single species that could be found in a "pine" forest in Chile; in fact the so-called pine forest of the latter would not have even a true pine of any kind but merely another coniferous tree more or less resembling a pine. One would find this same principle to be true of a prairie in the Mississippi Valley compared with one in southern Brazil, or of the deserts of our arid Southwest and the Sahara.

Illustrations of this sort might be multiplied to almost any extent to illustrate the important fact that *similar habitats* in any part of the world are occupied by a *similar type of vegetation*, but that the species are different and in general more different the further removed from one another are the regions under consideration. Thus it is to be understood that terms such as forest, desert, prairie refer to *vegetation types* without reference to the particular species that make up the plant assemblages, while *flora* applies to the aggregate of species without reference to the vegetation types which they may combine to produce.

THE BARRIERS TO UNIVERSAL DISTRIBUTION. — In the preceding topics the conditions *positively* concerned in diversifying the assemblages of plants and animals in different regions of the world have been emphasized and only bare mention made of certain *negative* factors of extreme importance. One may express the idea in this way: when plants and animals evolve into new species these would spread to all parts of the earth unless there were some sort of barrier to stop them or the conditions of the environment were unsuited to their habits of life. To put this positively one may say that in the absence of barriers of any kind all species of plants would ultimately spread all over the habitable world but would be restricted to those particular local areas or habitats which would be suitable to each. As a result of this there would be much the *same sort of vegetation types* as now exist, but the species in each would be the same *all the world over.* On the other hand, if all plants were suited to the same environmental conditions but the present barriers still existed, there would be a *uniform vegetation within each barrier limit* (except of course for the fact that the same barriers do not apply to all species), but the differences in the actual species now present in each great division of the world would remain just as they are. From considerations of this sort it is obvious that barriers play an important rôle in determining the *Geographical Distribution* of species and it will be pertinent to inquire into the nature of barriers and to consider how they operate.

TANGIBLE BARRIERS are literally those which can be touched but the term is used practically for all those of a material and non-living character. To any animal which can walk, but cannot fly or swim, water constitutes a barrier difficult but not always impossible to pass. To such, a river may be a very efficient check to migration provided that it is not practicable to go round its head-waters. An ocean constitutes a practically impassable barrier around an island or a continent to such animals or to plants whose seeds cannot be carried by wind or water. Fishes and strong-flying birds on the contrary as well as plants with thistle-down-like seeds readily cross very large bodies of water. Large land masses of course constitute efficient barriers against fishes. In fact in the Inter-Mountain Region of the United States there are streams which now lose their waters in the desert sands within a few miles of each other and yet have different species of fish in them, although they were both connected in the not distant geological past by the waters of the ancient and now dried-up lake into which they emptied. Aside from plants with small seeds easily dispersed by wind, plants in general are less rapid in extending their range than the higher animals. They too find oceans and high snow-clad mountains and suchlike physical forms serious and sometimes impassable barriers. It is not intended that this paragraph should attempt to list all the sorts of things which may constitute tangible barriers, but merely to indicate the fact by illustration that there are many sorts of physical elements which constitute efficient barriers for particular species and that what is a barrier for one may not be for another.

Intangible Barriers. — It is readily seen that plants often fail to spread into adjacent areas where there are no tangible barriers to stop them. For illustration the pine trees of Michigan would have neither mountain, desert, nor ocean to check their spread south through the prairie region to the Gulf of Mexico but, nevertheless, they do not do so. Neither do the prairies nor the individual species which grow in them spread north into the forest country to any great extent or west into the drier plains and mountains, although many species have seeds readily transported for long distances. Endless examples of this same sort of restraint of species within limits not established by material barriers might be cited. From this one may conclude that they do not spread because the conditions of soil and climate are not suitable to them beyond the limits of their natural ranges. A careful consideration of the factors shows that where no tangible barriers exist, and the region has an equally distributed rainfall, species spread over a far greater extent east and west than north and south. This suggests that temperature may be one of the conditioning factors, a supposition which can readily be verified experimentally in many cases. There will thus be a tendency for the world to be divided into temperature belts or zones each of which is adapted to particular species. But since the rainfall is unlikely to be uniform throughout the east and west extent of such zones, they will again tend to be divided into smaller areas on the general basis of the moisture factor of climate. Of course it is well known to everyone that on account of the position of mountains and large bodies of water and the direction of the winds, these zones of temperature are not straight horizontal belts extending uniformly around the earth but are in fact bent far to the north or south, widened out or greatly narrowed according to the various positions of these physical factors. In fact one may often go south and up a mountain and find the same changes in temperature and vegetation that he would find in going north over a very much longer distance on the level. This is due, of course, to the well known fact that temperature decreases with altitude as well as with latitude. Nor are the divisions dependent on moisture any more regular, since rainfall also usually increases with altitude, especially on the windward slopes of mountains. In considering facts of this sort it should not be forgotten that these differences of climate really act as *conditions for favorable development* and only occasionally as genuine barriers. It is true that there are numerous plants in North America which could readily grow in South America but do not spread from the one place to the other because the warm moist climate of the intervening zones, together with the plants which inhabit them, make it impossible to cross.

Biological Barriers. — In considering the treeless prairie and the adjacent forested areas one might suppose that they are distinct because the species found in each *could* not live in the other but this is daily proved untrue by the thriving groves planted about the farms of the prairie states and by the meadows of the forest region. The truth — in part, at least — seems to be that the plants of one region *can* actually grow in the other in many instances but they are not so well adapted to soil and climate as the natives and so are *unable to compete successfully* with them. Here again it is to be noted that it is not a question of actual barriers but rather one of a failure in competition due to imperfect adaptation. Of course a grassy prairie lying between two similar forested areas would act as a *barrier* to hinder species spreading from one to the other; for if they were unable to live in the grass-land they would be unlikely to reach the other area suitable to their growth.

The Great Plant Realms. — When the world as a whole is regarded on a basis of the principles set forth above and the actual distribution of the species of plants and animals is considered, it is found that it can be divided into five major divisions or Realms, as follows: (1) The Holarctic Realm, including the whole of Europe, most of North America and Asia, and Africa north of the Sahara Desert; (2) The Neo-tropical Realm, including South America, Central America, and the West Indies; (3) The Oriental Realm, including Asia south of the Himalayas, Borneo, Java, and the Philippines; (4) The Australian Realm, including Australia, New Guinea, Tasmania, and several smaller islands; (5) The

Ethiopian Realm, including Africa south of the Sahara, Madagascar, and part of Arabia. It would be neither possible nor desirable to set forth in a book of this character the details of the floras or faunas of these great realms. The purpose is rather to exhibit general biological principles and merely to illustrate them with sufficient detail to make them understandable. This end may be accomplished by consideration, in the remaining paragraphs of this chapter, of the chief vegetation types found in a limited region such as the United States and Canada, and in the following chapter a brief presentation of the characteristic *animal species* of the various realms.

THE HOLARCTIC REALM constitutes a nearly continuous land mass, being broken only by the very narrow Bering Strait. Moreover there is abundant evidence that in recent geologic time the connections have been far more extensive both in that region and via Greenland, so that communication and distribution were much easier than now. This was facilitated also by the warmer climate in the far north at that time. However, a considerable geologic time has elapsed since the present imperfect communication was established and the climate became colder, with the result that the species which have evolved since that time have been more largely confined to the continent of their origin. The consequence is that North America and Eurasia resemble each other far more than either of them resembles any other realm, but still have characteristic differences. North America may therefore be thought of as one of the vast regions of this enormous realm. The same principles, however, apply everywhere and may be illustrated satisfactorily by considering a still more limited region.

VEGETATION OF THE UNITED STATES AND CANADA (see accompanying map). — Within this area are to be found the principal vegetation types of the Temperate and

Arctic zones. Some or all of them are familiar to the readers of this book. Reference to the accompanying map will show the areas over which the several vegetation types are represented. They may be enumerated in the following brief synopsis: (1) Deciduous Forest, occupying most of the eastern United States, southeastern Canada, parts of the Mississippi Valley, and extending westward along the streams into the prairie region. (2) Coniferous Forest, occupying two rather distinct but connected areas, the eastern one lying north of the deciduous forest, extending north as far as southern Labrador and northwestward to join with the western coniferous forest. This western area includes first the entire Rocky Mountain region from Yukon Territory south into New Mexico and Arizona, and second the mountain ranges lying near the coast from Alaska to southern California. (3) The Tundra or the Barren Ground, north of the limit of trees and, what is nearly the same, the Alpine vegetation above the tree line on the higher mountain summits both east and west. (4) The Grasslands occupying the interior of the continent between the deciduous forests and the Rocky Mountains. (5) The Desert occupying the Great Basin and the arid plains and plateaus of the southwestern United States. (6) Mixed Coniferous and Deciduous Forests occupying the southeastern coastal plain from New Jersey to Florida and west along the gulf coast into Texas. (7) Chaparral, a shrubby growth of evergreen plants occupying the foothills of the Sierra Nevada and Coast Range Mountains of California. Each of these large regions is, of course, susceptible of analysis into smaller areas each of which has its own characteristics. For example, the southern extension of the Coniferous Forest has a fringe covered with a dense growth of evergreen broad-leaved plants producing a vegetation type called Chaparral. The central Grassland also naturally falls into two parts on the basis of rainfall. The eastern part of it is far moister and

458'

A
re
n
ti
th
o
C
w
(
c
o
a
fo
M
M
ly
(
o
ti
b
in
an
th
th
an
pl
co
of
N
E
bl
its
te
a
in
G
of

covered with luxuriant prairie in its natural state, whereas the so-called Great Plains in the western part have a much sparser covering of bunch grass.

Deciduous Forest (Fig. 125). — In this region the climate is temperate, with precipitation well distributed through the year. The winters are cold, snow often lies on the ground for considerable periods, and the ground

Fig. 124. — Forest of White Pine, one of the most characteristic trees of the Northwestern Coniferous forest. The lower branches have been killed by the dense shade cast by the upper foliage.

freezes to a considerable depth. All of these climatic conditions make it a region where growth is greatly favored in summer and at a very low ebb in winter. In general the soil is fertile and suited to the growth of the highest type of vegetation. The forests consist of beech, maple, oak, tulip tree, and many others characterized by having broad thin leaves able to do a maximum amount of photosynthesis during the warm moist summers but unfit to endure the winter (Fig. 126). The term deciduous refers to the fact that they shed their leaves on the approach of winter and thus present only bare branches during the inclement season. It is not to be understood that this region is exclusively occupied by deciduous forest trees. In the spring before the new crop of leaves comes

Fig. 125. — Deciduous Forest. Rich shady woods in a ravine near the Illinois River, central Illinois. Red oak is the principal forest tree, although there are numerous other kinds. (Vestal.)

out the forests are bright with spring flowers. Later in the season the leaves cast so much shade that the forest floor is either free from small plants or can support those only with broad thin leaves able to work with very weak light. This illustrates a principle of common application in that the chief vegetation type is the most powerful factor in determining the nature of the plants associated with it. Moreover the nature of the plant cover also exerts a powerful influence on the type of animals in-

Fig. 126. — The Highest Type of Deciduous Forest. A beech-maple woods in Michigan, with hemlock also. This forest develops into a type in which the beech, by reason of its dense shade, becomes the only tree. (Vestal.)

habiting the same region. A forest of beeches and oaks affords both abundant food and suitable homes for such types of animals as squirrels, which could survive with difficulty in a prairie, or desert.

The Western Coniferous Forest (Fig. 127) occupies a region that is on the whole cooler in summer and in some parts warmer in winter than that of the Deciduous Forest. Moreover, the rains are more copious in winter

(Fig. 128) and in some parts of it almost lacking in summer (Figs. 129–130). Obviously, trees which shed their leaves in winter would be ill-suited to this region. The coniferous trees, on the contrary, because they retain their leaves for longer than a year are evergreen and so constituted as to take advantage of opportunity to make food at any season. Trees with broad leaves,

Fig. 127. — The Coniferous Rain-Forest of the Pacific Northwest, in Washington. The heavy rainfall supports a dense forest of large trees. The smaller trunks in the foreground are those of the giant alder. The large striped trunk at the right is giant cedar. There are also Douglas fir, one or two true firs, and the Sitka spruce. (Vestal.)

shed in winter or during the dry hot summer, are found in this region but only along streams where the water supply in the soil is sufficient to replace that lost from the leaves. Away from the streams the moisture content of the soil is so much less that, in general, deciduous trees are unable to secure a supply adequate to their minimum needs in summer. The needle-leaved conifers, however, do not lose water so rapidly and find such habitats suitable. Another factor of some consequence in this connection is the poorer soil of this region over the particular areas where forests are found. Similar poor areas within the general limits of the Deciduous Forest region are also often occupied by local conif-

Fig. 128. — The Coast Redwood (*Sequoia sempervirens*) in central California. These trees grow to a diameter nearly equalling the giant sequoia of the Sierra Nevada, and to a somewhat greater height. They are rigidly confined to the zone of sea-fogs near the coast, and are best developed on the seaward slope of the outer line of coast ranges. (Crandall.)

erous forests, as for example, the Pine Barrens of New Jersey.

The Grasslands are covered with a vegetation of herbs and grasses, having trees only in specially favored localities. In the summer they often present a magnificent panorama of flowers (Figs. 131, 132), which varies from month to month with the advance of the season. The soil of parts of this region is among the most fertile to

Fig. 129. — A View in the Southern Rocky Mountains in Colorado, with western yellow pine in middle ground, Douglas fir on the two ridges, and a true fir between the ridges. Scrub oak occurs in right foreground and on distant slope at left. Forests of this type are characteristic of the higher, drier, and colder parts of the Western Coniferous Forest. (Vestal.)

Fig. 130. — White Pine in the Higher Part of the Sierra Nevada, Central California. This is near the upper limits of trees.

be found anywhere and capable of supporting a varied and highly successful agriculture. The summers are warm and often hot but, generally speaking, have less rain than in the forested regions. The winters are cold and the ground deeply frozen or snow-covered. It is also a region of strong winds. It is still, however, a matter of controversy as to precisely what are the controlling factors in determining this vegetation type. Trees can and do grow in this region when planted and cared for,

Fig. 131. — An Extensive View of Prairie, with the blazing star, a composite, in bloom. (F. C. Gates.)

but they do not naturally invade it with success. Along streams there is usually a fringe of trees or even a strip of forest. These are almost always deciduous and not coniferous forest. Under cultivation it has proved especially fitted for the production of wheat and corn and to a lesser extent of other cereals and herbaceous crops, particularly fiber plants. And moreover, just as the food supply and plant cover in nature once supported the immense herds of bison and other grazing animals of this region, so now the crops of corn, grain, and pasturage, make it a great center for the production of hogs, cattle, and dairy produce.

THE DESERT is largely characterized by a hot dry climate. This term is used to cover a very wide range of climatic and soil conditions, as well as for an equally wide range of vegetation. In all regions, however, the rainfall is scanty and therefore inadequate for the needs of the vegetation types so far discussed. In some parts the annual rainfall is not more than an inch or two

FIG. 132. — Prairie Vegetation of the Eastern Part of the Grassland Region. The broad-leaved plant is rosin-weed. The daisy-like plant is the purple cone-flower. Numerous grasses and other herbaceous plants are also present. (Vestal.)

and comes with great irregularity. Much of the soil is stony, thin, or sandy, although here and there are valleys with soil of great fertility needing only water to make a veritable plant paradise. Many such valleys are now irrigated and yield immense crops of cotton, melons, and a great variety of other produce. The natural vegetation varies from scrubby bushes (Fig. 133) on the Sage Brush plains to the scattered cacti (Fig. 134) of the more arid parts. The cactus exhibits a curious adaptation to the soil in which it grows. Because the rains are infrequent the only water available to the plant is to be found near

FIG. 133. — The Utah Desert (eastern Utah) with scattered desert shrubs in alkaline soil in the flood-plain which forms the foreground. The cliffs are practically devoid of plant life. (Vestal.)

FIG. 134. — Succulent Vegetation of the southern Arizona desert. The giant cactus or Sahuaro. (Shreve.)

the surface immediately after rain. As we have seen in the chapter on Tropisms and Correlations in Plants

(Chap. XII), most roots are sensitive to moisture, gravity, and dissolved salts in the soil, and respond to them in a way to secure a favorable position. A cactus root, however, must already be in position if it is to take advantage of the occasional showers. This is brought about through the response of the root to heat. Responding positively to a warm temperature keeps the roots in the upper and warmer layers of soil where the water will be when it does come. Certain other desert

Fig. 135. — Chaparral Vegetation on the inland side of one of the California Coast Ranges. The plants are mostly evergreen shrubs of manzanita, small oaks, and Ceanothus. Where local conditions are favorable tree growth is well developed. Live oak, California bay, and a few other broad-leaved evergreen trees, as well as a few deciduous trees, make up the tree growth in the picture. Dryer hills in Southern California have only the shrubs, and these are smaller and separated. (Crandall.)

plants grow where there is subterranean water to be had by sending enormously long roots down to it.

Chaparral (Fig. 135) is a name of a vegetation type exhibited in great perfection in California and in parts of the Mediterranean region of Europe. It occurs in regions with dry and sometimes hot summers but with comparatively mild wet winters. The plants themselves are shrubs or small trees mostly equipped with thick shiny leaves able to endure the heat and drought of summer without losing so much water from the leaves as to do them serious injury. They usually put out fresh green leaves during the wet season and so are able to make the best use of them during the time when conditions

FIG. 136. — Aquatic Vegetation in a protected bay of a Michigan lake. Rushes in shallow water in foreground. The floating leaves farther out are those of water-lilies and the water smartweed. There are also seven or eight kinds of submersed aquatic plants, in places where the depth is from two to ten feet. The forest on the farther shore consists of beech, hard maple, hemlock, elm, and paper birch. (H. A. Gleason.)

for photosynthesis are most favorable. As the season advances and the soil and air become dryer and dryer, the leaves deposit over their surfaces a shiny layer of waterproofing cutin. They can still do some photosynthesis, and yet have restricted water loss to a safe rate. This vegetation type merges into true forest in moister situations on north hillsides and into grassland on the dryer sides.

Swamps serve very well to illustrate on a small scale the effect of water on vegetation types. If one finds a pond with deep water in the middle and gradually shelving toward the shore with a bottom and banks composed of deep rich soil, he will find that the vegetation is distributed in more or less regular concentric zones (Fig. 136). The open water in the middle, if deep enough, can support only floating plants. Outside this there will probably be a zone of water lilies with their roots an-

Fig. 137. — A Typical Submersed Aquatic Flowering Plant, Ceratophyllum. The very narrow divisions of the leaves are especially characteristic of the aquatic habit. Both leaves and stems contain large air spaces.

chored in the bottom of the pond but with their leaves extending up to the top and there floating more or less freely (Fig. 137). In this zone may also be found other plants with long stems and submerged leaves. All these plants have weak bodies and depend largely on the water to support their upper free parts. Nearer shore is likely to be a zone of tall rush-like plants such as bulrushes, tule, cat-tails, etc. They extend to just about the line where soil appears above the water. Then comes a zone of swamp plants of various sorts such as sedges. This zone merges more or less gradually, as the ground rises and becomes drier, with the surrounding vegetation type, forest (Fig. 138) or meadow, for example. Within each zone there are usually more than one species of plant; and moreover, the species found in each vary according to the particular region in which the pond occurs.

SUMMARY. — Species of plants and animals have come into existence through evolution in all parts of the habitable earth. They have in the course of time spread

FIG. 138. — Bog Vegetation of the Northeastern Coniferous forest region. Surrounding open water is a zone of an evergreen shrub of the heath family; in the background is the eastern larch or tamarack. (H. A. Gleason.)

away from the places of origin in whatever directions they encountered suitable conditions. They have not reached all the places suitable to them because they have usually encountered barriers of one sort or other that check or stop them altogether. What is a barrier to one organism may be the means of travel to another or at least present little difficulty in being passed. Because all organisms do not find the same conditions equally suitable for their habitation, there arises a segregation of those with like adaptabilities in the same or similar regions. Since those plants adapted to similar habitats generally possess similar appearance, there rises the phenomenon of *vegetation types* as distinct from the geographical distribution of species or *flora*. The latter is more intimately related to the possibilities of migration or spreading, whereas the former depends more largely on the possibilities of adaptation. To put it another way, the one is largely determined by what species can get to a place, and the other by the arrivals which can actually compete successfully and so maintain themselves.

CHAPTER XXXVIII

DISTRIBUTION OF LAND ANIMALS

Extent of the Subject. — The geographical distribution of animals deals with the distribution of species over the earth's surface, the conditions which govern their existence in the region they occupy, and the agencies favoring or hindering their dispersal into other areas. It thus treats of distribution in space at the present time and appears to be distinct from paleontology, or the distribution of species in past times based on the study of fossil remains entombed in the rocks, and from geology dealing with the physical conditions and changes of the earth. In reality, these three sciences are closely linked, and many puzzling features of geographical distribution have been explained only after the migrations of extinct species and the relations of ancient land masses were understood. The family of camels, for example, is represented only in South America, Asia, and Northern Africa. From their fossil remains it is known that in ancient times they inhabited North America, that some individuals migrated to South America, while others crossed a land bridge into Asia, and thus with the extinction of the North American population their present distribution is made clear. Moreover, every other species of living animal comes from a long line of ancestors whose migrations in bygone times have determined its position on the earth to-day.

Means of Dispersal. — The migrations of animals are the results of agencies of varied character. The highest terrestrial species, such as horses, camels, elephants, bears, deer, and many more or less closely related forms, depend upon their own powers of locomotion. Insects, birds, and bats are actively flying creatures, and as a result of their efforts may be distributed over wide areas. Among the last named animals and a large number of lower forms, wind frequently plays an important part as a distributing agency. There are numerous records of birds and insects which have been captured aboard ship far out at sea, and it is altogether probable that many of the oceanic islands have been populated by wind-swept stragglers. An even greater number of animals, of widely different relationships, may be carried by ice or floating vegetation. Mice, rats, squirrels, insects, snails, worms, and a host of other species are known in many instances to have been transported by such means for long distances. Finally, there are large numbers of animals which have been widely scattered over the earth through the agency of man. In some instances, where a species has been introduced, to combat an insect pest for example, the results are highly satisfactory, but the rabbit in Australia and the English sparrow in America, or the Norway rat of the world at large and the cockroach in America are introduced species which have multiplied abundantly and become annoying, to say the least.

Tangible Barriers. — It is a well known fact that each species of animal occupies a definite area upon the earth's surface, and it is equally true, as pointed out, that many types when transported into a new territory thrive even better than in their original homes. Since every species broadens its range as far as it can, it is evident that barriers tend to check its movements. These barriers are very evident or tangible in some cases; in others they are intangible, or not so apparent. Mountain ranges, especially those whose summits are covered with snow, are important tangible barriers which hinder the wandering of many of the smaller animals. Deserts are likewise obstacles to the progress of delicate organisms or to those requiring considerable amounts of moisture. Large bodies of water set an effectual limit to the scattering of large terrestrial animals, and rivers, streams, and lakes are as impassable in the case of many smaller species. On the other hand, it is equally manifest that the movements of aquatic forms are checked by intervening tracts of land. Prairies and meadows, forests and brushy country, rocky outcrops, differences in the character of the soil and many other local features act as additional barriers to the wide dispersal of many species.

Intangible Barriers. — Adult animals may migrate or be transported into a new territory that suits their individual needs admirably, and yet be unable to exist for any length of time on account of the lack of suitable shelter from the attacks of enemies. Birds, for example, may be unable to rear their offspring owing to the absence of trees in which to build safe homes. Climatic conditions may also render a locality unsuitable as a habitation for numerous animals, yet even here a few are often able to exist if other conditions are favorable. The camel delights in a warm country, yet it exists in Mongolia, and tigers, certain apes, and the elephant, which we may think of as only tropical animals, are not infrequently found in regions where the winters are comparatively severe. But all of these intangible barriers — enemies, lack of shelter or refuges, and climatic conditions — are of less importance than food. An animal or a species, without food but in an otherwise favorable situation, becomes extinct; with sufficient nourishment each may persist, even though conditions are severe.

Laws and Results of Distribution. — It now follows from the facts noted in the preceding paragraph that (*a*) every species of animal is found in every quarter of the globe unless it has been hindered by some kind of barrier. If it is able to penetrate this barrier (*b*) it persists where the conditions of life are favorable. If it does continue and the surrounding conditions remain practically the same for a long period of time, the descendants closely resemble the original, pioneer ancestors. But if the conditions gradually change, and this is generally the case, (*c*) the successful species gradually changes also and so continues to find the territory favorable.

It has frequently happened in former geological ages that a few individuals of a species have been born which differed somewhat from their parents, and this difference has been sufficient to enable them to penetrate to some extent into new regions. Still further modified descendants in succeeding generations have correspondingly extended the range of the species, and by this gradual process wide areas have been occupied. Small groups of individuals within these large areas may become isolated from their fellows, and amid slightly differing surroundings they may undergo gradual changes which ultimately transform them into a distinct type. In this way one widely distributed species becomes broken up into a number of new ones, each of which is separated by some sort of barrier from the others.

Animals of Oceanic Islands. — The laws of geographical distribution are admirably illustrated by the history of many isolated volcanic islands that most certainly have never been united with a continent, and accordingly have been colonized by individuals carried by wind or water from some distant land mass. The Galapagos Group, situated more than five hundred miles west of Peru, is inhabited by animals, some of which are identical with those of the mainland, while others exhibit various degrees of modification. The land tortoises, lizards and snakes are all distinct species, and the same is true of more than half of the insects and snails. Where related forms are known these are invariably South American. The same general facts appear in the case of the Azores, though here the animals resemble those of Europe nine hundred miles distant. The species of the Bermudas are akin to those of America, while the Hawaiian Group in this regard bears an unmistakable resemblance to Japan.

In all of these instances, and in others that might be mentioned, the evidence unmistakably leads to the conclusion that while some immigrants from the mainland may reach a new territory and perish owing to unfavorable conditions, others, being better fitted, have persisted. The new surroundings — soil, climate, vegetation, and enemies — are different from those of the home land, however, and in these isolated districts the individuals of the species gradually undergo modifications as the centuries pass until they differ markedly from the original ancestors.

Zoölogical Realms. — The continents and islands of the earth, from the frozen north and south to the burning tropics, are to-day inhabited by more than a million different species of animals, which in past times have crossed barriers and become adapted to their surroundings. And in much the same way that the earth is divided into large physically different regions, so the animals have roughly been included in five great realms on the basis of their distribution. These are the Holarctic, Neotropical or South American, Ethiopian, Oriental, and Australian realms. The conditions peculiar to each of these large divisions serve as a barrier to the greater number of species of an adjacent realm, although there are a few (except in the case of the Australian realm) that intermingle along the border line and render the boundary somewhat vague and indistinct.

Holarctic Realm. — The Holarctic realm comprises approximately all of the land surface north of the Tropic of Cancer, and accordingly includes nearly the whole of North America, all of Europe, and Asia north of the Himalayas. No other region of the globe is so highly diversified with tracts of perpetual ice, immense treeless districts, deserts, swamps, and an almost endless variety of soil conditions.

In ancient times a land bridge united Alaska and Asia, and apparently there was a similar connection with Europe by way of Greenland, so that animals in both hemispheres were free to mingle. This accounts for the fact that both the Old and the New World are the home of wildcats, foxes, weasels, bears, elk, deer, wild oxen, beavers, squirrels, and hares. Among the animals characteristic of this realm in the Western Hemisphere are the musk ox, prong-horn, antelope, raccoon, musk rat, and prairie dog, while the Eastern Hemisphere is the home of the two-humped camel, musk deer, chamois, and yak. The differences between these two sub-realms are, however, no greater than those separating Alaska and California; and they are far less than those distinguishing the Holarctic from any other realm.

The Neotropical Realm. — The Neotropical or South American realm includes South America, Central America, and the West Indies. Like the Holarctic, it is an enormous tract, characterized by mountain chains, vast expanses of grassy plains, and fully half of its area is covered by dense and luxuriant forests. No other realm is so rich in species, and over half of the known families of animals are represented within its borders. Among the characteristic mammals are the distinct group of broad-nosed monkeys, the vampire bats, the guinea-pig and several related species, sloths, armadillos, the tapir, and several wild dogs and tiger cats. The birds are represented by over four hundred species of humming birds, many parrots, toucans, tanagers, the ostrich-like rheas, and numerous other species. In Mexico the boundaries of this realm are not perfectly distinct, since several Holarctic species, such as the hare, the ground squirrel, certain mice, the puma, deer, and skunk, are distributed as far south as the Isthmus of Panama and even farther. On the other hand, certain species of monkeys, the jaguar, armadillo, tapir, peccary (a pig-like creature), and several other animals extend from the south into Mexico or beyond. Broadly speaking, however, the South American realm is clearly defined and is one of the most interesting in the world.

Ethiopian Realm. — This realm includes the whole of Africa south of the Sahara Desert, Arabia south of the Tropic of Cancer, Madagascar and several adjacent islands. It thus corresponds in position to the South American realm, and while many of the fishes and land shells of the two districts are closely related, the mammals are very distinct. The apes and monkeys are of the narrow-nosed type, and in addition to the man-like chimpanzee and gorilla there are several species of baboons and lemurs. Open or forested country is the home of the African elephant, giraffe, zebras, and other wild asses, and many antelopes, while in regions where marshy tracts prevail the rhinoceros and hippopotamus are characteristic animals. The lion, leopard, and ostrich are likewise inhabitants of this realm though they extend beyond its limits through Arabia. The Sahara Desert acts as an almost perfect barrier, so that the African animals along the Mediterranean Sea are very distinct from those elsewhere on the continent.

The Oriental Realm embraces that part of Asia south of the Himalaya Mountains, Java, Borneo, the Philippines, and many other islands between India and Australia. The animals of this region are clearly related to those of Africa, yet there are many characteristic species that are found in no other region. The man-like apes are represented by the orang-utan and the gibbons. There are also the Indian elephant, the tiger, several species of bears and deer, the peacocks, and the jungle fowl from which our domesticated fowl has descended. On the other hand there are very few species of horses, asses, and zebras, no rhinoceros, and scarcely any antelopes.

The Australian Realm comprises Australia, Tasmania, New Guinea, and several of the adjacent islands of smaller size. The greater part of this territory is arid, some districts being a desert with but scanty vegetation. Accordingly, it is not favorable for a rich and varied development of species, but the ones that do exist are more distinctive than those of any other realm. Deep water acts as a barrier, and for millions of years its animals have evolved without entering into competition with more powerful and more specialized types. A very few hogs, the dingo or native dog, and several species of bats very nearly complete the list of higher mammals. On the other hand, there are many unique species of primitive mammals such as the kangaroos, wombats, and numerous other related species that likewise are akin to the opossum. This realm is also the home of the remarkable egg-laying duck-bill and spiny anteater, as well as of numerous species of birds, such as the brush turkey, parrots and pigeons, that occur in no other realm.

Realm Subdivisions. — In much the same manner that the United States is composed of states, counties, and townships, each of the zoölogical realms is subdivided into lesser districts, each with a characteristic assemblage of animal forms. The Holarctic of North America, for example, is divided into not less than eight geographical regions (see map facing page 458), with fairly well defined and characteristic conditions dependent upon the nature of the climate, soil, and vegetation. Each region also possesses a distinctive group of animal species which are specially adapted for feeding upon a particular kind of vegetation, for example, or for living amid surroundings of a very definite character, although a smaller number of less specialized types may roam from one region to the next.

As a rule, the distribution of a given species of animal is not as extensive as the region it occupies. It may be confined, for example, to a forested area, a desert, a marsh, or a definite type of soil. No two species occupy exactly the same range, however, so the controlling factors obviously differ with the species concerned. Speakly broadly, these factors are suitable and available food, shelter from enemies, and favorable climatic conditions.

Migrations of Animals. — In the discussion of the distribution of animals it has been assumed that each species is confined to a fairly definite area; but, while in general this is true, shad and smelt migrate from the sea to lay their eggs in fresh water; certain species of eels leave fresh water to deposit their eggs in the sea; many other species of fishes migrate from deep water into shallow water at the breeding season. The reindeer, musk-ox, bison, certain species of hares, rats, and many other animals may journey widely from one region to another chiefly in search of food.

The birds, however, afford the most striking examples of extended migrations whose impelling cause remains an unsettled question. Practically all the insect-eating species of temperate and cold regions spend their winters in warmer climates, the shore birds, such as the sandpipers, plovers and phalaropes, traveling at least one thousand miles. The golden plover, nesting in the neighborhood of the Arctic Circle in North America, flies southward to Nova Scotia, and thence by a direct flight of twenty-five hundred miles reaches South America where it winters in Argentina. It is a further remarkable fact that in completing its round trip of seven thousand miles it returns north by way of Texas. A few Alaskan shore birds winter in the Hawaiian Islands two thousand miles distant; a Siberian swallow winters in Mexico or Burmah; the European swallow migrates to Africa; and there are hosts of other species whose journeyings are as remarkable and as difficult to comprehend.

CHAPTER XXXIX

DISTRIBUTION OF LIFE IN THE OCEAN

PHYSICAL CHARACTERS. — Two-thirds of the surface of the earth is covered by oceans. Throughout four-fifths of their extent the water is over a mile in depth, more than two miles over two-thirds of their area, while one-fifteenth is over three miles deep. The greatest depth ever sounded, 32,089 feet, is located east of the Philippine Islands.

Sea water, as we know, is salty, containing about 27 grams of common salt to the liter. It also contains, in much smaller quantities, salts of magnesium, calcium, potassium and traces of a considerable number of other substances, some of which are of prime importance in the growth of many animals and plants. Oxygen, nitrogen and carbon dioxide gases are also dissolved in it.

In the neighborhood of large land masses the sea bottom usually slopes rather gradually to a point where the water becomes approximately 600 feet in depth. Here this continental plateau, as it is termed, unites with the continental slope that falls away with comparative abruptness into the abyss. In these deeper oceanic regions the configuration of the bottom varies widely. It may present the appearance of a gently undulating plain, hundreds or thousands of square miles in extent, with here and there a tremendous saucer-like depression known as a deep. Or there may be rolling hills with wide intervening valleys, or narrow gorges between mountains whose lofty summits, rising to the surface, form islands such as those of the Hawaiian Group.

Temperature of the Sea. — The heating effect of the sun on ocean water is not perceptible below a depth of about one hundred feet, and obviously is most marked in tropical regions. Owing to the rotation of the earth and the restraining influence of the continental land masses this heated water is made to travel in great circles in both the northern and southern hemispheres. In the north Atlantic this current is named the Gulf Stream, while the corresponding one in the north Pacific is the Japan Current. The deeper waters of the ocean, since these are unaffected by the sun, probably remain at about the same temperature from year to year; and, it may be added, the temperature in deep water is close to freezing at the bottom and gradually rises as the surface is approached.

Effect of Ocean Currents. — It may perhaps be unnecessary to call attention to the fact that these oceanic currents are of the highest importance in the distribution of life in the sea. Not only do they carry the floating animals and plants for thousands of miles and thus establish many species in homes they would otherwise never occupy, but also, to a large extent, they govern the migration of fishes and whales that prey upon this food and are thus of great importance to the fishing industry.

Pressure. — The air presses upon our bodies and other objects with a weight of about 15 pounds to the square inch at sea level. In the sea the pressure is doubled at a depth of 35 feet, and continues to increase at practically the same rate to the greatest depths. Accordingly the body of a man, if sunk to the bottom of the deep off the Philippines, would support the enormous weight of approximately 31,000,000 lbs. Since animals are known to live at a depth of at least three miles the question naturally suggested is, how is this possible when the pressure amounts to considerably more than 6,000 lbs. per square inch. It is chiefly because the body is largely composed of water, and water is practically incompressible. A sponge, living along the coast, if sunk to a great depth would show little diminution in size owing to its watery consistency, its tissues accordingly would suffer no collapse, and if food were available it probably would live. At all events, several species of widely related animals dredged from depths ranging from one to two miles have been kept alive for days and even weeks.

On the other hand it frequently happens that comparatively large amounts of gases are dissolved in the tissues of deep sea animals. When such individuals are captured in nets and drawn to the surface this gas expands with the reduced pressure, and as it escapes from the tissues literally tears the body into shreds.

Light. — White light is the combined product of vibrations or waves in the ether of different lengths. Those of relatively great length produce the sensation of red when they fall upon the retina of the eye, and shorter vibrations produce orange, still shorter yellow, and so through green, blue, to violet with the shortest length of all. When the sun's rays enter the ocean the depth of their penetration depends upon their wave length. No red reaches a greater depth than 300 feet. No green passes the 1500 foot level and at the depth of a mile there is no sunlight whatever. Four-fifths of the ocean floor, therefore, is in absolute darkness so far as the sun is concerned. Nevertheless, there is a strong probability that a feeble light may be present, as we shall see presently.

These physical features, salinity, temperature, pressure and light, are very evidently not peculiar to the ocean, but play an important part in the distribution of land and freshwater animals as well. Their relative importance, however, differs in the two cases. A few other distribution factors will be noted in some of the succeeding paragraphs.

Distribution of Shore Plants. — Practically all of the attached seaweeds or marine algæ grow at depths less than 150 feet, and accordingly are coastal forms. The green species thrive best in yellow light, and as this is most plentiful in shallow water they fringe the immediate shore line. Brown and red species flourish in blue light, and therefore are in deeper water. While light thus controls the distribution of these plants in a given locality, temperature is a prime factor in determining their distribution over wider areas. Cold water species extend well to the southward but stop short of temperate waters whose characteristic forms are in turn replaced by warm water species in the tropics.

Sea weeds are not only commercially valuable for the potash and iodine they contain, but they are extensively eaten by many species of crabs, snails, sea urchins, etc., whose distribution is thus determined. Of greater importance is the fact that the decomposition of their bodies, together with that of organic matter swept from the soil, supplies the ocean with nitrogen and nitrogenous compounds upon which the growth of a vast number of other plants as well as animals depends.

Floating Plants. — Since the discovery of the microscope it has been found that the superficial waters of the ocean support a wealth of plant life that in point of numbers of individuals and aggregate bulk far outstrips the shore forms. These floating species agree in being unicellular and in containing chlorophyll and other pigments that enable them to utilize the energy of sunlight after the fashion of land plants. Hence, directly or indirectly, all of the animal life in the sea depends upon marine plants for their primary food supply.

Among the common floating plants are the diatoms (Fig. 139) that are at once distinguished by being enclosed with a shell of flint, exquisitely sculptured and with shapes ranging from discs and ellipses to rectangles, which may form threads where many are attached together. These plants are extraordinarily abundant in cold water, but in the tropics are largely replaced by other types among which are many that possess skeletons of lime. In both regions there are additional species, known as peridineans, without mineral skeletons but important as an article in the diet of many fishes and interesting in that several species are brilliantly phosphorescent.

PLANKTON. — Although floating plants normally occur at depths less than 200 feet, their bodies are heavier than water, and at all times great numbers are gradually

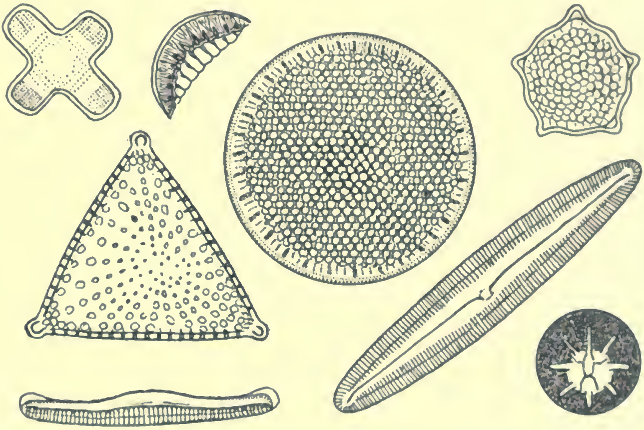


FIG. 139. — Diatoms, microscopic plants with flinty skeletons.

settling to the bottom. Hence it is not surprising to find that each of the many different species of animals that directly or indirectly live on this food supply is fitted to live at fairly definite depths anywhere from the surface to the ocean floor. All of these swimming and floating organisms, plant and animal, are collectively known as *plankton*. In the plankton the plants outnumber the animals, but to what extent is not exactly known. In the Baltic sea it has been estimated that the plants make up fifty-six per cent and the animals forty-four per cent of the total amount. It has further been calculated that the volume of plants doubles in a little over three days, the excess serving as food for animals or settling to the bottom. Whether these estimates are of general application is unknown. It is certain, however, that the number of individuals per unit volume of sea water varies according to seasonal and other conditions.

Unicellular Organisms and Bottom Deposits. — Several thousand species of one-celled animals occur in the plankton of all the oceans of the globe. The larger number of these are related to the amœba, but differ in the presence of a supporting skeleton (Fig. 140). Those

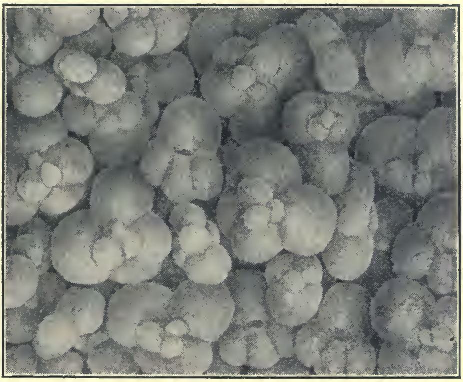


Fig. 140. — Microscopic One-Celled Marine Animals (Globirgerina) with chambered cells, largely responsible for chalk deposits.

with flinty skeletons, the radiolarians, comprise at least 5,000 species, living for the most part in deep tropical waters of the Pacific ocean. Others with skeletons of lime (the foraminifera) are likewise tropical forms of wider distribution. The numbers of both of these groups become incredibly great under favorable conditions, as many as 100,000 individuals occurring in every liter of water at or near the surface throughout thousands of square miles.

The bodies of these animals are heavier than water, and while very many are buoyed up by oil drops and other flotation devices, others gradually sink and finally settle to the sea bottom where they form extensive deposits. It has been calculated that in certain districts this sediment increases one inch every ten years, and the number of organisms included is beyond comprehension. In England and France, for example, there are great chalk deposits, approximately 600 feet in thickness, and in this country similar accumulations of somewhat lesser thickness extend through several states. This material, in large measure, consists of the skeletons of unicellular organisms that number from 1,000,000 to 4,000,000 to the cubic inch.

Some Pelagic many-celled Animals. — In addition to the free-swimming or floating young of practically every large group of the animal kingdom, there are many adult animals of widely different form and relationship which also swim or float (Fig. 141). The most important of these are the copepods, small shrimp-like organisms bearing a slight resemblance to a miniature mandolin. These creatures, rarely over a fourth of an inch in length, feed on plants, and in many regions are so abundant that they are practically the only food of many commercially valuable fishes as well as of several species of whales. They are also preyed upon by shoals of jelly-fishes, various worms, several species of free-swimming snails and numerous other creatures related to the vertebrates. Many other animals, such as the squids, fishes large and small, shrimps and crab-like animals of various forms and sizes usually with crimson colored bodies or as transparent as glass, also live upon copepods or upon other animals that feed upon them. At the same time it should be noted that very many other animals feed upon plants, but none of these is so widely distributed or of such high economic importance as the copepod.

Organs of Flotation. — Protoplasm is somewhat heavier than sea water, and hence will sink. To overcome this tendency many animals are supplied with definite locomotor organs that enable them not only to keep afloat but to move rapidly through the water. The sharks, mackerels and herrings, all active swimmers, fall in this class. Many species of shrimp-like animals, certain snails and worms, and the young or larval stages of many animals are likewise provided with fins, paddles, cilia, etc., that enable them to maintain favorable positions.

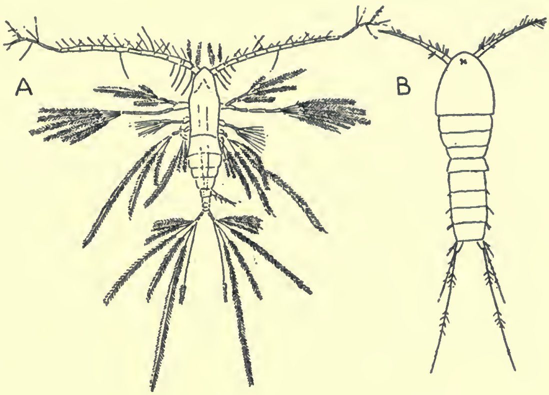


Fig. 141. — Marine Copepods. *A*, cold-water form; *B*, tropical.

In numerous other animals, with or without locomotor organs, the body is made lighter by the presence of oil or fats. In certain fishes air bladders, filled by gulping air at the surface or by secretory activity of the enclosing walls are also of service in keeping the body afloat. Then again there are feather-like appendages, bristles, plates, etc., that, while they do not actually prevent sinking, nevertheless prevent it taking place rapidly in the case of large numbers of mostly small-sized organisms. Just as a lead shot sinks more rapidly than when beaten into a thin sheet, so these structures that greatly increase the surface of the body enable the organism to keep afloat without the excessive use of locomotor organs.

Animals of the Sea Floor. — Our knowledge of the animals living in shallow water is fairly complete, but of life at depths of over a mile much remains to be learned. Such deep-sea animals as are brought to the surface are usually attached to the bottom or are of sluggish habits, and are thus the ones that are readily captured by nets dragged along the bottom. If one were to drag a net from a balloon along the surface of the earth it is obvious that birds, many insects and other active creatures would rarely if ever be captured. Nevertheless a sufficient number of specimens have been secured to enable us to say that every one of the larger groups of animals has its deep-sea representatives. Sponges, corals, worms of widely different appearance, snails, clams, crabs, shrimps, sea urchins, starfishes as well as fishes are present in abundance. Many of these are quite similar to species along shore. Others depart more or less widely in structure from their shallow water relatives. It has also been pointed out that deep-sea animals have a large amount of water in their tissues which enables them to withstand the enormous pressure to which they are subjected. As no green plants live in deep water, the organisms that rain down from the lesser depths serve as food for many deep-sea species that in turn may be preyed upon by the others.

Phosphorescence. — From time immemorial man has known of the phosphorescence of the sea, and for a comparatively long period it has been recognized that it is produced by numerous species of organisms. Nevertheless it is only in very recent times that various deep-sea expeditions have given us a fairly accurate notion of its general features. We now know that many unicellular animals and plants possess this peculiarity of emitting flashes like those of the firefly, and that some of the fishes, a considerable number of free-swimming worms, and certain species of small crab-like animals liberate from the surface of their bodies slime that glows like a torch. In many fishes and several squids eye-like phosphorescent organs are imbedded in the skin in various parts of the body and the phosphorescent or glowing material is backed up by a reflector and the light is made to shine through a lens after the fashion of a bull's eye lantern. In certain localities it is known that the organic matter on the ocean floor contains great numbers of bacteria, or small unicellular plants, that are also luminous. Hence it is believed by many students of the subject that the ocean depths, though devoid of sunlight, may nevertheless be feebly illuminated by phosphorescent light. This would perhaps account for the great owl-like eyes of several deep-sea animals, although it is to be noted that many species are totally blind.

The use of these phosphorescent organs is somewhat problematical. In some species they are almost certainly used to attract organisms that serve as food. In other cases they may serve to drive off enemies or be used as signals to attract the opposite sex.

Summary. — Plant life in the ocean comprises a scanty fringe of algæ attached in the shallows along shore, and widely distributed and exceedingly abundant unicellular species floating near the surface. Vast numbers of individuals of this last class are continually settling to the bottom, and at all depths are fed upon by various species of animals. This floating population, or plankton, thus extends from the surface to the bottom, though the larger proportion is confined to waters less than a mile in depth. On the ocean floor other animals crawl over or through the mud or are anchored in it.

Deep-sea exploration, as a science, is less than fifty years old and much regarding the distribution of marine organisms remains to be learned before we can determine the factors controlling it. In many instances the effects of light and temperature, in their relation to distribution appear to be fairly clear, but the effects of salinity and pressure are too imperfectly understood to allow of wide generalizations.

SECTION 12
MAN

CHAPTER XL

THE EVOLUTION OF MAN

Time Required for Man's Evolution. — At the present time there is but one species of man, comprising several distinct races which differ from each other as regards complexion, color of hair and eyes, stature, shape of head, and many other structural as well as mental peculiarities. If all of these widely differing races are the result of evolution from a single ancestral type — and there is no good reason for believing the contrary — then the length of time required for these changes must have been enormous.

It is also reasonably certain that the great differences existing among modern races with regard to their religious and social customs, their laws and the various phases of communal life are the result of gradual changes extending over a long period of years. The world-wide distribution of man as well as the great size of his brain, when compared with the highest apes, also indicates his great antiquity. On the basis of these facts it is assumed by some investigators that man, or rather an ape-like creature with an admixture of human characters, first appeared on the earth 2,000,000 years ago. Other students of the subject are convinced that 5,000,000 years is nearer the truth.

Place of Origin. — Granted that man first appeared millions of years ago, it now remains to determine his place of origin. For several reasons Asia appears to fulfil the requirements most satisfactorily. In the first place there are very strong indications that human civilization has endured for a much longer period on that continent than elsewhere. Secondly, it is the home of many of the oldest domesticated animals, the common fowl, camel, goats, cattle, and some of the breeds of the horse, dog, and cat, being of Asiatic origin. This region also is adjacent to Java, the home of the most ancient known type of man-like animal. Furthermore this continent was the center of many human migrations which are known to have radiated into other regions. Also certain features of man's present distribution are best explained on this assumption. Finally, the ancient climatic conditions of central Asia were such as to favor the rapid evolution of the human ancestor.

Earlier History of the Human Race. — The earlier stages of human evolution are unknown. Nevertheless there are many features associated with the geological changes of Asia, a few million years ago, which when studied in connection with the structure of modern man-like apes and the fossil remains of early man, enable the skilled investigator to make a shrewd guess as to what actually occurred. In the first place the continent was largely covered with tropical forests inhabited, it is believed, by animals resembling, in a broad way, the modern lemur, a monkey-like species. With the elevation of the land and the resultant lowered temperature and increased dryness, these forests in large measure disappeared. Some of the lemur ancestors persisted in living in the trees, and their modern descendants are the gibbons, orang-utan, chimpanzee and gorilla. Others in the struggle for existence were compelled to abandon the trees and make their home in open country. The hind limbs became adapted for walking on the ground. The hands were released from climbing and served more particularly for gathering food and grasping weapons. The brain developed in connection with the increased facility of hand movement, and with the power of speech the traits which characterize the human species became established. This history appears highly fanciful perhaps, but that it contains more than a grain of truth will become evident after the examination of certain fossil remains which actually have been discovered (Fig. 142).

THE JAVA MAN-APE. — Between the years 1891 and 1894 the somewhat scattered and incomplete fossil remains of a man-like creature, the Java man-ape (Pithecanthropus), were discovered in Java, and aroused a

FIG. 142 — Reconstruction of Prehistoric Man. Left, Java Man-Ape, *Pithecanthropus erectus;* center, Neanderthal man, and, right, Cro-Magnon man modelled on the restored skulls by Professor J. H. McGregor. The second and third heads are modelled on nearly complete skulls. Of the first head only the upper part of the cranium and two teeth were found. Photographed from originals in American Museum of Natural History, New York.

high degree of interest as well as controversy in both popular and scientific circles. From the position of the geological formation, and the nature of the accompanying fossils, it is believed that the age of this species is not less than 500,000 years. It is also reasonably certain that the form and structure of the body, and its mode of locomotion were essentially human, while the skull and the size and shape of the brain are as characteristic of the higher apes as of man. The size of the brain of the highest apes is six hundred cubic centimeters, or about four hundred cubic centimeters less than in the lowest races of man, while the man-ape holds an intermediate position, with a capacity of somewhere between eight hundred and fifty and nine hundred cubic centimeters. The Java man-ape thus represents a stage in human evolution where the body was held erect and the hands were no longer used for locomotion; where the teeth most closely resembled those in man, and speech appears to have been feebly developed; while the size of the brain indicates a degree of intelligence much above that of the apes though inferior to man (Fig. 142).

Piltdown Man. — The discovery of the remains of a very primitive type of human being in Piltdown, south of London, was announced in 1913. Owing to the fact that several important portions of the skull are missing, its original form and the general appearance of the members of the race are somewhat uncertain. It is evident, however, that the brain case is typically human though unusually thick, while the forehead is high and without the great ridges above the eyes which characterize the Java man-ape and the Neanderthal man. The lower jaw, on the other hand, is most emphatically ape-like. In fact it was at one time assumed by certain critics that the jaw actually is that of an extinct chimpanzee. This objection has been removed by the recent discovery of a second skeleton with the same characteristic features.

So far as scientists are able to judge, the Piltdown man was of low stature, with a tremendous lower jaw and retreating chin, but with a brain capacity at least as great as that of the more primitive races of modern man. The age at which he lived has been variously estimated from 100,000 to 250,000 years ago, and the fact that he understood the use of fire and fashioned weapons of the chase indicates that the human stock was clearly defined at that remote period.

Other Traces of Man's Antiquity. — That the human stem is of great age is also evidenced by the discovery of camp sites in England with traces of fire and an abundance of flint implements. No skeletal remains have been discovered, with the possible exception of a lower jaw, but these other evidences and the geological formation in which they occur clearly point to the fact that England was inhabited by some type of human beings at least 400,000 years ago.

In 1917 the skeleton of another ancient type of man was discovered in a cave in Rhodesia, South Africa. The character of the geological formation gives no clue to its exact age, but in respect to the face especially it is one of the most primitive thus far discovered. The ridges above the eyes resemble those of an adult gorilla, and together with certain features of the nose and mouth must have given this race a most bestial appearance.

Concerning its relationships little can be said until qualified scientists render a verdict. The size of the brain and various other characters suggest that it occupies a position somewhere between the Piltdown and Neanderthal races. And there is at least a remote possibility that it may be closely related to the Heidelberg race which up to the present time is known only from a lower jaw discovered in Germany in 1907.

THE NEANDERTHAL MAN. — This species migrated (seemingly from Asia) into Europe not less than 50,000 years ago, and became widely distributed throughout the western portion of the continent. From numerous skeletons it is evident that the body was short (4 ft. 10 in. to 5 ft. 3 in.), thick-set, with powerful shoulders, short arms, and stubby fingers and thumbs with less freedom of movement than in modern man. There was also a permanent ape-like bend to the knee and a hunch to the shoulders that very evidently resulted in an awkward shuffling gait. The head was relatively enormous, with great overhanging eyebrows, sloping forehead, long upper lip and retreating chin, all of which must have given this race a most repulsive appearance.

The families of this people made their homes in caves or rock shelters where they fashioned slings and spears with heads of stone. With these weapons they probably defended themselves and it appears that they successfully hunted the woolly mammoth and rhinoceros, the cave bears, lions and leopards and several other animals which since have become extinct.

While it is unquestionably true that this race resembled the apes in certain respects, it is a most significant fact that they carefully buried their dead, left food and weapons near them and very evidently believed in immortality. This represents a vast stride forward and places the Neanderthal man almost at the same level as the Australian and Tasmanian native.

Modern Man. — Not long since it was believed that the Java man-ape, the Piltdown man, and the Neanderthal man represented stages in the gradual evolution of modern man. Now it is thought that they are merely offshoots from the main human stem (Fig. 143), and though they throw a flood of light on the problem of man's evolution, they are not to be regarded as his direct ancestors. These primitive types have completely disappeared, whereas the main branch has persisted, and not only has it continued, but as man overcame barriers and became widely distributed throughout the globe, the species became differentiated into the present-day races or sub-species. Some of these peoples, like the Australians and the recently extinct Tasmanian races, never evolved intellectually much beyond the Neanderthal stage; others became much more highly developed.

Cro-Magnon Man. — Among the highly developed races of the modern human species the Cro-Magnon holds a prominent position. Evolved in Asia, to the best of our knowledge, it entered Europe by way of the Mediterranean coast not less than 25,000 years ago, and spread over practically the same territory as that held by the Neanderthal people. In general appearance this later race was unusually tall (6 ft. 1 in. on the average), with broad faces, long and narrow skulls and long limbs capable of great freedom of movement. The brain capacity surpassed that of the average man of to-day.

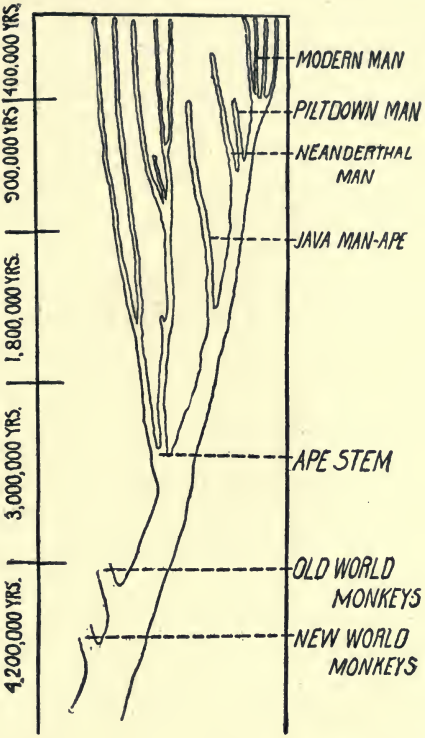


FIG. 143. — Genealogical Tree, illustrating probable origin of man and the apes. Data largely from Keith.

The Cro-Magnon people were skilled in the use of tools, their weapons and ornaments displaying a high degree of workmanship and artistic ability. They also drew remarkably well, as the paintings on the walls of many caves bear witness. Their burial customs indicate a belief in life hereafter. Furthermore, it appears to be fairly well established, that they conquered the Neanderthal people, and there are no indications that in turn they fell before a superior foe. Nevertheless about 10,000 years ago the race gradually declined, leaving no descendants with the possible exception of a few people now living in southern France, Brittany, and possibly in the Pyrenees.

Later European Races. — Near the close of the Cro-Magnon period several races of people migrated from Asia into Europe and became differentiated into the peoples living there to-day. One stream, constituting the so-called Mediterranean type, flowed along the southern coast, extended northward along the Atlantic seaboard and entered the British Isles. Their descendants are represented by many Greeks, Italians, Spaniards, Portuguese, and Englishmen, of short stature, dark complexion, brown eyes and long heads. The Alpine type migrated by way of the Black Sea and occupied Central Europe. They are represented by many Greeks, Turks, Armenians, South Germans, North Italians, many French and Swiss and other inhabitants of that general region. In stature these people are short, thick-set, with dark eyes and skin and round heads. The Nordic type journeyed by way of Russia into Northern Europe. In olden days they were the Persians, Dorians, Thracians, Gauls, Goths, Vandals, Franks, Danes, Angles and Norsemen. Their modern descendants are the Scandinavians, Danes, some Russians, North Germans and many inhabitants of the British Isles. This type is characterized by great stature, fair hair and blue eyes. Thus the Europeans to-day belong to three distinct racial groups, the Mediterranean, the Alpine, and the Nordic.

Man in America. — The first important fact which appears in connection with the study of man in America is that all of the native tribes belong to one type. The Eskimo and Aleut of Alaska, the various Indian tribes of both North and South America, the Aztecs of Mexico, the Mayas of Central America, and the Incas of Peru are all fairly closely related modifications of a single stream or branch of the human race. This conclusion rests not only on physical measurements, but on many similarities relating to tools, weapons, buildings, customs, language and legends.

It appears therefore probable that from time to time adventurous spirits, in search of new hunting grounds, either actually crossed a land bridge uniting Asia with Alaska or travelled in canoes. When the first migration occurred is unknown. The oldest human remains in North America do not appear to be older than recent glacial times, and accordingly may not be over 25,000 years old. In South America there is no conclusive evidence of man earlier than 5,000 years ago.

Sub-Species of Modern Man. — From the picture drawn in the foregoing paragraphs, it is seen that the human race emerged perhaps 2,000,000 years ago; that it gradually evolved in different directions; and that all of the branches with one exception have become extinct. This exception represents the single species of modern man, which long ago also underwent evolutionary changes resulting, according to one view, in the production of four sub-species sometimes termed races.

The first of these is the Australian represented by the chocolate-colored, tall and long-limbed natives of Australia and Hindustan. The second sub-species is the Negroid with flattened nose and woolly hair and black or chocolate-colored skin. The races of Madagascar and Africa south of the Sahara belong to this group. The third or Mongolian sub-species is short, thick-set with oblique eyes, coarse black hair and golden or reddish-brown skin. This type is widely distributed over Asia and Polynesia and likewise includes the native races of the New World. Finally, there remains the Caucasian, with white or slightly dark skin, whose division into the Mediterranean, Alpine and Nordic has been mentioned in a previous paragraph.

Man's Future. — Concerning the future of the human race no one can speak with authority. Owing to his superior mental development, inventive ingenuity and spirit of coöperation, man has been able in past times to overcome barriers and migrate over the earth and live amid surroundings that would have annihilated a less intelligent species. Brute strength and keenness of sense are no longer the important factors they once were in the struggle for existence and probably they are not as highly developed as formerly. A hairy covering for protection is no longer a necessity and it is more sparse than in ancient man. The teeth are smaller and weaker, the size of the toes, with the exception of the first digit, is reduced, and many other organs are more rudimentary. The brain appears to be increasing in size, and skill in the use of the hand may likewise be developing as a result of more perfect adjustments of bones and muscles, but beyond this point no progressive changes are known to be taking place.

Whether man will ultimately become extinct, and a new and perhaps more highly developed species take his place is a much debated and insoluble question. Every "highest species" in the past has been replaced by more competent, better adapted types, and it may very well happen in the ages to come that a weakened constitution, unfavorable mutations, new parasitic diseases or some other agencies will forever remove man from the face of the earth.

CHAPTER XLI

HUMAN INHERITANCE

Human Traits. — Man, like all other animals, is a composite of many characters, which depend on the presence of definite genes or factors in the germ cells which unite as the first step in his being. The manner in which the genes bring about the development of their corresponding characters is, however, in many cases more complicated in man than in a vinegar fly or a plant. It has already been shown in previous chapters (XVI, XVII) that certain characters depend for their expression on the actions of hormones. Obviously in these cases the factors which control the development of the hormone-producing glands will also indirectly control other more obvious characters. It has recently been claimed that a large number of human characters are determined in this indirect fashion, though this remains yet to be proved. On the other hand a great many characters appear to vary more or less continuously through a wide range. Examples of this sort of quantitative variation have already been examined in plants and animals (Chaps. XXXI–XXXIII) and shown to depend on what are commonly called "cumulative factors."

Difficulties of Studying Human Inheritance. — The fact that many characters in man are controlled indirectly through hormone secretion and many more through cumulative factors, makes the study of man's inheritance difficult. These are not, however, the only difficulties, for the chief ones are concerned with the impossibility of conducting controlled experiments on man. In the first place, no one lives long enough to observe much more than his own generation. He may, to be sure, ordinarily observe his own parents and his own children, and more rarely his grandparents and grandchildren. At most he may hope to see a part of four or five generations, commonly totaling fewer than a hundred individuals. Moreover he will have practically no control over the various marriages, and this will render his meager observations of still less value. However, notwithstanding all this, there are some human traits which are sufficiently striking and simple that it has been possible to determine with certainty how they are inherited, and to show that they behave in the same way as similar characters in the animals commonly used in genetic experiments.

Heritable Characters in Man. — In plants and the lower animals, practically all our knowledge of heredity necessarily concerns physical traits. In man, however, we are concerned with mental traits also. It is indeed probable that knowledge of the way in which grades of intelligence may be accurately measured and of the manner in which they are inherited is of greater value than any other sort of knowledge which we may ever hope to attain, for on it depends the sole possibility of any extensive improvement of the human race. Physical traits appear, however, to be simpler. It will be desirable, therefore, to treat briefly in this chapter of some physical traits which are either known to obey the ordinary laws of heredity or may reasonably be supposed to do so on the basis of the incomplete data available, and then to consider the inheritance of mental traits in the next chapter.

Physical Characters. — It is an interesting fact that man possesses very few distinctly marked physical traits. Almost all of them vary through a wide range without any sharp line of separation. Thus there are blondes and brunettes, fat and lean people, straight-haired and curly-haired, tall and short, strong and feeble, and all gradations between. Certain more or less abnormal

A. PIGMENT OF CHOROID COAT AND PIGMENT OF IRIS ABSENT. 1. The ALBINO eye. Red from unobscured blood vessels.

B. PIGMENT OF CHOROID PRESENT.

α. IRIS WITHOUT TRUE PIGMENT. 2. BLUE. Due to a purple layer on back of eye.

β. IRIS WITH TRUE PIGMENTS.

a. *Lipochrome or yellow pigment*. 3. GREEN or cat eye. Yellow pigment on blue background.

b. *Melanic or black pigment*. 4. HAZEL or gray eye. Dilute brown pigment around pupil only.

5. BROWN eye. Melanic pigment; various shades from various dilutions.

6. BLACK eye. An abundance of melanic pigment.

EYE COLORS IN MAN.

traits do show a sharp discontinuity and are consequently more easily studied. Altogether about fifty traits have been sufficiently studied to know that they are inherited and in some cases to know definitely how. Among normal characters may be mentioned: color of hair, eyes, and skin; form of hair whether straight, curly, or kinky; stature, proportion, and weight of the body. Hands and feet with two-jointed fingers or toes or with six digits in place of five, web feet, color blindness (inability to distinguish red from green most common), night blindness (inability to see in dim light), hoemophilia (a certain type of persistent bleeding), and cretinism (a disease due to deficiency of the thyroid gland hormone) are among the better known.

The Inheritance of Eye-Color. — The color of the eye (Fig. 144) depends on pigment granules deposited in the iris. All eyes have some pigment on the back side of the iris, which pigment when present alone gives pure blue eyes. Non-blue eyes have in addition to this pigment more or less brown pigment in the cells forming the front side of the iris. The varying shades of eye-color from gray to black depend on the amount and distribution of this second pigment on the front. If a blue-eyed person marries a pure dark-eyed one all the children will have dark eyes. If these dark-eyed hybrid children marry blue-eyed mates one-half their children (i.e., the F_2) will be dark-eyed and one-half blue-eyed. If the dark-eyed hybrids marry other dark-eyed hybrids (i.e., the offspring of a blue-eyed by a dark-eyed parent) their children (i.e., the F_2) will show three dark-eyed to one blue-eyed, approximately. This is clear and sufficient proof to show that this eye-color difference depends on only one pair of factors or genes. It behaves exactly like coat-color in guinea pigs or flower color in plants.

Brachydactyly is a condition of the hands in which they appear proportionally very broad in comparison to their length (Fig. 145). It is due to the fact that the fingers have only two joints in place of the usual three. A brachydactylous individual ordinarily transmits the peculiarity to about one-half of his children, when mated to a normal woman. His affected children transmit it in the

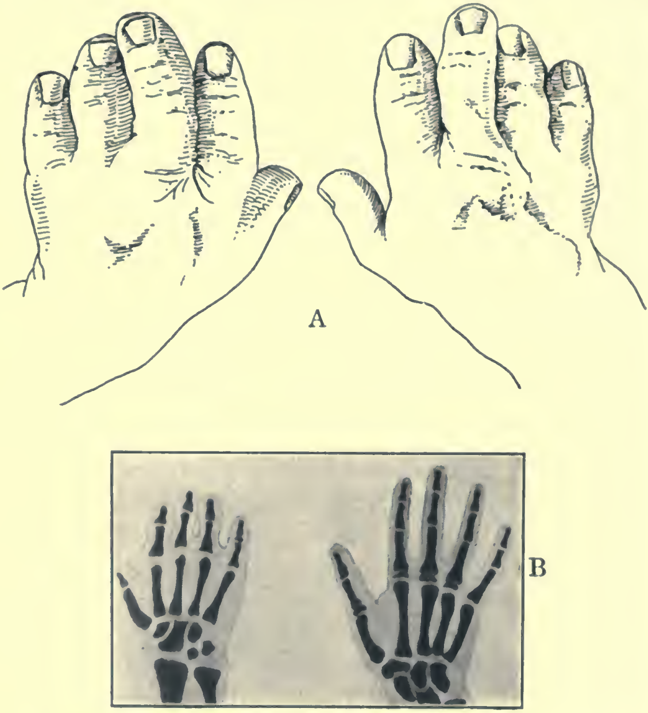


Fig. 145. — Brachydactylous Hands. 1, shows the proportionally short broad hands and 2, an X-ray photograph of a normal and brachydactylous hand. Note that in the latter the last two bones of each finger are fused together to form a single short one.
Plate, *Vererbungslehre*. Englemann.

same way but the normal children probably never transmit it to their descendants. From these data one may conclude that a single factor difference is responsible and that the gene for brachydactyly is dominant over the corresponding normal gene. In the cases of which there are records it would appear that the brachydactylous individuals were hybrid since they give two equal classes of descendants when mated, i.e., back-crossed, to the normal recessive. Doubtless individuals may occur who are pure for brachydactyly and would have all their children affected, i.e., produce a uniform F_1.

POLYDACTYLY AND SYNDACTYLY (Fig. 146). — In the former there is an extra finger or toe. It not only occurs in man but is also well-known in poultry. The gene for this character is dominant over normal and is transmitted usually to about half the offspring, because the affected

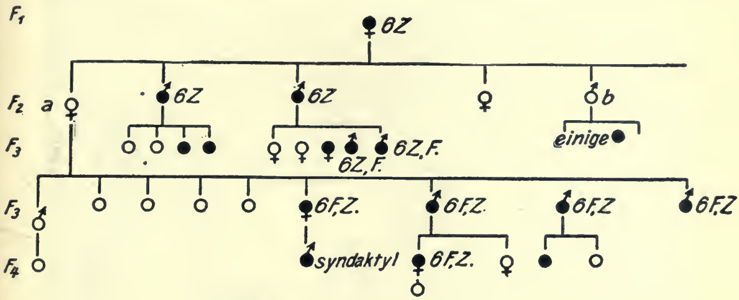


FIG. 146. — Inheritance of Supernumerary Digits. Affected individuals are indicated by dark symbols and unaffected by light ones. *F* indicates extra fingers and *Z* extra toes. Females are indicated by ♀ and males by ♂.
Plate, *Vererbungslehre.* Englemann.

parent is ordinarily a hybrid. It occasionally happens that apparently normal (i.e., recessive) offspring transmit the abnormality to their children. This would indicate that other factors or conditions are concerned in the *expression* of this character. In syndactyly the fingers or toes are united side by side, hence the common term "web-foot." This condition is also due to a single dominant factor difference. Affected individuals (usually being hybrid) transmit it to approximately half their offspring, and the normal children (being pure recessives) do not transmit it.

SKIN COLOR presents a more complicated situation and one which is not yet certainly or fully understood. The fact appears to be that a hybrid between a light skinned Caucasian and a dark skinned Negro is usually about midway between the parents in color (Fig. 147). Dark skin appears thus to be, like the red color in the four o'clock described in Chapter XXVIII, only partially dominant over light. However, when the pink four o'clocks are selfed or inbred the F_2 consists of 1 red: 2 pink: 1 white, while the medium colored mulattoes when inbred do not segregate cleanly into

FIG. 147. — Inheritance of Skin Color and Hair Form. The family of a kinky-haired African Negro and a straight-haired Englishwoman. Note the dominance of the kinky over straight hair and the varying color of the children due to the fact that the dark parent was not pure for all the color genes.
Plate, *Vererbungslehre*. Englemann.

3 classes in the 1:2:1 ratio. In fact, they produce several shades of color of which it rarely happens that any are either as light or as dark as the grandparents. This result strongly resembles that obtained in the cross of the red-grained wheat by the white-grained one described in Chapter XXXI. The current explanation assumes that the Negro and the Caucasian races differ

by two chief pairs of factors or genes neither of which is fully dominant. If the reader will work out such a cross by means of the Punnett square he will find that this will account for nine different genotypes or shades of color that might be expected in the second generation. If the dominant color factors present in the Negro be represented by *A* and *B*, of which *A* produces more color than *B*, and their recessive genes in the Caucasian by *a* and *b*, then the mulatto of intermediate color would be *AaBb*. Genotypes of this constitution, when interbred, would be expected to produce an F_2 generation consisting of 1 *AABB* (like the original Negro parent), 2 *AABb* (a shade lighter), 2 *AaBB* (slightly lighter still), 1 *AAbb* (still lighter), 4 *AaBb* (intermediate or mulatto), 1 *aaBB*, 2 *Aabb*, 2 *aaBb* (of decreasing color grades), and 1 *aabb* (like original Caucasian parent), out of sixteen. When it is remembered that color is not uniform in either parent race owing to modifying factors, it appears probable that this hypothesis is sufficient to explain all the diversity of color actually found in these interracial hybrids.

Stature and Weight are very evidently hereditary (Fig. 148) but owing to the great influence of the environment, it has not been possible so far to determine with satisfactory accuracy the number of factors concerned. Certain families and races are unusually tall, as for example the natives of Patagonia and Scotland, while others, for example, Welsh or Eskimos, are unusually short. Since these races maintain their characteristic stature, even when living in other countries, it is obvious that the causes controlling height are chiefly hereditary. In families where tall has mated with tall the children are mostly tall. Some, however, are short, as would be expected from the fact that both parents would rarely be pure for all the factors for tallness. Human families are, however, too small to enable one to determine the number of factors concerned. What has been said for stature seems to hold for weight also. It is even more difficult to ascertain the factors governing weight since it is so greatly influenced by diet and exercise.

Color-Blindness serves well to illustrate sex-linked inheritance in man. The reader has already learned that there are many sex-linked characters in the vinegar fly, whose genes or factors are carried in the so-called

Fig. 148. — Dwarfs. At the right is a man of normal stature. The next two figures are those of dwarfs with very short legs but with nearly normal trunk. The next two figures are of dwarfs whose bodies are proportionally reduced throughout. The figure to the left is a dwarf (cretin) whose underdevelopment is due to the failure of a ductless gland to produce the normal amount of hormones. Plate, *Vererbungslehre.* Englemann.

"sex-chromosomes." The type of color-blindness in which the affected person is unable to distinguish red and green is fairly common (about one person in twenty-five) among men but rare among women. When a color-blind man marries a normal woman he transmits to his daughters the sex-chromosome containing the recessive factor for color-blindness, but the daughters are not color-blind because they have also received a sex-chromosome with the dominant normal factor from the mother. Since the human female has two sex-chromosomes all eggs will be alike and always have a sex-chromosome. But on the other hand the male has only one sex-chromosome and, therefore, produces two kinds of sperms, one kind with the sex-chromosome and the other lacking it. The sons in the family just mentioned receive their single sex-chromosome from their mother and are consequently free from any trait of color-blindness. Should the normal-appearing daughters marry normal husbands all their daughters would be able to distinguish colors, but half of them would be hybrid like their mother. Half the sons would receive a "color-blind" sex-chromosome and half a normal one. The first would, of course, be color-blind, like their grandfather, and the second would be strictly normal.

Cretinism is an abnormal state of the human species due in some cases, at least, to a deficiency of the hormone produced in the thyroid gland in the neck. The individual affected is likely to be dwarfed in stature and distorted in features and to have a very low grade intelligence. It is known that some forms, at least, of cretinism are heritable. Presumably the hereditary factors directly control the development of the thyroid gland and through it produce the observed effects. It has recently been claimed by a competent biologist that there is evidence indicating that many racial characters depend on hormone action. If this should be substantiated by further investigation, these hereditary traits would also be controlled in the same indirect fashion as cretinism.

CHAPTER XLII

INHERITANCE OF MENTAL TRAITS

(By Lewis M. Terman)

Mental as well as Physical Traits are Heritable. — That mental as well as physical traits are heritable is indicated by all the available evidence. This is what we should expect, considering that mental functions are dependent upon physical structures, namely, those of the central nervous system.

However, we know much less about mental than about physical inheritance. This is partly due to the fact that traits of mind cannot be identified and measured with anything like the accuracy which is possible in the case of height, weight, skin color, etc. Nevertheless considerable progress has been made in the measurement of intelligence and of a few of the more specialized mental abilities.

Amount and Nature of Variability in Intelligence. — Mental tests have shown that unselected individuals of a given race differ enormously in their intelligence, and that these differences are "continuous." Figure 149, which gives the distribution of "intelligence quotients" of nine hundred and five unselected California school children, illustrates both of these facts. The intelligence quotient is an index of brightness. The quotient 100 represents average brightness. The highest grade feeble-minded have a quotient of 65 or 70, the merely dull a quotient of 80 or 85. Children brighter than the average test above 100, about one in two hundred fifty testing as high as 140.

It will be noted that among these 905 children the intelligence quotients cover the range from below 60 to above 140, that is, from feeble-mindedness to a very high degree of superiority. The brightest child in the group is as far above the average as the dullest of the group is below. It will also be noted that as we go from the average toward either extreme the number of cases decreases gradually. There are far more cases just above

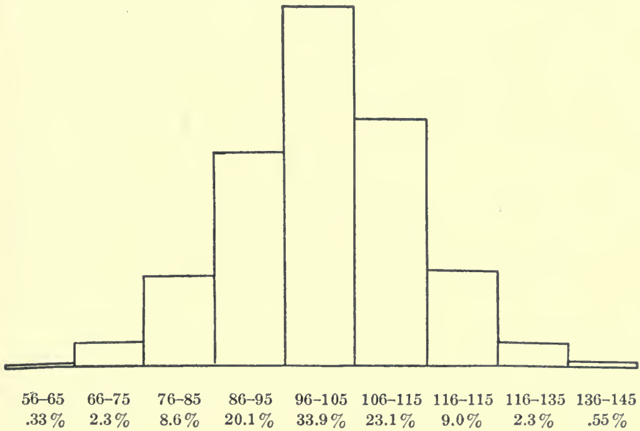


FIG. 149

(Reproduced from Terman, *The Measurement of Intelligence.*)

the borderline of feeble-mindedness than in the same range just below it, and more cases of moderate than of extreme brightness. There is no sharp dividing line between any two grades of mental ability. The entire range of human intelligence is from profound idiocy, which is represented by an intelligence quotient of less than 10, to a degree of superiority represented by an intelligence quotient of 180 or 190. The greatest extremes of intelligence were not found in this group of 905 children.

Variability in Other Traits. — Tests of musical ability show similar ranges of differences for such traits as discrimination of pitch, sense of rhythm, tonal memory, and appreciation of consonance; and that the variation in these traits also is continuous. It is probable that if we could measure such traits as conscientiousness, will power, sanity or social adaptability, we would find the range of individual differences as great as for intelligence and musical ability, and that the differences found would be continuous. With mental traits it is rarely a question of simple absence or presence, but rather of presence in greater or less degree. The inference is that such traits do not depend upon single factors in the chromosomes, but upon several factors. Intellect, like height, is perhaps in reality a composite of several more elemental traits. Epilepsy and possibly a few other forms of mental defect may be exceptions to this rule.

Statistical Methods Used in the Measurement of Resemblance. — Since the study of mental inheritance involves a consideration of *degrees* of resemblance between parents and offspring, rather than the mere noting of presence or absence of particular traits, certain statistical devices have been found necessary. Among these is the coefficient of correlation, which is a numerical index expressing the amount of agreement between two sets of facts.

For example, let us suppose that it is desired to express the relationship existing between intelligence of fathers and intelligence of sons, and that the intelligence of a thousand father-son pairs has been measured by mental tests. If the brightest father were found to have the brightest son, the next-brightest father the next-brightest son, and so on down to the dullest, the correlation coefficient would be $+1$, which would represent complete agreement between the two sets of facts. If the brightest father were found to have the dullest son, the next-brightest father the next-dullest son, etc., the correlation would be -1, which would represent complete disagreement. A correlation of 0 would mean no more resemblance than we should get if we paired off any father with anyone else's son at random. Correlations between 0 and 1 would therefore represent all degrees of positive resemblance from very slight to practically perfect. We are now ready to examine the correlation coefficients of resemblance, which have actually been found for related individuals in the case of intelligence.

FAMILY RESEMBLANCE IN INTELLIGENCE. — The coefficient of resemblance between parents and children in intelligence seems to be in the neighborhood of .50, which is about half way between perfect resemblance and no resemblance at all. It is a striking fact that the parent-child resemblance in many physical traits also turns out to be rather uniformly in the neighborhood of .50. This would suggest that mental and physical traits are inherited to much the same degree.

The correlations between *sibs* (i.e., children of the same parents) have also been found to approximate .50, both for physical and mental traits. This holds for spelling and arithmetical ability as measured by standard tests, and for ability in other school subjects as measured by school marks. Ratings of 2000 school children by their teachers on such traits as intelligence, vivacity, conscientiousness, popularity, temper, self-consciousness and assertiveness gave correlations between sibs approximating .50 for all of these traits.

In Germany school marks earned by several hundred children were compared with the school marks earned by their parents and grandparents. Correlation coefficients were not computed, but the results shown in Table 1 are significant. The marks were given on a scale of five, 1 being highest and 5 lowest.

TABLE 1. (From Peters)

Average Marks of		Average Marks of Both Parents	Average Marks of Children
One Parent	Other Parent		
1	1	1	1.46
1	2	1.5	1.98
1	3	2	2.16
2	2	2	2.12
1	4	2.5	1.92
2	3	2.5	2.35
1	5	3	2.28
2	4	3	2.24
3	3	3	2.51
2	5	3.5	2.46
3	4	3.5	2.34
3	5	4	2.61
4	4		
4	5	4.6	2.71
5	5		

The Law of Filial Regression. — From Table 1 it will be seen that superior parents tend to have children who are also superior, but less superior than themselves; and that inferior parents tend to have children who are inferior, but less so than themselves. This illustrates the "law of filial regression," which was first formulated by Francis Galton. It is merely a statement of the fact that the offspring of parents who are exceptional in a particular trait tend to be less exceptional in that trait than their parents. The law holds for complex traits like height or intelligence, but not for simple traits like eye-pigment, color-blindness, etc.

Mental Resemblance of Twins. — Both in physical and mental traits a much higher coefficient of resemblance has been found for twin-pairs than for ordinary sibs, namely .70 to .90 for twins as compared with .50 for sibs. Twins, however, are believed to be of two kinds, those originating from two eggs separately fertilized and those produced by the division of a single fertilized egg. It is probable that the latter mode of origin accounts for all cases of so-called "identical" twins, that is, twins who are almost exact duplicates of each other. Identical twins are always of the same sex, while "fraternal" twins may be either of the same or opposite sex. It is believed that it is the presence of identical twins in the groups which have been measured and tested that is largely responsible for the greater resemblance of twin-pairs as compared with ordinary sib-pairs. However, the question is still in dispute, largely owing to the impossibility of our knowing to a certainty which twins are of single-egg or of two-egg origin.

Family Resemblance not Wholly Accounted for by Environment. — One is naturally tempted to explain the mental resemblance of parent and child, and especially that of sib and sib, or twin and twin, as due to similarity of environment and training. There are several facts, however, which render this theory untenable. (1) The resemblance in mental traits is about as great as in physical traits, and it is known that the latter are not determined chiefly by environment. (2) The resemblance of twins in mental tests which have novel content is as great as in tests whose content is more subject to the influence of training. (3) Older twins have no higher coefficient of mental resemblance than younger twins. If the resemblance were due chiefly to environment, then it should become greater the longer that environment operates. It does not. (4) Galton found twins who had been subjected to very different environment who were nevertheless extremely similar. (5) It is a matter of common observation that sibs who differ greatly from each other in early childhood may continue to differ, notwithstanding the similar environment they enjoy throughout their period of plasticity. (6) Galton found that the adopted sons of popes were far less likely to become eminent than the real sons of great men who ranked with popes in intelligence. (7) Wood's study of heredity in the royal families of Europe shows that sons who inherit thrones and fortunes are but little more likely to be numbered by posterity among the great than are their younger brothers.

THE INHERITANCE OF GENIUS. — The genius is not sharply differentiated from other human beings, but is merely a person of very superior ability in one or more lines. All degrees of mental ability tend to be transmitted, and genius is no exception to the rule. Galton found that 977 men of genius whom he studied ("genius" being defined as that degree of ability possessed by the most intellectually eminent person in a population of 4,000) had a total of 535 fathers, brothers, sons, grandfathers, grandsons, uncles and nephews as eminent as themselves. It has been calculated that this is about 135 times as many eminent relatives as would be found for 977 average men. Of 1030 British men and women of genius studied by Ellis, 40 per cent had either a father or mother of very superior ability. An extensive study of several hundred gifted children of California, each of whom equalled or exceeded in intelligence the brightest out of 200 children taken at random, showed that these also had several times as many relatives of superior ability as do children of average intelligence.

Convincing evidence has also been found for the heritability of artistic and musical ability. In 30 families in which both parents were artistic, Galton found that 64 per cent of the children showed special talent in art. This was three times the proportion found in families in which neither parent was artistic. Musical ability, especially, is prone to "run in" families. The Bach family, for example, produced in eight generations no less than 57 individuals of very superior musical ability, 20 of whom became eminent.

INHERITANCE OF FEEBLE-MINDEDNESS. — Investigations by Goddard, Davenport and others have shown that a majority of the cases of mental deficiency are traceable to heredity, possibly as large a proportion as two-thirds or three-fourths. The remainder are due to a variety of causes, including injury at birth, diseases or accidents during infancy, and syphilis or alcoholism of parents.

Social studies have been made of many feeble-minded or otherwise degenerate strains, good examples of which are the Kallikaks, the Nam Family, the Hill Folk, the Pineys, the Jukes and the Ishmaelites. Representatives of such families are to be found in almost any neighborhood, and everywhere they make up a large proportion of the ne'er-do-wells, paupers, criminals, and sex-offenders.

Some investigators, notably Goddard and Davenport, are inclined to believe that mental deficiency is due to a single factor or gene which behaves as a Mendelian recessive. This would mean that defective mated with defective would give only defectives in the F_1. Defective mated with normal would give an F_1 composed entirely of normal but hybrid individuals. If the latter should mate with others who were hybrid like themselves, the result would be an F_2 yielding the familiar 3:1 ratio. It is by no means certain, however, that this interpretation of the data is correct. The graded character of mental defect would suggest that probably more than one factor is involved.

THE KALLIKAK FAMILY. — This family is of special interest by reason of the fact that it contained two branches, a normal and a defective. Both branches trace back to a mentally normal young soldier of the Revolutionary War. During the war this soldier mated temporarily with a feeble-minded woman, giving rise to a feeble-minded strain which exists to this day. From this union 480 individuals have been traced, 143 of whom are known to have been feeble-minded and many others criminal, immoral, or alcoholic. Only 46 are known to have been normal. After the war this same soldier married a woman of good heredity and founded another family of whom 496 individuals have been traced. Practically every member of this branch was normal, nearly all of them being prosperous farmers or successful lawyers, judges, or holders of important public office. Not even a well-controlled experiment could have shown more convincingly the important part played by heredity in the causation of mental deficiency.

Inheritance of Other Forms of Mental Defect. — Both epilepsy and insanity are also known to be hereditary, though the laws governing their transmission are not fully understood. It seems to be fairly well-established that epilepsy is due to a single recessive Mendelian factor. There are many forms of insanity and it is possible that not all of these are transmitted according to the same laws. It has been found that epilepsy, insanity, and feeble-mindedness frequently appear in the same families, often one kind of defect appearing when another would be expected, and it is possible that these various types of defect may be related to each other in some as yet unknown manner. The predisposition to alcoholism is also to some extent hereditary and often appears in families marked by other types of defect. Criminality, as such, is probably not hereditary, but a considerable proportion of criminals are feeble-minded, and feeble-mindedness, as we have seen, is hereditary.

Figures 150–1–2 are typical family histories of epilepsy and insanity.

Endowment of the Different Social and Occupational Classes. — What has been said in the preceding paragraphs would suggest that, in general, members of the socially successful classes and higher occupational groups are on the average better endowed mentally than those of inferior social status. That such is the case is indicated by the intelligence of their offspring. Mental tests have brought out the fact that the children of successful lawyers, doctors, ministers, or college professors have an average intelligence quotient of 115 or higher, and that children of totally unskilled laborers have an

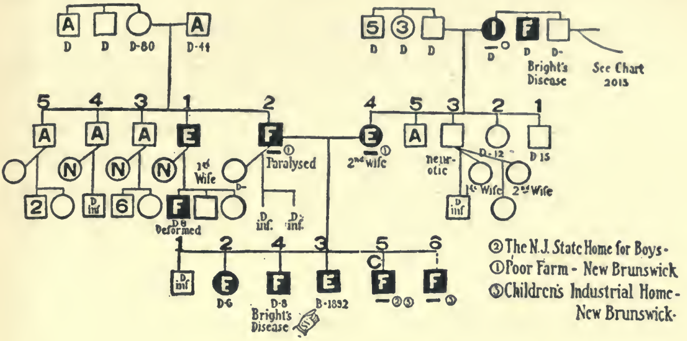


FIG. 150. — The Product of a Feeble-Minded Man (who has an epileptic brother) and his epileptic wife (whose father was insane and uncle feeble-minded); the first child died in infancy, the next two were feeble-minded and died young, the next is an epileptic at the New Jersey State Village; the next is feeble-minded, has a criminal record and is in the State Home for Boys; the last is feeble-minded and is in the Children's Industrial Home. Six in this family have been or are wards of the state. *A*, alcoholic; *C*, criminalistic; *D*, deaf; *E*, epileptic; *F*, feeble-minded; *I*, insane, *N*, normal, *SV* in ☞ means an inmate of a State Village for Epileptics.
Davenport, *Heredity in Relation to Eugenics*.

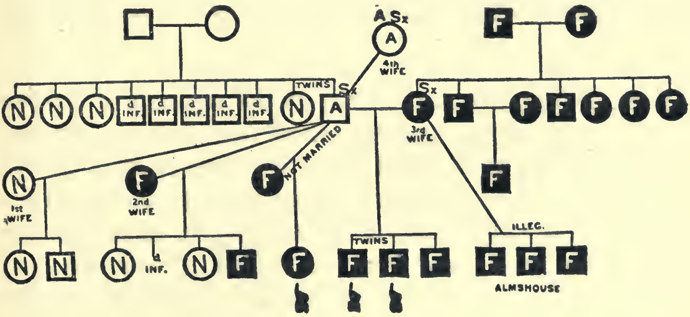


FIG. 151. — An Alcoholic Man of Good Family but probably simplex in mentality has by a normal woman 2 normal children and by a feeble-minded woman 2 normals and 1 feeble-minded. He has had 4 other children by feeble-minded women, all feeble-minded.
Davenport, *Heredity in Relation to Eugenics*.

average quotient of 85 or lower. It should be emphasized, however, that the figures refer to averages. In both cases the range of quotients is wide and each distribution curve greatly overlaps the other.

Although feeble-minded children are occasionally found in socially successful families, they are several times as frequent in the families of low occupational and social status; and although gifted children are sometimes found in the families of unskilled laborers, they are many times as frequent in families belonging to the professional classes.

Of several hundred California children who were found to have an intelligence quotient of 140 or higher, and all

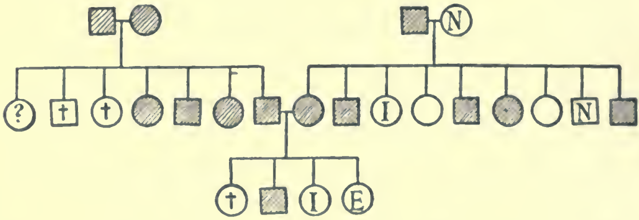


Fig. 152. — Inheritance of "insanity." From the central mating of two normal persons there are derived 8 children, 3 insane. But there is the hereditary tendency in the germ plasm of *both* parents. Mott, 1905.

of whom probably ranked within the top half of the top 1 per cent of the general school population, approximately 50 per cent had fathers who belonged to one or another of the professions. More than 35 per cent were from the semi-professional or mercantile classes, something over 10 per cent from the skilled labor classes, and less than 5 per cent from the unskilled and semi-skilled occupational classes combined. Galton, Ellis, and others have brought out similar facts regarding the social origin of men of genius.

Such facts are of great significance. They mean that we must usually look to the higher social classes to produce the intellectual leaders who will advance science, art, government, education, and social welfare generally. Our civilization of a thousand or ten thousand years hence will depend largely upon the relative fecundity of our low grade and high grade stocks.

The Decreasing Fertility of Superior Stocks. — Until recently there had not been, at least for hundreds of years, any marked tendency in most civilized countries for one class to reproduce more rapidly than another. For centuries the average mental endowment of the European and American peoples had held its own, or possibly even advanced slightly as a result of the greater mortality among the undesirables. About half a century ago, however, an ill-boding change began to take place. The intellectually superior families are no longer reproducing as rapidly as formerly, and their rate of reproduction has fallen far below that of the socially incompetent. While the fecundity of feeble-minded families continues undiminished, that of university graduates and others of corresponding intellectual superiority has in two or three generations decreased by something like one-half. The tendency toward a differential birth rate is making alarming progress in all civilized countries, although less in Italy, Germany, and Japan than in France, England, or America. The situation is only in part relieved by the somewhat lower mortality among the better classes.

If the differential birth rate should continue, and especially if its differential character should become more and more marked, it would be but a few hundreds or thousands of years until the surviving stocks would be those descended chiefly from the dregs of our present-day population. If this should occur, no amount of educational effort would prevent the decay of the leading modern nations. There is reason to believe that such an influence was largely accountable for the waning of earlier civilizations, notably in the case of Greece and Rome.

The Importance of Eugenics. — There is no evidence that the decreased birth rate in the superior classes is to any great extent due to biological causes. It is probably due entirely to the voluntary acts of individuals in the postponement of marriage and the prevention of conception. There is the possibility, therefore, that the situation may be saved by education in eugenics. The difficulty is that although it is relatively easy to teach people the significance of the issues involved, it is very hard to persuade them to care enough about the future of civilization to make any sacrifices in its behalf.

It is evident, at any rate, that man faces few, if any, problems of greater importance for his future welfare than those relating to the control of heredity. By the strict application of eugenic principles it would be possible to reduce greatly the number of defectives, to increase the production of genius, and to improve the average level of morality and intelligence.

The Effect of Undesirable Immigration. — The mental tests given to nearly two million of our soldiers during the recent war disclosed large differences in the intellectual ability of various racial groups. Evidence to the same effect is also available from numerous experimental studies. The following conclusions seem warranted.

1. Probably not more than 10 or 15 per cent of American Negroes equal or exceed in intelligence the average White. The intelligence of the average Negro is vastly inferior to that of the average white, and the mulatto occupies a position about mid-way between.

2. The intelligence of the average American Indian is appreciably but not greatly superior to that of the average Negro. Our Mexican population (Indian hybrids for the most part) which has recently increased with great rapidity, barely surpasses the Negro in average endowment.

3. The immigrants who have been coming to us from

the extreme southern and southeastern parts of Europe (South Italians, Portuguese, Greeks, and Slavs) are in general distinctly inferior to those who come to us from Northern, Central, and Western Europe. The influx of the former has been so great, and their rate of reproduction is so excessive, as to give rise to a serious menace.

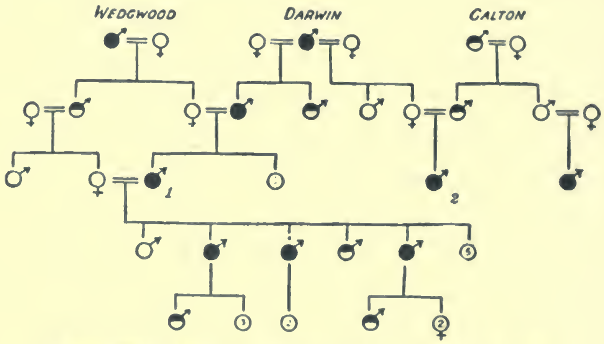
4. The few mental test studies which have been made of Chinese and Japanese indicate that these races are approximately the equals of Europeans in mental ability.

5. No nation can afford to overlook the danger that the average quality of its germ plasm may gradually deteriorate as a result of unrestricted immigration.

Eugenics and Marriage. — The laws of mental and physical inheritance are not yet well enough understood to warrant laying down a detailed program for securing eugenic matings. Some of the facts which have been set forth have an obvious bearing on the problem. One who has regard for the quality of his descendants should of course avoid mating into a racial or family stock which is inferior to his own, even if it is not characterized by outright defect. The results *may* be satisfactory, but the chances are on the other side. The unwisdom of mating with one whose family is seriously tainted with feeble-mindedness, insanity, epilepsy, pauperism, or alcoholism, is too obvious to demand emphasis. The danger of such matings is greatly increased when both parties to the marriage come of defective stock.

The desirability of adopting legal measures to prevent the feeble-minded from reproducing is self-evident. Many states have laws designed to accomplish this, but unfortunately they are rarely enforced against the higher grades of defectives. Sterilization of the unfit has gained little headway. However, reduction of the number of defectives is only a small part of the problem of eugenics. Elimination of all the feeble-minded would not raise the average level of intelligence in the general population to more than a barely noticeable extent, and it is the improvement of our entire population that counts in the long run. Still more important is the adoption of eugenic measures which will increase the number of intellectual and moral geniuses.

THE INFLUENCE OF ENVIRONMENT AND EDUCATION UPON MENTAL PERFORMANCE. — From the preceding discussion it might be inferred that one's mental traits are determined almost entirely by hereditary factors, and that the influences of environment and formal training



shows a man of scientific ability; shows a man of scientific ability, who is also a Fellow of the Royal Society; (5) shows five other children, and so on.

FIG. 153. — Inheritance of Ability (chart condensed and incomplete) in three markedly able families (from Kellicott after Whetham) 1, Charles Darwin; 2, his cousin, Francis Galton, founder of the modern eugenic movement.
Guyer, *Being Well-born.*

count for next to nothing. Such a conclusion is by no means justified. Although it is true that we cannot cure congenital feeble-mindedness, develop a dullard into a genius, or transform a person who is tone-deaf into a Mendelssohn, it is possible by means of education to raise enormously the general level of accomplishment of an entire race or population group. One has only to compare the Negroes in America with their "cousins" in Africa to see what an immense difference education can make. Our ancestors of two thousand years ago were probably as well endowed mentally as ourselves, but for lack of education they were practically barbarians. Our schools hand over to children in ten or a dozen years much of the knowledge and skill which it has taken the race thousands of years to acquire.

Heredity Sets the Limits. — It is not a question of heredity *or* environment, but of heredity *and* environment. Both influences are operative in determining what manner of person any given individual shall become. What heredity does is to set limits to the influence which it is possible for education to exert. It is to a great extent education which decides what the *absolute* achievement of a given population group shall be — that is, whether its intellectual life shall in general be on a high or low plane. On the other hand, it is heredity, chiefly, which determines the *relative* achievement of an individual as compared with other members of his population group. At least this tends to be the case in a democratic country where class privileges have been abolished and where inequalities of opportunity have been reduced to a minimum. To state it concretely, the average Englishman of to-day is more civilized than his ancestors of two thousand years ago, chiefly because of education and environment, but Englishmen like Faraday, Lord Kelvin, or Lloyd George surpass the average present-day Englishman in achievement chiefly because of their superior endowment.

Ordinary observation suggests the possibility that education may have a greater influence upon moral traits than upon general intelligence. This may be true, but it is probable that even here original endowment counts heavily. No nation has ever succeeded in reforming its entire criminal class.

Modifications of Mental Traits not Transmitted. — In earlier chapters (XXVIII and XXXIII) it has been shown that physical traits acquired during the lifetime of an individual do not affect the germ cell, that is, do not become hereditary. This appears to be equally true of mental traits. The fact that our parents have spoken English or studied Latin or refrained from doing evil does not make it any easier for us to acquire these habits. The chances that a parent of a given degree of musical ability will transmit that ability to his offspring are not in the least affected by the amount of musical training he himself has received. There is only one way in which we can benefit from the lessons our parents have learned, namely, by following their example and learning the same lessons for ourselves. Education must begin all over again with every generation; which means that the school is and will always be the most important of all our social institutions.

CHAPTER XLIII

MAN'S PLACE IN NATURE

Man the Apex of the Animal Series. — If the presentation of the facts and principles of biology given in this book has accomplished its purpose, it should be clear in the mind of the reader that no sharp line separates man from other living creatures. The world of nature presents a vast array of forms, varying in complexity, but all having a common basis of protoplasm and all showing a high degree of adjustment to their environment. Man is without doubt the most highly specialized of them all, and yet his metabolic processes are essentially like theirs. Man occupies, then, a definite position in nature. The fact that his position is at the peak of the scale of development should not cause man to lose sight of the fundamental fact that he is a part of the order of nature and is subject to the same laws by which the activities of other living things are controlled.

Man's Similarity to the Higher Animals. — From what has been said in previous sections of this book it should be clear that in physical constitution man differs only slightly from many of the higher animals. His plan of bodily structure is the same as that of mammals generally. Except for a few details, his physical structure is strikingly similar to that of the highest mammalian groups, the monkeys and apes. The fundamental basis of nervous functioning in man is — so far as we can learn — precisely similar to that of other mammals, and in fact, of all except the most lowly animals. In man as in other animals simple reflexes, complex reflex actions, the properties of memory and association, form the basis of the intellectual life. In man as in other animals, agreeable and disagreeable emotions are aroused under particular conditions and are accompanied by characteristic bodily changes. In all these fundamental matters there is no escaping the conclusion that man is at one with the whole group of mammals to which he belongs.

THE FACT OF PROGRESS. — Notwithstanding the points of similarity emphasized in the last paragraph, one who studies human *behavior* in comparison with the behavior of higher animals cannot fail to be struck with a feature of difference which is absolutely fundamental and which, in fact, sets man in a category by himself. In a word, this difference lies — as expressed in the head of this paragraph — in the fact of human progress which contrasts with the absence of progress among the other animals. What is meant by progress in this connection is simply this: human beings, from generation to generation, behave differently from the generations which preceded them, they do new things and think new thoughts. Animals, on the other hand, generation by generation, behave in a manner which does not essentially change, their reactions to the environment are on the whole the same now as they were hundreds of generations ago. This difference in behavior is both real and fundamental, and to the extent to which it can be explained man's position in nature in comparison with the other animals' can be made clear.

THE HUMAN RACE UNCHANGED. — If we were to find present generations of animals behaving differently from past generations, we should have no hesitation in asserting such difference in behavior to be due to bodily alterations. The changes in *human* behavior from generation to generation are not thus accounted for. The evidence is convincing that man in his present physical, intellectual, and emotional characters has existed on the earth since the beginning of recorded history, and in all likelihood for a period at least two or three times as long preceding the first making of permanent records. We know that very early in historic time men lived who were in all probability fully equal to modern man, not only in physical power, but in intellectual ability and emotional characteristics as well. This leads to the conclusion that the progress of humanity in historic and late prehistoric time has not been due to racial development, but rather to the utilization of qualities which were possessed by primitive man equally with modern man.

Explanation of Progress. — The explanation of progress is to be sought in some qualities which man possesses and which other animals do not, since it is clear that if the other animals were in possesssion of the same or of similar qualities they would show the same ability. Human and animal characteristics have been classified as physical, intellectual, and emotional. In these three realms are to be sought the special properties which have formed the basis of human progress.

Physical Characteristics. — Notwithstanding man's marked physical similarity to the other mammals, his body presents two special features which undoubtedly have contributed to his achievements. The first of these is the erect posture. It is characteristic of man that he alone among animals stands definitely upon two feet and performs the major part of his locomotion with the lower limbs only. The advantage that this confers upon him is chiefly in the release of the front limbs from locomotor duty and in thus freeing them for use as organs of touch and for carrying on the grasping function. It is quite true that many other kinds of animals use the front limb, sometimes to a large extent, as an organ of touch and of grasping, but only in man are these the primary functions, and locomotion the secondary. In all other mammals locomotion is the primary function of the front limb, other functions being only incidental.

The second significant physical difference between man and other animals is in the superior flexibility of the hand. In no other animal can the thumb be moved across the palm of the hand as can be done freely and accurately by man. This flexibility lies at the basis of manual dexterity, and when it is recalled how much of his progress man owes to skillful use of his hands, the importance of this physical character is clear. Not only in the use of mechanical devices, but in the use of instruments for writing and drawing is this of prime significance. There is no intention here of asserting that these physical peculiarities are of themselves a sufficient basis for human progress, which rests primarily on characters to be described presently, but as contributory elements they are not to be neglected.

Intellectual Characteristics. — Probably nearly everyone, if asked to what man owes his superiority to animals, would reply, in possessing a better mind. And there is of course no doubt that the average human mind is very far superior to the average animal mind, and the best human mind immeasureably superior to the best animal mind. Yet sight must not be lost of the fact that there is among men — as probably among animals — an exceedingly wide range in mental ability, so that one is fairly safe in making the assertion that the most intelligent individuals among animals are superior to the least intelligent human beings. Notwithstanding that possibility, there are certain *kinds* of mental power which are possessed probably by every normal human being, the unintelligent as well as the intelligent, that are not shared by any of the lower animals. Whether these special kinds of power necessarily indicate mental superiority is a debatable question. Consider, for example, three very simple instances: appreciation of the possibilities of fire, of clothing, and of cultivation of the soil.

Fire. — Explorations have covered practically the entire habitable globe, and no race of men has yet been found which does not know and make use of fire. The knowledge that fire may be kept going by throwing wood on it from time to time seems not to involve an exceptionally high order of mentality. It is within the scope of quite young children; yet no case has ever been credibly recorded of any lower animal learning how to keep up a fire. It is quite true that in a wild state animals are afraid of fire, and this fear may readily act as a deterrent influence against their learning to make use of fire. Yet dogs, which are among the most intelligent of animals, have no fear of fire; in fact, they derive great enjoyment from basking in its warmth; but a dog whose intelligence seems to be almost human will allow a fire to go out and itself to lose the enjoyment of its warmth without any effort toward maintaining it.

The significance of fire in human progress is so obvious as to require only a word regarding it. It is one of the factors which enable men to live outside the tropics. The historical fact that civilization thrives and has thriven from the beginning in climates too cold for human habitation without artificial protection, emphasizes the significance of fire. In view of the further fact that metallurgy and the most important applications of power depend upon fire, the significance of this particular ability of mankind becomes clearly manifest.

CLOTHING. — Related to the appreciation of fire is the appreciation of clothing. It is a common thing for animals to seek protection against the inclemencies of climate by crawling into sheltered nooks, but only man has discovered how to carry his shelter around with him in the form of clothing. Just as fire extends his range by allowing him to live in cold as well as in warm climates, so clothing increases his effective life by allowing him to be active when the weather is so inclement that without it he could remain alive only by curling himself up in some sheltered spot and waiting for conditions to moderate.

THE CULTIVATION OF THE SOIL involved in its beginnings no greater effort of mentality than the observation that plants spring from seeds and that by putting a number of seeds into the ground in accessible locations one will have in due time a considerable stock of food convenient to hand. No animal so far as we know can or does till the soil. There is scarcely a race of men outside the polar regions that fails to practice agriculture in some form. The primary advantage of agriculture relates itself to the advantages of fire and clothing in extending man's range. In this particular case the extension takes the direction of affording him time for other occupations in the intervals of food-production. Progress is born of spare time. So long as every waking moment must be devoted to the fundamental activities of satisfying hunger, securing safety, and perpetuating the race, there is no opportunity for progress.

Although the ability to carry on agriculture is here stated to be a strictly human characteristic, it must not be forgotten that among certain kinds of ants elaborate systems of crop-raising are maintained. The reason these are not admitted to be of comparable importance with human agriculture is that they show no signs of being other than complicated instincts; they have no basis of genuine intelligence, that is to say, of associated memory, as is proved by the absence of adaptability in their performance. Crop-raising ants can be placed in circumstances where the carrying on of their regular tasks is futile to absurdity, yet not the slightest modification of their routine behavior is observable; the entirely useless manœuvers are performed with the persistency which characterizes instincts and distinguishes them from intelligent activities.

Language. — In addition to the three examples of mental power described above, with regard to which one might question whether they require higher intelligence than do some of the things regularly done by intelligent animals, and yet whose possession by man and not by animals enables him to progress along lines which they cannot follow, there is the mental property which forms the topic of this paragraph, in which — so far as experiment reveals — man stands apart from all other animals. Language is in its essence nothing more than the adoption by mutual consent of arbitrary spoken or written symbols to represent things, actions, and ideas. These symbols are employed as auditory or visual stimuli, registered in the brain as memories, and by the process of association combined with other memories of the particular things, actions, or ideas with which they belong. Language memories thus become part of the machinery of association, namely, of thinking, in the human mind. To illustrate: consider the following sequence of marks, "b o o k". Looked at simply as a spot from which light is reflected into the eye in a certain manner, with the initiation of a certain visual stimulus, this sequence of marks has no meaning whatever. But because the English-speaking races have agreed that these marks when put together in this way are to stand in our minds for the aggregation of printed pages which we know as a book, the symbol achieves great importance. In man the thought processes are carried on in terms of language. We cannot think clearly about anything to which we cannot assign words. It is this fact which makes it so difficult for us to evaluate properly the intellectual activities of animals, which because they have no words with which to think — so far as we can judge — have thoughts that are hazy indeed in comparison with our own. Contrast the education of a young wild animal with that of a child. The former learns chiefly by experience, to some extent by observation. But only things which happen to itself or within its range of observation can possibly contribute to the formation of those associated memories which make up its intellectual equipment. The child, on the other hand, although basing much of its education upon experience and observation, particularly in early years, receives in addition a vast amount of instruction by means of language. The sum total of the child's education, gained thus, exceeds by many fold the utmost that any of the lower animals can achieve. As was emphasized in Chapter XV, memory and association have their prime importance as the means whereby the organism is enabled to profit by experience. Language extends this ability so that it includes the experience of others, both present and past. It must be borne in mind that in the absence of language only those experiences which have happened directly to the organism or have come within its immediate range are of any value to it. But with language added as a feature of associated memory, the experience of a great many other individuals becomes available as a guide to conduct. Students of history believe that spoken language came into use among human beings earlier than written. Spoken language is narrower in its application than written, because of the impermanence of the thing which gives rise to the stimulation in the one case, as contrasted with its permanence in the other. In the main, spoken language covers the present experience of others, or their experiences in the recent past; the longer ago the experience the greater the liability to error in its imparting. Written language, on the other hand, permits the making of permanent and accurate records of past experiences, and so their utilization in identical form at any time.

Language as a Factor in Individual Progress. — Considered from the standpoint of the individual, there is no doubt that language as an aid to clear thinking has contributed greatly to the advancement of mankind. No person with sufficient intelligence to think at all, but achieves much more than he otherwise would through his ability to think in terms of words. From the standpoint of the race, language, the spoken word to a great extent and the written in incalculable measure, has forwarded progress nation by nation and generation by generation. To appreciate the advantages man enjoys over the other animals in this regard he has only to bear in mind that no matter how much one of the lower animals might learn, or how many important inventions he might make, his achievement would do his fellow animals almost no good because his means of imparting his knowledge to them are so limited. The spread of information from man to man by word of mouth, on the other hand, can be and often is very effective. The limits to the usefulness of spoken languages, and by the same token the superiority of written records, lie in the impermanence and lack of reliability of the former, due to the fallibility of human memory, contrasted with the permanence and accuracy of the latter.

THE SIGNIFICANCE OF LANGUAGE TO RACIAL PROGRESS is twofold. In the first place, each generation is enabled to begin substantially where the last left off. On the whole, the important achievements of mankind are recorded, generation by generation; thus they become available for succeeding ages and do not have to be rediscovered. In the second place, and perhaps even more importantly, language serves to make available the achievements of individuals of superior attainments. The point has been emphasized in a previous chapter (XLII) that a certain percentage of the population is definitely superior to the rank and file in intellectual power. It is a fact of history which cannot be gainsaid that on the whole the contributions to knowledge upon which progress depends are made by the highly intelligent minority. The actual progress itself, however, depends on the adoption by the rank and file of the achievements of the intelligent. Only by means of language, written or spoken, is this adoption brought to pass.

EMOTIONAL CHARACTERISTICS. — The emotions, or feelings, represent the driving forces of human conduct. In man, as in the higher animals, conduct or behavior is made up of very complex activities which result from and rest upon equally complex sensory and nervous relationships. Among these, as has already been pointed out, are many simple reflexes, many activities which through frequent repetition have become so habitual as to be to all intents and purposes reflexes, a certain number that rest upon a purely intellectual basis — in other words depend upon associated memory — and, finally, another great group — including probably nearly all our volitional acts — that are carried on at the instance of some feeling. Since the emotions underlie volition so largely, one is entitled to speak of them as the driving forces of conduct. By way of illustration, curiosity, avarice, hatred, love, may be mentioned as such driving forces. Biologically, they count as factors in individual or racial perpetuation. When one attempts to compare the emotional characteristics in men and in animals, the difficulty is encountered that there is no means of judging what emotions are present in animals except through the study of the bodily manifestations which accompany them and the actions which result from them. So far as this kind of observation goes it indicates that the fundamental emotions, those associated immediately and definitely with individual or racial preservation, are very similar in man and in the higher animals. In addition to these, men exhibit certain feelings which — so far as can be judged — are without counterpart among lower animals. Among these are feelings associated with high moral standards; the sense of responsibility, the traits of honesty, justice, and generosity influence human conduct — and therefore human progress — profoundly, and are consequently factors of prime importance.

The Interaction of the Emotions with Intelligence. — In the actual working out of mental functioning it is clear that the emotions may on the one hand direct the intelligence, and on the other hand the intelligence may affect the manifestations of feeling. The emotional reactions of a savage to personal abuse, for example, are likely to be very different from those of the highly civilized man. Likewise the thought process itself, which lies at the basis of all intellectual power, is guided to a very large extent by the emotions. Evidently, the highest type of individual is one who is endowed with great mental power and in whom the actual process of mental functioning is guided by well-balanced emotions.

CHAPTER XLIV

HUMAN PROGRESS

PAST PROGRESS THE REALIZATION OF INHERENT POSSIBILITIES. — In the last chapter emphasis was placed upon the fact that progress within historical times has not consisted — to any large extent, at least — in the development of fundamentally better human beings, but in a partial realization of the possibilities inherent in mankind, primitive as well as modern. It is obvious that if every organism fully realizes its inherent possibilities there can be no further progress except by improving the race. This seems to be, generally speaking, the situation among all kinds of animals except man. Generation by generation, they appear to realize approximately their inherent possibilities. It is pertinent, therefore, to inquire what are the handicaps which delay man's progress and the means by which they are to be overcome.

INHERENT POSSIBILITIES ARE NOT YET FULLY REALIZED because of difficulties imposed by the environment. It is quite clear that if the environment were ideal in every respect every individual would actually show all that he is capable of. By the expression, ideal environment, is meant one in which all the conditions of living and all the sensory stimuli making up the basis of behavior are those best suited to the welfare of the organism and the race.

ANIMALS EXERCISE A LIMITED CONTROL OVER THE ENVIRONMENT. — The study of animal behavior shows that animals do comparatively little to bring about conditions favorable to themselves. They may move from an exposed spot to one that is sheltered, or from a region where food is scarce to one where it is abundant, or from a perilous area to one of security; aside from such activities as these, they accept the situation that exists and get along as best they can. Definite efforts to change conditions for the better can hardly be said to exist among even the most intelligent of animals other than man.

Man Largely Controls His Environment. — The fact that human beings do not submit dumbly to unfavorable conditions but exert themselves to bring about favorable conditions lies at the basis of progress. Civilized races surpass the uncivilized in the first place because they are hereditarily more intelligent, and in the second place because they have unceasingly improved their environment; savages are on the whole less intelligent and more submissive, and exercise themselves only to the point of achieving bodily comfort, personal security, and racial perpetuation. In other words savages have utilized their characteristic human traits little more than to secure for themselves the *fundamental* biological needs in the easiest manner possible. As soon as these needs are met they rest content. Civilized man, on the other hand, has pushed his control over the environment far beyond the satisfaction of these immediate needs, and compels it to yield him greater and greater wealth of experience on which to base broader and ever broader mental development; and thus attains a plane of living in which the simple satisfaction of the fundamental biological requirements of food, security, and racial perpetuation plays a relatively minor rôle.

The Details of Progress. — Since progress depends upon the control of the environment it is evident that one can learn how progress has been made by noting the environmental handicaps which man has had to overcome and by considering how he has gone about the task of overcoming them. Also, since the human race is very far from having achieved the ultimate of progress, this same consideration of the environmental handicaps should point the way to further progress.

THE SATISFACTION OF THE PRIMARY NEEDS AND THE ENRICHMENT OF LIFE. — Throughout the discussion of human progress the fundamental fact should not be forgotten that the primary biological requirements of food, security, and racial perpetuation form the groundwork of human as well as of all animal behavior. Progress concerns itself first with securing for the whole race satisfaction of these fundamental needs; thereafter, it may be devoted to less immediate although exceedingly important demands which may be grouped under the general head of *enrichment of life.* In contrasting animal with human behavior, the total absence in animals of anything that tends toward enrichment, and the increasing presence of enriching factors as man becomes more civilized, are the outstanding features of comparison. In striving to improve his environment man devotes himself first to the satisfaction of his fundamental necessities, and thereafter to the enrichment of his life. In the following paragraphs, some of the most important of the environmental handicaps are mentioned, and the ways in which mankind strives to overcome them are considered.

THE FOOD SUPPLY. — Every animal concerns itself first with securing food. This is as true of human beings as of any other kind of animal. If the human race is to survive, food supplies must be adequate for its nourishment. There are no efforts directed toward controlling the environment more fundamental than those which concern themselves with food resources. From the rude beginnings of progress in which seeds were scattered in soil that had been slightly loosened with the aid of a sharp stick, mankind has seen advancement to the point where costly schools of agriculture, experiment stations, and research institutions are devoted wholly to the problem of producing, conserving, and distributing food. Control of the environment in this respect means not only the production of sufficient food for the feeding of mankind, but its production in the most efficient manner possible, since, as has already been pointed out, it is only as leisure time is gained from the satisfaction of the fundamental requirements that man is enabled to devote himself to the enrichment of life. Even so elementary a part of the problem as securing for *every human being* the amount of food required for his adequate nourishment is still far from solution. Competent authorities assert that there are millions who live out their entire lives without having ever been adequately nourished. So long as this condition prevails the environmental handicap imposed by food shortage must be considered acute. And even when progress has reached the point where every human being always has enough to eat, there will still remain the task of producing food so efficiently that all mankind will be assured of adequate leisure which he may devote to the higher phases of living.

Security of Life. — The second of the fundamental biological requirements is that of individual security. Mankind strives to control the environment in such a way as to lessen his liability to injury and death. The greatest menace to human security has always been man's competitive struggle with other organisms — either with wild animals or with the organisms of disease, or with other men either in individual struggle or on the wholesale scale of war. Progress toward overcoming the handicap of personal insecurity is achieved — so far as danger from wild animals or from disease-producing organisms is concerned — by a policy of extermination. The first care of the pioneer is to destroy such wild animals as constitute an immediate menace. The final aim of medical science is to exterminate the organisms of disease or to render man immune to their attacks. A preceding chapter has emphasized the difficulty of this struggle and the great progress that has been made in some directions. No one can fail to realize, however, that disease still constitutes a serious threat to personal security, and that only by continued and prolonged exertions on the part of medical investigators can we hope to see this menace reduced to a degree where it will cease to be a very present concern.

The Destructive Competition of Man with Man on the *individual scale* has been reduced, in civilized communities, to the attacks upon society by the criminal classes. Security against this menace obviously depends on increasingly efficient control of criminals. The vast *destructiveness of war* will be ended when man realizes that progress, both individual and racial, depends upon securing time and opportunity for those activities which enrich his life, and that to the extent to which he devotes time and effort to securing himself against the attacks of his fellowman or to fitting himself to attack them in turn, he is denying himself opportunity for development along lines that are really worth while. The practical means to bring to an end the destructive activity of man against man must finally be the adjustment of human relationships on a basis — not of selfish prejudice, but of unselfish application of scientific principles.

Coöperation a Biological Necessity for Progress.— At this point it would be well for the reader to recall that progress among all sorts of organisms has been repeatedly shown to depend on specialization and harmonious coöperation. This is equally true of the parts of a man's body or of the individuals of animal and plant associations. Much of man's progress in the past has rested on this same secure foundation. When this truth is once fully realized, destructive competition — whether of warring nations, industrial strife, or individual combat — will be seen to be at worst a horror and at best a silly waste of time, and will be replaced by constructive efforts directed to the enrichment of life.

Lessened Child Mortality. — Among animals generally there is a direct relation between the number of offspring and the hazards of early life. Those species in which the chance of attaining maturity is good produce few young; those in which the hazards are great produce large — sometimes enormous — numbers. With increasing civilization human families tend to become smaller. That this fact constitutes a menace to the perpetuation of the highly civilized races cannot be denied. Man must strive to overcome this handicap as he strives to overcome other handicaps which interfere with human progress, and an evident line along which achievement in this respect is to be secured is by preserving to maturity all the young that are fit examples of their race. Much has been done in this direction in the past few decades, so that at the present time infants have a much better chance of living to maturity than did those born fifty years ago. Much remains to be achieved in this direction, but it is reasonable to look forward to a time when every infant born in families of good stock will survive to maturity and thus be able to bear its part in the perpetuation of the race.

Education. — In the last chapter progress was stated to be commonly based on the achievements of the highly intelligent, but to depend on the adoption of these achievements by mankind in general. It is evident that since this is the case it is only as such achievements become known that progress will be made. Organized society has adopted the plan of setting aside the years of childhood and adolescence as a period of formal education, namely, as a period during which shall be made known to the members of the coming generation those facts of human achievement upon which their own behavior and such progress as they in turn may make shall be established. That part of the community which devotes itself to the task of education has to select from the sum total of human experience those achievements which mean most to mankind, and then to drive them home in such fashion as to make them actual controlling factors in behavior. That this task is imperfectly performed everyone will admit. There remains, then, room for great progress in this field.

Isolation. — It is evident that since the achievements of those who have the ability to accomplish must be passed on to the general population if progress is to be made, the extent to which members of the population are isolated has great influence upon progress. In Chapter XXXVIII the tendency of animals to spread throughout regions to which they are adapted has been pointed out. Man shares this tendency with the other animals; in fact, he goes far beyond all others, since his control over his environment enables him to establish himself in situations in which otherwise he could not endure. The inevitable effect of man's migrations is isolation, both physical and intellectual. The first is being overcome by improved means of transportation, the latter by printing and the allied arts.

Printing. — There can be no doubt that the greatest single achievement by which isolation has been overcome is the invention of means for multiplying records on a large scale. Printing with movable type forms the basis of this achievement, although — as has been pointed out recently — the invention of paper-making had probably almost as much to do with the actual development of the book-maker's art. To the knowledge of how to produce records had to be added the knowledge of how to reproduce them. There is probably no human environment which is not susceptible of betterment through influences that can be brought to bear by means of the printed page. It is almost impossible for anyone now to live in such remoteness that his isolation cannot in large measure be relieved through the agency of the press.

Telephone, Telegraph, and Radio. — A glance at one's morning paper is sufficient to indicate what these agencies are doing to annihilate isolation. There one may find what the Premier of England said but a few minutes before, the price of stocks on the Paris or Berlin stock exchanges, the progress of an expedition attempting to climb Mt. Everest, as well as the multifarious doings of his own countrymen. All this is possible because news may be flashed over the world, at almost the speed of light, by cable or radio. With rural mail delivery, parcels post, and telephones, the farmer is not only likely to be as well informed as his city brothers but often better. So efficient, in fact, are the means of disseminating news that the question now is not one of more news but of sifting it and choosing only that worth knowing.

TRANSPORTATION. — We have the greatest difficulty in appreciating the physical isolation and consequent utter provincialism of our ancestors of half-a-dozen generations ago. Whole families lived out their lives without ever wandering so much as ten miles from home. To the majority of people the adjoining shire was as unknown and foreign a region as are the ends of the earth to us to-day. The difficulties and hazards of transportation operated as effective deterrents to all but the adventurous or those driven by necessity. Contrast with this the present time in which a large percentage of the population is able to travel about. Mechanical transport has improved and cheapened the means of getting from place to place until scarcely any adult member of a civilized community but has some first-hand experience of districts other than his own. To the free motion of persons must be added the tremendous volume attained in the transportation of goods. Thus one may to-day not only go to the ends of the earth, on occasion, but he is daily in contact with articles brought from its four corners. Anyone who reads this will have about his person a dozen things from remote parts of the world: shoes from Argentine hides; coat of Australian wool, with buttons of

South-sea vegetable ivory; a pencil made in Germany, with an eraser made from the sap of a Brazilian or Sumatran rubber tree; a Swiss watch, Egyptian cigarettes, or what not.

ADEQUATE PRODUCTION. — As civilization advances and life becomes richer, more and more material things are felt to be desirable. Contrast the satisfaction of an untutored savage in the possession of a few strings of beads and a small hand mirror with the yearning for books, pictures, musical instruments, and the other accessories of life on the part of the civilized world. The obvious handicap to the realization of the desire for these benefits is that there are not enough of them to go round. By way of illustration, take the matter of individual transport. No one will deny the enormous contribution automobiles make toward the enrichment of life. Anyone may legitimately desire to share in this enjoyment. Obviously, this desire cannot be fulfilled until sufficient numbers of motor cars have been produced, with sufficient supplies of motor fuel, so that there will be enough for all. The increasing desires of mankind call for continually increased production. This demand can be met only by inventions and discoveries, especially of machinery which takes the place of human hands. The limit of productivity by hand is obviously very far below present human needs and desires. Mechanical devices have played a great part in human achievement, and must play an even greater part if mankind is to continue to progress to that point at which all legitimate human desires are satisfied.

HIGH IDEALS. — In previous paragraphs it has been emphasized that an essential feature of human progress has been its passage beyond the satisfaction of the fundamental biological requirements of food, security, and racial perpetuation, to those achievements which constitute enrichment of life. An important element in this latter group has been the setting forth of high ideals of human conduct. Men of superior intelligence, from early historical times down to the present, have stressed the enrichment of life through the practice of those traits which we associate with the highest and most unselfish standards. Human progress along these lines depends upon the effectiveness with which high ideals can be caused to prevail among men. This is to be attained by a concerted effort on the part of those individuals who are sufficiently intelligent to perceive the hindrance offered to achievement by low ideals, and to drive home to their fellow-men the duty of living up to the highest standards. It is necessary, therefore, to discover what ideals lead to progressive achievement and then to include this knowledge in the education of everyone, but particularly of those destined by high ability to be leaders of their fellow-men.

THE IMPULSE TO COMBAT. — A fact of fundamental biological importance, and one which has been emphasized repeatedly in previous sections, is that organisms come into competition in attempting to obtain food supplies, in making themselves secure, or in perpetuating the race. This competition frequently leads to direct combat. And just as hunger is a powerful impulse to the taking of food, and its effectiveness is reinforced by the enjoyment afforded by eating, so there is an impulse to combat which is attended by feelings of enjoyment or satisfaction whereby the combat impulse is reinforced. It is clear that the thrill which attends strife is a very real biological phenomenon, applying to man as well as to other animals, and must be taken into account, therefore, as a factor to be reckoned with in human progress. The recognition of the fundamental character of the impulse to combat has led in some instances to the expression of the view that strife among human beings is not only desirable but biologically necessary. This argument has been advanced as a justification for war, although probably not many will be found at the present time who are prepared to maintain the argument in this extreme form. It appears to be sound logic to recognize the existence of the strife impulse, and to seek means whereby it may find expression without harming mankind.

Sports. — A suggestion often made, and one that certainly has much to recommend it, is that in organized competitive sports the impulse to combat may be satisfied, to the benefit rather than to the harm of humanity. The great and apparently increasing vogue of competitive sports offers the possibility that man may through this channel achieve, at least in part, such satisfaction of the strife impulse as he desires, without such hindrance to his progress as the destructive competition of war inevitably entails.

Commercial Success. — Without doubt much of the lure of business life lies in the opportunity it affords for obtaining the thrill of strife. To compete successfully in the world of commerce; to pit one's abilities against the abilities of other men and come off victorious; to wield the power that attends success; for a large fraction of civilized humanity these count among the supreme rewards life has to offer. While to the abstract thinker such ideals may seem to fall short of the best of which mankind is capable, the fact cannot be denied that commercial strife includes, with its undoubted evils, much of good; while the strife of war, perhaps not wholly evil in past times, has for modern civilization no redeeming feature. To substitute industrial competition for warfare means, then, to make an advance. One may reasonably look forward to a time when an adequate substitute for commercial strife will be found, when a further advance will be achieved. Of the nature of this substitute there is only this to say — that it must be founded upon the nature of man as a biological entity, and not upon any philosophical speculations upon what man might attain were he different than he is.

Future Progress. — So far as we are able to perceive, progress in the future must be in large part along the same general lines as in the past. So long as there are environmental handicaps that have not been fully overcome, so long as any individual is unable to realize his inherent possibilities because the conditions for such realization have not been fulfilled, there is still room for and need of effort. Achievement has gone so far that in imagination a time can be foreseen when man will have attained to complete control over his environment. Only when that time has come will progress in the direction here outlined come to an end.

Racial Betterment. — Although progress by controlling the environment might conceivably thus come to an end, the progress of humanity need not stop, since there continues the ever-present possibility of actual improvement of the race. It will be recalled that in the discussion of progress thus far the point has been stressed that the achievements which mankind has made are not to be accounted for by demonstrable improvement in human quality. When mankind with his present abilities has gone as far as he can, there will still remain possibilities of breeding better men. It is true that to obtain individuals superior to the best that have yet lived is a feat of great difficulty, theoretically as well as practically. But to raise the general average of the race, physically, intellectually, and emotionally, is entirely feasible, requiring nothing more than the application to the human family of well known principles of genetics. There are, to be sure, great difficulties in applying these principles, even to the extent of raising the average by cutting down the number of distinctly inferior individuals. To do what is even more desirable, viz., to bring about an actual increase in the number of superior individuals, is a matter of greater practical difficulty. It may be that mankind will never be able to overcome these difficulties entirely. It is quite sure that at best their solution can only be gradual, and — because of the in-frequency of human generations, which run only three to the century — it will obviously be a long time after a beginning is made before striking results can be obtained. It is clear, however, that the sooner serious general attention is paid to racial betterment through eugenics the better it will be for mankind, both in the near and in the long distant future.

FINIS

INDEX

Burlingame, Leonas Lancelot
General biology.