PRACTICAL BOTANY

BERGEN AND CALDWELL

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PREFACE

There are already so many books embodying elementary courses in botany that whoever offers another should give reasons for so doing. As here set forth, the study of plants is related to everyday life more closely than is usually done. Those aspects of plant life are presented which have the largest significance to the public in general, and which are of interest and educative value to beginning students. The book includes the principles of plant nutrition, the relation of plant nutrition to soils and climate and to the food of animals and men; it discusses some of those diseases of plants, animals, and men, which are produced by parasitic plants; the propagation of plants, plant breeding, forestry, and the main uses of plants and plant products are given in an elementary way. The elements of plant life and structure are presented synthetically rather than by use of the special divisions of botanical study, which are more helpful to advanced students than to beginners. It is believed that this mode of treatment stimulates and develops a scientific method of thinking by directing attention to the plant as a living unit and a citizen of the plant world. No attempt is made to include references to such recent discoveries in the field of botany as are botanically significant but not important for elementary instruction.

Chapters I and II are so arranged that a student may secure a general introductory appreciation of the significance of plant structure and work. It is intended that Chapter I should be used as a means of raising questions concerning the place of plants in nature. Chapter II presents an outline of the five dominant structures of seed plants, and the kind of work that is done by each. It is intended that this chapter shall enable the student to see the plant as a working unit, while the chapters following it give a more detailed treatment of each of the dominant structures, and the outline sketch of the whole plant now serves as the basis of interpretation of this more special study. Then follow rather brief though adequate chapters dealing with the great groups in the order of their increasing complexity, and these are followed by chapters which treat of broad aspects of plants and their relation to plant industries.

The material in the book, which is sufficient for a year's course, is so arranged that it can be adjusted to a half-year course when local needs make this desirable. When seasons are favorable it is thought best to follow the order of chapters as given, but seasonal conditions are so diverse in different parts of the country that the teacher is urged to rearrange chapters whenever necessary for adequate illustration of such topics as flowers, seeds, and weeds. If this is done, Chapters I and II may be studied briefly, and then followed by chapters dealing with special topics.

When the book is used in a half-year course, Chapters I and II should constitute an introduction, and it will usually be found advisable to follow these with Chapters III–XI and XXI–XXV. In some cases, however, it will be found advisable to follow Chapters I and II with Chapters X–XX. In any event, in a half-year course, Chapters XXI–XXV, because of their practical significance, should be assigned for collateral reading if they are not used as the basis of regular class work.

Not infrequently facts are restated in connection with topics other than those with which they first appear. This seems unavoidable unless other important considerations are sacrificed, such as securing plasticity in the order of use of the various chapters and avoiding excessive cross reference.

The number of botanical terms used is as small as is consistent with a clear presentation of the facts. The order of the great groups of plants agrees with the most recent usage of the best botanists. In accordance with this usage the bacteria and the blue-green algæ are presented first in the studies of the great groups. The relatively large importance to general students of a knowledge of bacteria justifies the considerable amount of space that is given to this group.

The course outlined in this book will meet the needs of students who wish to present botany for college entrance. While the point of view is somewhat different from that which is usual in elementary textbooks of botany, the topics treated are those outlined for secondary schools by the Botanical Society of America and the North Central Association of Colleges and Secondary Schools. These units are the ones generally recognized throughout the United States.

The authors wish heartily to recognize the valuable assistance that has been rendered them by the following authorities: Professor Henry C. Cowles, Mr. George D. Fuller, and Professor Edwin O. Jordan, of The University of Chicago; Professor Benjamin M. Davis, of Miami University; Professor William F. Ganong, of Smith College; Director Charles E. Thorne, Botanist Augustine D. Selby, and Agronomist C. G. Williams, of the Ohio Agricultural Experiment Station; Acting Director Herbert J. Webber and Professor C. G. Warren, of the New York State College of Agriculture; and Professor Edgar N.Transeau, of the Eastern Illinois State Normal School.

A large number of high-school teachers of botany have given suggestions and criticisms, and we desire to express our appreciation of this assistance from those who are in direct contact with the problems of teaching botany in secondary schools. Mr. William L. Eikenberry, of the University High School, Chicago, has given abundantly of his experience and his time in making suggestions and reading manuscript and proof. Mr. Paul T. Sargent, Mr. E. N. Fischer, and Mr. F. Schuyler Mathews, the illustrators, have added to their artistic ability a genuine interest in the presentation of plant life to beginning students, for which we wish to express our appreciation.

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CHAPTER I

INTRODUCTORY — PLANTS IN NATURE

1. Abundance and distribution of plants. We are so accustomed to the presençe of plant life almost everywhere on the earth that an extreme scarcity of plants over any considerable area seems more remarkable than does their abundance. The complete absence of living plants from any large part of the land surface or the shallower waters is a condition which probably seldom occurs. It may occur in regions where there are poisonous salt deposits, or in times of extreme dryness, or when the temperature is too high or too low for plants to live. Some of the simplest plants can for long periods withstand the most intense cold ever encountered upon the earth, and a few of these plants can withstand high temperatures for a brief time. Ordinarily volcanoes or bodies of hot lava, and some hot springs and alkali deposits are therefore the chief visible portions of the earth which are quite lifeless.

It is a matter of familiar knowledge that the lands and the waters differ greatly in the density of their plant population. Some areas of the barest Nebraska sand hills do not on the average contain more than one flowering plant to every three thousand square feet, while a weedy garden has been found to contain as many as 75,000 plants in a similar area. If the barest portions of the Sahara were compared with a good lawn or meadow, the disproportion would be far greater. The purest natural waters contain no organisms visible to the eye, while stagnant pools are often so filled with pond scums and other simple and minute plants that each cubic inch contains many thousands of individuals. We cannot enumerate all the kinds of places in which plants find lodgment and grow. They occur in all the seas, as well as in the fresh waters, on every kind of soil from the wettest swamps to arid deserts, on rocky cliffs and the bark and leaves of trees. Microscopic forms sometimes occur in myriads in the blood of animals, and most soils teem with them to the depth of several inches below the surface.

It is a notable fact that some plants are the smallest and others the largest of living beings, and it is evident that plants are on the whole by far the most conspicuous of living things.

2. Plants and animals. A little thought about the things upon which common animals feed will show that plants directly or indirectly supply food for animals. Many animals get their food directly from living plants, in the form of roots, leaves, seeds, fruits, etc., and these are called herbivores (plant eaters). Those animals called carnivores, which eat the flesh of other animals, are dependent upon plants, since their prey are plant feeders or may live upon those that are plant feeders. In one way or another all animals are dependent upon plants for food.

3. Plants and the industries. Man is also directly or indirectly dependent upon plants for his food. His animal food is indirectly derived from plants, his bread is made from the seeds of plants, and there is a constantly growing list of foods, spices, and flavors that are prepared from roots, stems, leaves, seeds, and fruits.

Much of the work in which men are engaged is performed by domesticated animals as beasts of burden, or is concerned with rearing domesticated animals or growing plants for the market. These animals could not be cared for were it not possible to feed them with the products of domesticated plants, and many of the kinds of work for which beasts of burden are used would not exist were it not for the need of growing plants for the world's uses.

The domestication and improvement of plants has been an essential part of the development of many industries, and has advanced until at the present time the greater part of the food of the world is secured from certain kinds of plants which once grew wild and produced little that was of value to men. The plant producing the biggest crop in the world is the potato, which in 1906 produced 284,000,000,000 pounds of potatoes. But the most important crop in the world from the point of view of the market value of its product is wheat. In each of three great agricultural regions of the United States one plant is dominant in its value. In the central corn belt there are seven states that produce nearly one half the corn used in the whole world, an amount which in 1909 was worth nearly $3,000,000,000. The Southern States produce over three fifths of the cotton of the world, an amount worth nearly $1,000,000,000. The Northwestern States produce wheat, which, while not so large a proportion of the world's crop, is of tremendous importance to the welfare of the nation.

Plant fibers are extensively used in the manufacture of clothing. Timber is used in the construction of buildings, furniture, vehicles, and implements for use in the industries. Plant extracts compose the most of our medicines. The paper upon which our ideas are recorded is made chiefly from wood pulp, though it is now proposed to make it from cornstalks. The processes by means of which green plants live, as will be shown later, contribute to the purification of the atmosphere that we breathe.

The farmers' barns, the city feed stores, warehouses, cold-storage establishments, almost every manufactory and salesroom, and many of the railway and steamship transportation lines in some way are illustrations of the important relations which plant life bears to the fundamental industries.

4. How plants live: the most important phase of botany. In connection with the preceding discussion regarding the place of plants in nature, it must be clearly understood that plant structures and processes are of importance primarily for their function in maintaining the life of plants themselves, and that their use in the industries is a by-product of plant life. The body of a tree is produced in the tree's ordinary processes of growth, and thereafter it chances to be useful to men for timber. Though corn and wheat have been improved artificially until now they supply much of the food of mankind, in nature as wild plants they produced seeds which were small but sufficed to give rise to new plants. The possibilities of utility result from the ordinary activities and structures of plants, and the study of these possibilities must be made accessory to the consideration of the general principles of plant life. What plants are and how and where they live are the most fundamental questions, and are the ones which we shall first consider in the following chapters.

CHAPTER II

GENERAL STRUCTURE AND WORK OF PLANTS[1]

5. Introductory. Any one of our most familiar plants consists of roots, stem, leaves, flowers, and fruits containing seeds. Each of these parts is usually distinct (Fig. 1). Each does one or more particular kinds of work, and together they do the work of the whole plant. The plant, therefore, is a complex structure, whose life is dependent upon the work of its different parts.

6. Roots and their work: anchorage. The most obvious work of roots is done in holding plants in place, or in giving them anchorage. On steep hillsides, on banks of streams, and in shallow soil which lies upon stone, the amount of anchorage which roots afford is often so small

FIG. 1. A buttercup (*Ranunculus acris*)

The plant consists of roots, stem, leaves, flowers, and seeds. *A*, the plant, shown about one eighth natural size; *B*, cluster of ripened seeds, shown almost natural size; *C*, a section through one seed, shown almost three times natural size

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[1] This chapter presents an outline of a plant as a working machine. It does not include details but gives a general view of the plant and the kind of work that it does. If this outline chapter is studied briefly, later discussions will be more easily understood and more profitable than if numerous details are presented first. The chapter should be read carefully by each member of the class and discussed in one or two recitations, or it may be read and discussed by pupils and teacher together.

that trees are uprooted (Fig. 4) in times of heavy wind. In other cases the anchorage may be so great that during a heavy wind the plant will be broken off instead of having its roots upturned. A study of such situations as those just mentioned will give some idea of the distance to which the larger roots spread and of the amount of soil that lies as weight upon them.

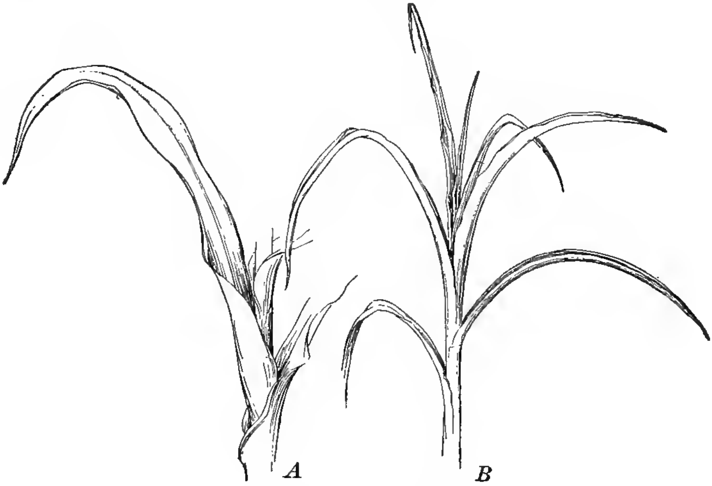

FIG. 2. Tips of two cornstalks

A is in normal growing condition, while *B*, through excessive loss of water, has wilted and its leaves are contracted into tube-like rolls

7. Roots and their work: water supply. Water is essential to the growth of plants. Plants of the farm, garden, lawn, and those commonly grown in our homes have their roots in the soil and their stems and leaves in the air, and therefore, if they secure water at all, must get it from the soil or air, or both. When roots are deprived of water the plants soon wilt (Fig. 2) and eventually die. If one should pour water upon the stems and leaves, but deprive the roots of it, the plants would not thrive. Ordinarily roots secure water for the entire plant.

8. Roots and their work: root hairs. Most root systems branch near the base of the stem and continue to subdivide (Fig. 3)

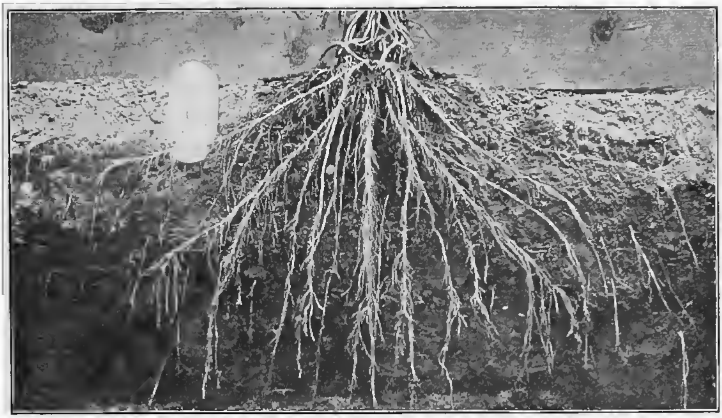

FIG. 3. The root system of the corn plant

The soil has been washed away so as to show the quantity and spread of the roots, and, to some extent, the positions that they assume in the soil. Photograph by the United States Department of Agriculture

FIG. 4. Two upturned spruce trees which grew upon a stony surface

The entire root system spread over the rock did not provide sufficient anchorage to hold the tree in place in time of a very heavy wind until the roots are extremely small. During periods of active growth root hairs appear upon the smaller rootlets (Fig. 5). These rootlets, like the other parts of the plant, are made up of many cells (Fig. 6). Each cell has a wall, the *cell wall*, which incloses the living material, called the *protoplasm.* In the root hairs, as in Fig. 6, two parts of the protoplasm are shown, the *nucleus* and the granular *cytoplasm.* Cells contain other protoplasmic bodies, which need not be discussed at this time.

FIG. 5. A mustard seedling grown in a band of filter paper inside a drinking glass so as to show the root hairs

Note the difference in length and condition of the root hairs on the different parts of the root

The root hairs are extensions of the surface or epidermal cells of the rootlet and are parts of those cells. They grow a little way back from the tip of the rootlet and new ones appear as the root tip pushes forward in the soil, so that with the dying of older root hairs and the development of newer ones on new growth of the rootlet, the actual number of root hairs on a rootlet during the growing season may remain practically constant. It is evident that the area of root hairs on a rootlet advances, although the single root hairs do not move forward through the soil. The root hairs extend laterally from the rootlet, growing through the soft particles of the soil and around the harder ones, thus constituting a

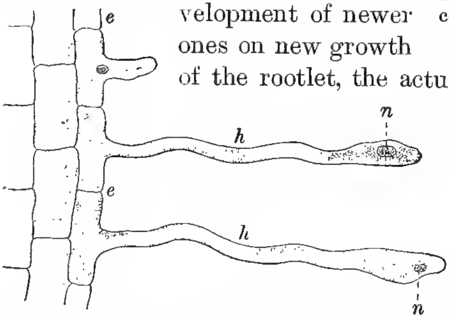

FIG. 6. Cells from the surface of a young rootlet

Showing epidermal cells (*e*), and one young and two older root hairs (*h*). In the root hairs the nucleus (*n*) and granular cytoplasm of the cells are shown. Greatly magnified network in the region about the tip of the rootlet. If the seedlings are grown in sawdust, on damp blotting paper, or within earthen pots that are kept moist by covering or by being inverted upon a damp surface, they will afford interesting demonstrations of how rootlets and root hairs grow under different conditions.

9. Roots and their work: water-lifting power. If the top of a vigorously growing potted plant is cut off and an upright glass tube is attached to the plant stump by means of a rubber tube, water may be forced upward in the latter, thus showing that roots can lift water from the soil. Actively growing trees and shrubs, when cut, often show this same phenomenon by forcing out through the cut surface some of the water that is brought up from the soil. This is sometimes incorrectly spoken of as "bleeding" of the stump. The roots, however, are not the only parts of the plant that may lift water. That the leaves and stem may also do this work may be shown by cutting off the top of a plant under water, and, while still under water, attaching the stem to a water-filled U-shaped tube. The top of a plant that has been so treated may continue to lift water for several days.

In plants that are growing normally, the roots, by means of the root hairs, take up water from the soil. It passes into the interior of the rootlet, then into the larger roots, into the stem, and finally into the leaves. Some of this water is carried from the leaves into the air, and that process will be discussed under the topic *transpiration.*

10. Roots and their work: turgidity. Root hairs and other cells of plants usually take up water until the cell walls are distended with water and protoplasm. The outward pressure which distends and stretches the walls is called *turgor*, and the resulting condition is called *turgidity.* Turgor doubtless helps to force water upward through the stem. The distention of cells due to turgor also accounts for the rigid or erect position of most leaves, growing shoots, and succulent stems. Each distended cell, like an inflated balloon, assumes a semi-rigid position, and a mass of distended cells pressing against one another makes the whole structure rigid. But as when the air escapes from a balloon its wall collapses of its own weight, so do the cells of the leaves and shoots when, through loss of water, they lose their turgidity. When soil water is not

Fig. 7. A photograph of a cottonwood leaf from which the green tissue has been removed so as to show the network of veins through which the food material is carried throughout the leaf and to the stem

Natural size. Leaf prepared by Ellsworth Bethel available to the plant, the outgo from the leaves is often greater than the income from the roots, and in such cases wilting follows. If water does not again become available, the plant will die, but with a renewed supply turgidity and the resulting rigidity soon return.

11. Stems and their work: water passes through the stem. The stem is a means of connection between the roots and the leaves. It also serves to support the leaves in the air. Ascending water passes mainly through special regions of the stem and the leaf. When a fresh leaf of celery or leafy stem of hydrangea is placed for a few minutes in one of the aniline dyes, and then removed and examined by sectioning, definitely stained regions appear, which show not only that the staining liquid passed upward into the stalk, but that it passed through only certain tissues of the stalk. These special tissues through which the liquids pass are composed of bundles of very small tubular cells which are many times as long as they are thick. The bundles are known as *fibrovascular bundles*, — which term simply means "collections of thread-like tubes." The different cells of these bundles overlap one another in such a way that they are continuous from roots, through stem and branches, into the leaves. In the leaves the bundles are the so-called veins (Fig. 7).

12. Stems and their work: kinds of stems. There is a striking and important difference in the arrangement of fibrovascular bundles in the stems of different kinds of plants. If a stem of corn or a plantain leafstalk is broken, whitish strings are pulled from the pith (Fig. 8). These are vascular bundles. They are somewhat irregularly distributed throughout the stem, and

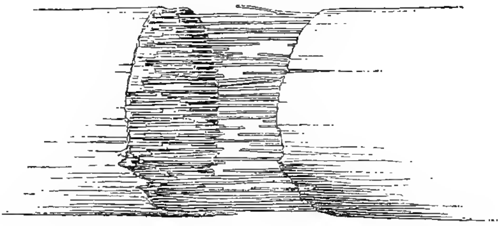

FIG. 8. A cornstalk broken so as to show the number and distribution of the vascular bundles

are intermingled with the soft pith tissue. There is a large group of plants, the *monocotyledons*, which have the irregular distribution of bundles just described. In such stems there is usually, around the outside, a much harder tissue, which is extremely strong, and which serves to strengthen the stem.

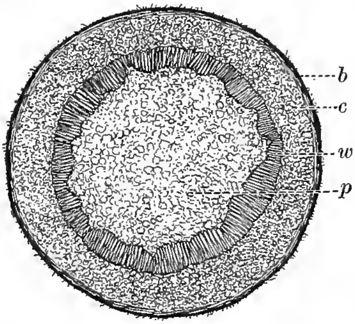

FIG. 9. Diagram of a cross section of a geranium stem

The regions are the outer bark (*b*), the cortex (*c*), the woody tissue (*w*), and the pith (*p*)

In other kinds of plants a cylinder of bundles is definitely arranged about the pith (Fig. 9), and this arrangement is also characteristic of a great group, the *dicotyledons.* Other features of these groups are discussed in later chapters, and in this connection it is important only to note some general characters of the stem.

13. Stems and their work: annual growth. In many of our common *annual* plants (those that live for but one year) the arrangement of the bundles or woody tissue in the form of a cylinder about the pith is readily seen. In such plants the pith usually occupies more of the stem than does the wood. The proportion of pith to wood is much less in the *perennial* plants (those that live for two or more years). In a cross section of one of the common trees, unless the specimen be quite young, it will be difficult or impossible to discover any pith region. The greater part of the section is made up of wood. Each year there is formed a layer of this woody tissue from the inner, heavy-walled cells of the bundles, which persist and give strength and support to the whole tree. The great size of our forest trees is made possible by this arrangement of bundle tissues. The record of growth may be read by studying the rings of wood. The amount of a year's growth and the total time that a tree has lived can be reckoned. You will also find it interesting to study the top of your desk or the furniture in the room to see if you can recognize the partial rings of wood or can tell the way in which the timber was sawed. In later chapters there will be a more extensive study of stems and the ways in which they grow.

14. Leaves, general form : the epidermis. Most leaves consist of two parts, — the leafstalk or the *petiole*, and the *blade*, which is the expanded portion. In some leaves the petiole is absent, and in others the blade is subdivided into several parts, in which case the leaf is said to be compound. To most observers leaves appear to be a uniformly green mass of material. More careful observation discloses the fact that many leaves are not equally green on both surfaces, and that running throughout the leaf there are more or less regularly arranged veins or fibrovascular bundles which are not green.

From the upper and lower surfaces of leaves such as those of live-forever, Wandering Jew, Easter lily, and spiderwort one may peel a thin, almost colorless layer, which is known as the epidermis (Fig. 10). The epidermis is composed of cells more or less compactly arranged. In the epidermis from one and sometimes from both surfaces there are special structures known as *stomata* (Fig. 10). From a surface view a *stoma* (plural, *stomata*) presents two more or less crescentic or kidney-shaped cells, the *guard cells*, between which is an elliptical opening, the *stomatal opening.* Unlike other epidermal cells, the guard cells are greenish. The opening serves as a place of entrance for

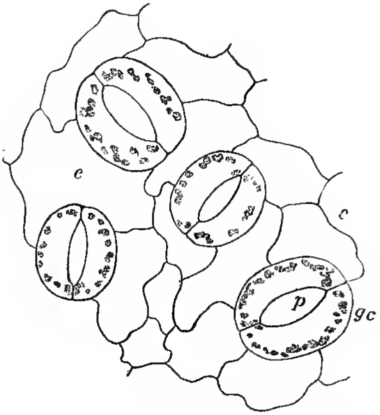

FIG. 10. A surface view of leaf epidermis from the geranium (*Pelargonium*)

Among the ordinary epidermal cells (c) are four stomata, each with two guard cells (*gc*) and the mouth of an air cavity (*p*). Considerably magnified most of the carbon dioxide used by the plant. The guard cells press closely together, or they may separate until a circular opening is formed, and in thus closing and opening they influence the interchange of air between the interior and the exterior of the leaf. This obviously affects the interchange of such gases as carbon dioxide and oxygen, as well as the outgo of moisture from the leaf.

15. Leaves: internal structure. The interior cells of the leaf, except those of the veins, are colored green by *chlorophyll*, which means "leaf green." The cells are not uniformly green, but the chlorophyll is contained in special small bodies, known as *chloroplasts* or chlorophyll bodies (Fig. 11), which are within the cells. It must be clearly understood that the chloroplast and the chlorophyll are not the same. Plastids (plasts) may or may not contain chlorophyll, just as a sponge may or may not contain water. It is evident, therefore, that a plastid can properly be called a chloroplast only when it contains chlorophyll.

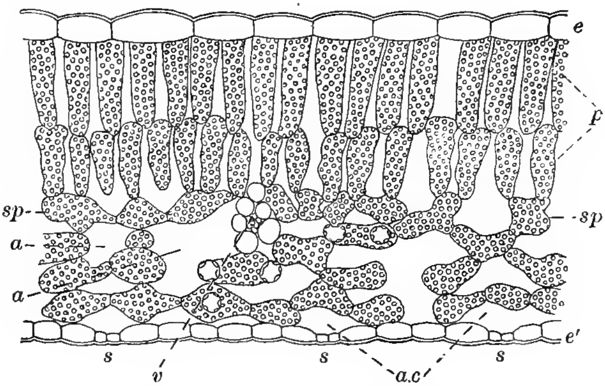

FIG. 11. Cross section of a geranium leaf

a, air space; *a.c*, air chamber; *e*, upper epidermis; *e′*, lower epidermis; *p*, palisade cells; *s*, stoma; *sp*, spongy parenchyma (usually spongy parenchyma has fewer chloroplasts than the palisade tissue); *v*, vein. Magnified 150 times. After drawing by Mrs. F. E. Clements

In summing up the structures of the leaf we may say that it usually consists of a *petiole* and a *blade*. The outer portions of the blade both above and below are the *epidermis;* in addition to the ordinary epidermal cells the epidermis contains special structures, — the *stomata;* within the epidermis are the *veins* and masses of green tissue; the green tissues are made up of more or less compact cells in which, in addition to other cell contents, are *plastids*, which contain the green coloring matter, *chlorophyll*.

16. Leaves: material for leaf work. In connection with the discussion of roots and stems it was found that water is carried into the leaves. In the soil are many substances which are dissolved by the water, just as common salt or sugar would be. When water is taken up into the plant some of these substances that are in solution also enter. In this way there may be carried into the plant compounds containing such things as nitrogen, potassium, phosphorus, sulphur, and iron. Through the surface of the leaf, chiefly through the stomata, the plant secures carbon dioxide. This is a gaseous substance which exists in the atmosphere in the ratio of about 3 parts in 10,000 of air. Inside the leaf, therefore, there is a supply of the so-called raw materials for food, — as water, carbon dioxide, and substances that were in solution in soil water.

17. Leaves: food manufacture. Carbon dioxide and water must undergo change before they can be used in nourishing and building up the plant. The sun shines upon the leaf and the chlorophyll absorbs some of the energy from the sun's rays. This energy serves in some way as yet unknown to break up the compounds water and carbon dioxide into the carbon, hydrogen, and oxygen of which they are made. The carbon, hydrogen, and some of the oxygen immediately unite again; not, however, into the compounds carbon dioxide and water, but into new compounds. These rapidly pass through several changes and may finally become sugar and starch. At present the changes before starch and sugar are formed are not all known. Some of the oxygen resulting from the breaking up of carbon dioxide and water is used in making starch and sugar, but much of it is set free and may pass out into the air. The oxygen thus set free by plants may be collected as shown in Fig. 12 and then tested. This process that is carried on by green plants is a principal factor in maintaining the oxygen supply that is so necessary to the life of animals. Plants also use some free oxygen in some of their later food-making processes. This series of occurrences by means of which green plants under the influence of sunlight make foods, such as starch and sugar, from carbon dioxide and water, is known as *photosynthesis.* The word *photosynthesis* means "putting together by means of light."[1]

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[1] The chemistry of photosynthesis is not completely known, but some of the simpler aspects of it may prove valuable at this point. Water is usually expressed by the chemist by the formula H_2O, in which H stands for hydrogen and O for oxygen, and the figure 2 indicates that two parts of hydrogen are united with one part of oxygen. Similarly CO_2 indicates that one part of carbon is united with two parts of oxygen to form carbon dioxide. When these compounds are broken up, there is, for a very brief time at least, free C, H, and O. If one unit of each compound (H_2O and CO_2) is thus broken up, there will be two H, one O, one C, and two O (or in all three O). After photosynthesis has been going on for some time, starch is usually formed. Starch consists of ($C_6H_{10}O_5$) "n". This means that six parts of carbon, ten parts of hydrogen, and five parts of oxygen unite to form starch, and the "n" means that the unit $C_6H_{10}O_5$ does not appear singly, but that an unknown number of them are united. Disregarding the fact that several of the starch units are held together, and considering the single unit $C_6H_{10}O_5$, we may be able to see what happens in the work of photosynthesis. To secure the amount of carbon necessary to form starch, six times the unit CO_2 must be taken, since there are to be used six units of carbon. To secure the needed amount of hydrogen, five times the unit H_2O must be used, since there must be ten units of hydrogen and two are secured with each unit of water. We have, therefore, $6\,CO_2$ and $5\,H_2O$. When the energy of the sun has broken these things into their constituent parts there are 6 C, 12 O, 10 H, and 5 O, or 17 O in all. But starch consists of $C_6H_{10}O_5$, and in making this unit of starch there has been used all of the carbon, all of the hydrogen, and five units of the oxygen, thus leaving twelve units of oxygen to be set free or to be used by the plant in some other way. Some of this free oxygen passes into the air, though some of it is used by the plant in a later process.

The compounds thus constructed, as starch and sugar, are called carbohydrates, the name indicating that they are compounds of carbon and water.

Sugar and starch may be used as food by the plant, being transported to and made into the living parts of the plant. Or these things may be made into more complex foods, known as the proteins, by the addition of some of the compounds of nitrogen, potassium, phosphorus, or other substances, and then digested and used by the plant. Replenishment and growth of new parts can take place only by means of foods, and since the plant makes its own supply, the importance of the process is very great.

Manufactured foods are carried to all the living parts of the plant. They may also be stored in almost any plant structure. When in process of moving through the plant, these foods are believed to pass through the soft portions of the fibrovascular bundles.

Furthermore, often more food is made by green plants than they need at the time, or even, in case of some plants, than they ever use, and this is stored most commonly in the form of starch, though sometimes in other forms. This stored food may be used later by the plant, or as food for men and other animals. It may also be moved by the plant and stored in a different structure from that in which it was first located.

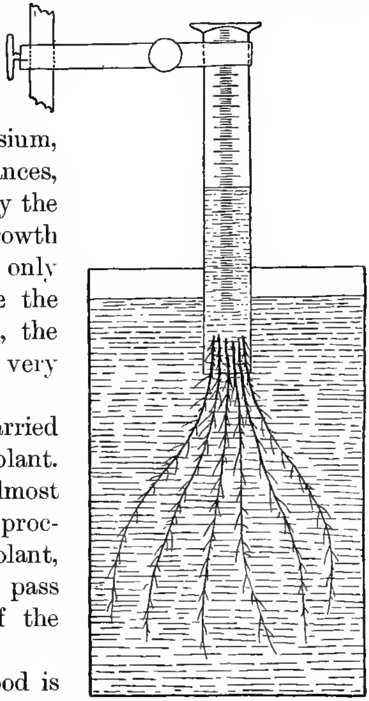

Fig. 12. Apparatus for collecting oxygen from working plants

Water plants are submerged with one end in the mouth of the graduate. Bubbles of oxygen pass upward from the cut ends of the stems and crowd out some water from the previously filled graduate. The ordinary test for oxygen with a burning stick will determine whether it is present. In such an experiment care must be taken to see that there is plenty of space about the collecting tube to permit free passage of the gases that are in the water. After Ganong

18. The work of the leaf: transpiration. When a potted plant, so covered that no moisture can escape from the pot or earth, is placed under a dry bell jar, within a few hours moisture is seen to collect upon the inner surface of the jar. After a longer time the amount of moisture may cause streams or large drops of water to run down the inner wall of the jar.

If a plant that will thrive with its roots in water is planted in a jar of water and carefully sealed around the stem, and the whole apparatus weighed from day to day, a constant loss of water may be demonstrated. Water is ordinarily taken up by the plant in much larger quantities than are used for the work of photosynthesis. Large amounts of water are carried into the air through the leaves. By making careful demonstrations of the weight and volume of this water loss and the area of the leaf surface that is exposed, it is possible to determine the amount of water which, on an average, passes through each square inch of leaf surface in a given time. This evaporation or loss of water from the plant is known as *transpiration*, and the current of water thus passing through the plant is called the transpiration current. Water evaporates from the stomatal openings or from other parts of the leaf surface. As superficial evaporation occurs, water from the moister portions of the plant must take the place of that evaporated, or there is danger of injury to the plant. Such danger and resulting death often occur, due to great or sudden loss of water.

The quantity of water loss in transpiration is often surprisingly great. It has been estimated in one case that a beech tree 110 years old, in one summer transpired approximately 2250 gallons of water; that an oak tree with 700,000 leaves transpired about 180 gallons of water daily; and that an acre of cabbages in their growing season (about four months) transpired 500,000 gallons of water. One can scarcely picture in his mind the enormous quantity of water that is constantly transpiring from all the vast stretches of forests, grasslands, farm crops, roadside weeds, and swamp plants.

19. The work of the leaf: temporary responses. On excessively dry days plants such as wheat and corn sometimes wilt, since they are transpiring more water than they are securing. If the soil becomes very hard, the water passes into the air quite readily; but if the soil is kept well pulverized upon the surface, more soil water is held and a larger supply is available. Observations made upon a garden that is constantly cultivated during hot, dry weather, and upon one that is not so cultivated, show a great difference in ability of the plants to withstand drought. In a cornfield on a dry, hot day the leaves of the corn often roll into rather tight tubes. This form of leaf exposes less surface to evaporation and consequently loses less water than would the fully expanded leaves. This habit is doubtless of advantage in maintaining a balance in water supply.

In setting out young orchard or shade trees, nurserymen recommend that the branches be well pruned; otherwise the leaves may soon grow in such numbers that they will transpire more water than comes into the newly transplanted trees, which do not have their ordinary amount of absorbing root surface. Obviously newly transplanted trees and garden plants should be kept especially well watered until their root systems are well formed.

20. Respiration. The work of respiration in both plants and animals is commonly associated with the interchange of gases between the exterior and interior of the living body. In plants the interchange of gases may take place through the leaf or through other parts of the plant. This interchange, however, is no longer regarded as the fundamental thing in respiration, since respiration takes place in active, living protoplasm in all parts of the plant. It consists in decomposition of protoplasm or of some of its parts, or, as is supposed by some physiologists, it may consist in decomposition of food materials that have not yet become protoplasm. Through respiration complex plant substances are broken down, and the energy released by this decomposition is the energy by means of which plants carry on their work. Energy in the form of heat is also one of the results of respiration. Respiration may occur in the absence of free oxygen, but is more complete, and thus releases more energy, when oxygen is present. When respiration is complete, it results in the formation of various compounds, chief of which are carbon dioxide and water. Carbon dioxide and water may be carried from the plant through the leaf, or other parts of the plant, and the oxygen supply may enter in the same way. It is evident, however, that the transfer of these gases is an incident associated with the real respiration, which consists in decomposition of complex substances and the release of energy therefrom. Also it is evident that, so far as respiration is concerned, plants and animals behave in the same way. It should be noted that in photosynthesis green plants utilize carbon dioxide, though they, like other plants and animals, may produce carbon dioxide as one of the products of respiration.

21. Flowers and seeds: the parts of the flower. The flower is the part of the plant by means of which seeds are produced. Flowers differ widely, but an examination of any such simple flower as that of the geranium or the oxalis shows that there are four kinds of floral parts in it (Fig. 13). Outermost and lowest is a set of greenish leaves known collectively as the *calyx*, the separate leaves being known as the *sepals*. Just above the calyx, and usually larger and more conspicuous, is the *corolla*, each leaf of which is a *petal*. Above the corolla is the group of

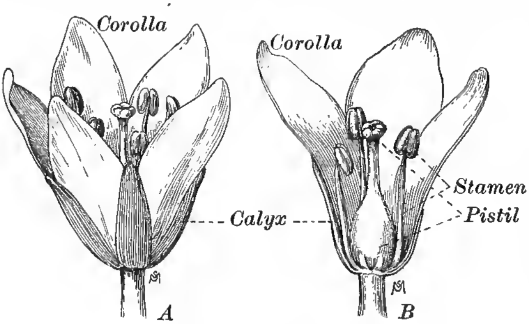

FIG. 13. Drawings of two flowers

A, entire flower; *B*, part of the floral structures removed *stamens*, easily recognized by their slender stalks and the enlarged tips which are known as the *anthers.* Within the anther is the *pollen* or pollen grains. At the tip of the flower, within the group of stamens, is the *pistil*, consisting of one or more units or *carpels.* Often the tip of the pistil is expanded, and sometimes divided into two or more short branches, this portion being called the *stigma;* the elongated part of the pistil is the *style*, and the swollen base is the *ovary*, so called because it contains the *ovule* or ovules. The ovules are the developing seeds.

22. Flowers and seeds: seed formation. The ovules begin their development within the ovary, but cannot alone form mature seeds which will grow into new plants. Some of the pollen from the anther of the same or another flower falls upon the stigma (Figs. 13, 14, and 15). From one or more of these pollen grains there grows down through the style into the ovule an extremely small tube. Inside this tube are carried some of the cellular contents of the pollen grain, which meantime have divided into three cells. One of these cells thus carried into the ovule by the pollen tube unites with a special egg cell that is formed within the ovule (Fig. 14). The cell that is made by the union of the one from the ovule and the one from the pollen tube grows into the new plant within

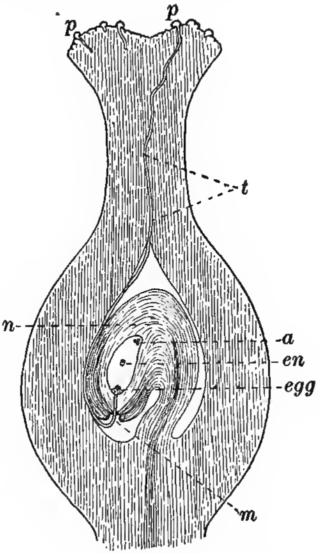

FIG. 14. A diagram of a pistil (carpel)

Within the cavity of the ovary is an ovule (n), and within the ovule is an embryo sac. At the free end of the ovule is the micropyle (m). In the end of the embryo sac near the micropyle is the egg (egg) with two other nuclei lying close to it; in the center of the sac is the endosperm nucleus (en); and at the other end are the antipodal nuclei (a). Pollen grains (p) are on the stigma, and from one is shown a pollen tube which has grown down to the egg

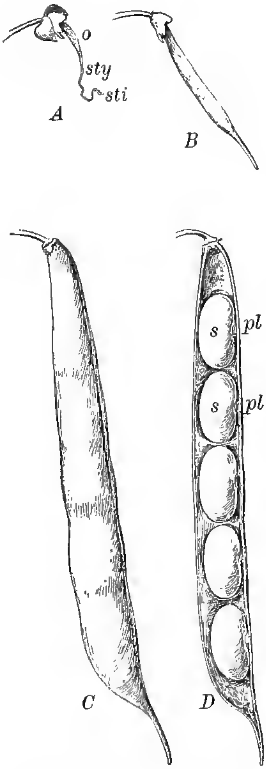

FIG. 15. Stages in the development of the bean pod

A, pistil of a bean flower, showing the ovary (*o*), style (*sty*), and stigma (*sti*); also the calyx at the base of the pistil. *B*, a pistil a few days older, in which the ovary has grown, and from which the style and stigma have disappeared. *C*, a pistil which has grown into the ripe bean pod. *D*, a ripe pod opened so as to show the arrangement of the seeds (beans) in the pod; each seed (*s*) is attached to a region along the wall of the ovary, known as the placenta (*pl*), by means of the base of the old ovule. All two thirds natural size

FIG. 16. Seedling of the peanut

Below the seed leaves or *cotyledons* (*c*) is the *hypocotyl* (*h*), from the lower end of which the roots (*r*) have grown; from the main stem (*s*) branches (*br*) and leaves (*l*) have grown; at the base of the leaves are *stipules* (*st*), and at the tip is the bud (*b*) the ovule. While still within the ovule wall, the root, stem, and leaves of the new plant are formed. The ovule wall becomes hard, and, with the new plant within it and with more or less stored food, constitutes the seed. During the time when the seeds are developing the ovary may also grow (Fig. 15).

FIG. 17. Growth of new plants from seeds of the beech tree

At the left are very young seedlings, one of which shows only the seed leaves (cotyledons), the other showing between the seed leaves a slender stalk which is the beginning of the stem. In the plants at the right the seed leaves still are present, but other leaves and the stems have grown considerably

23. Flowers and seeds: the fruit, and seed germination. When the seeds are ripe they may fall from the ovary, or with one or more of the structures about them they may compose the so-called fruit.

Under favorable conditions the young plant within the seed bursts the seed coat and begins its growth. It pushes out its roots, stem, and leaves, and soon assumes the appearance of the kind of plant that formed it (Figs. 16 and 17).

Details regarding the parts of the plant and the work they do will be treated in later chapters.

CHAPTER III

ROOTS

24. Structure of roots. A very young root is often translucent enough to be examined directly with a low power of the compound microscope. It is then seen to be composed of an exterior hollow *cortex*, nearly cylindrical in form, and a *central cylinder* within the cortex. The outermost portion of the cortex is a layer of somewhat brick-shaped cells constituting the *epidermis*, and from some of the cells of the epidermis root hairs often spring (Fig. 6). The growing tip of the root is covered with several layers of cells, most of them dead or dying, constituting the *root cap*.

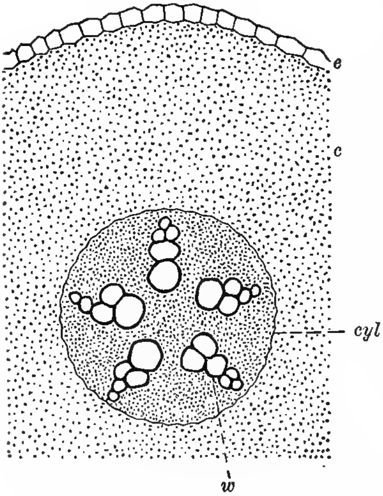

FIG. 18. Diagrammatic cross section of a very young dicotyledonous root

e, epidermis; *c*, cellular layer of cortex; *cyl*, central cylinder; *w*, woody strands of fibrovascular bundles of central cylinder. Alternating with these are much smaller strands of bast fibers, not shown in the diagram. Modified after Bonnier and Sablon

A moderately magnified cross section of a very young dicotyledonous root shows the epidermis as a narrow ring, surrounding a much broader ring of the underlying cortex, and within this the central cylinder, containing a fixed number of radially arranged fibrovascular bundles. The relative proportions of the several regions can be understood from Fig. 18.

25. Uses of roots. It was explained in Sects. 9 and 10 that water is absorbed by roots and forced up into the stem of a plant under considerable pressure.

All plants must have water, at any rate during the part of their lives when they are actively manufacturing plant food, and it is by means of their roots that most familiar plants absorb water and the substances that are dissolved in it. Yet absorption of water is not the only function of roots. They often absorb oxygen; they commonly serve to anchor the plant; they may aid it to climb; they frequently store food, water, or both; and in or on them there are sometimes carried on important chemical operations which result in gaining material for the production of plant food (Sect. 17). Many kinds of roots reproduce the plant; that is, a root or part of one may grow into a new individual plant like the one to which the root belonged.

The great importance of roots to life and growth is well shown by the results which follow from any severe injury to the root system. Cut off most of the roots of a tree and it will die for lack of water.

On the other hand, many (though not all) kinds of trees may be cut down nearly level with the ground and still survive, the stump throwing up a vigorous crop of sprouts which grow into saplings that eventually replace the fallen trunk.

The necessity of roots for anchorage is well shown by Fig. 4. In many cases the power of the roots to hold trees upright is greatly increased by the formation of buttresses of wood, which extend some distance up the trunk from the origins of the larger roots (Figs. 259 and 260). In some great tropical trees these buttresses attain enormous dimensions.

26. Earth roots. The roots of most of the higher plants with which we have practical dealings, such as forest trees and the plants of the orchard, farm, and garden, are *earth roots;* that is, they are formed, grow, and live at a moderate distance under ground. Plants with roots suited to life in the earth usually cannot grow as well in water as in soil, and they cannot grow at all upon a bare rock, though sometimes they grow with their roots in the crevices of rocks. It makes a great difference to the plant in what sort of soil it grows. Every good farmer knows that beans will thrive well in a light sandy soil in which corn or broom corn would starve. All who are familiar with the distribution of our forest trees and shrubs have noticed that some kinds, such as the spruces, most pines, the chestnut, and the jack oak, do well in sandy or other poor soils. On the other hand, the black walnut, the tulip tree, the mulberry, the Osage orange, and the papaw usually flourish only in a deep rich soil.

27. Direction and extent of the root system. In sand or porous loam the root system of the plant is usually much more extensively developed than in clay. If there is a shallow layer of loam overlying a shaly or clayey subsoil, the roots spread out horizontally but do not go far down in the earth. In sand, roots are usually long and branch but little, while in rich soil they branch so freely as to form a close network. If nutrient materials are irregularly distributed in the earth in which a plant is growing, rootlets are so much more extensively developed in the richer portions of the soil that, as the great agricultural chemist Liebig forcibly said, "Roots search for food as if they had eyes." The various kinds of plants differ greatly in the general direction taken by their roots, — those of asparagus, for example, forming a sort of shallow mat, and those of many hardwood trees, the radish, and the sugar beet beginning with a single taproot which descends for a considerable distance nearly or quite vertically.

It is impossible to get an accurate idea of the root system of a very large plant, since its length usually consists mainly of slender fibers which are inextricably interwoven with each other and penetrate the soil in every direction. The root system even of an oat plant, all contained in a cubic yard or two of soil, has in one instance been found to measure altogether over 450 feet in length. Many plants which ordinarily have their roots near the surface, when grown in dry soils send their roots to great depths to secure the needed water supply. In some of the drier parts of California wheat roots have been known to grow to a depth of 15 feet and the roots of the California poppy to a depth of 13 feet. Roots may penetrate to much greater depths, those of the mesquite of the Southwestern States and Mexico sometimes descending to reach water as much as 60 feet. It is not difficult to get an idea of the extent of the root system of such a plant as Indian corn. Carefully dig away the earth from one side of the plant at a distance of about two feet, keeping a constant lookout for smaller rootlets. If none are found, extend a trench completely about the plant at the distance already used as a radius. Make the trench about two feet deep and stand a piece of poultry netting in it, so as to make a circular fence about the roots of the plant. Run some wire stakes crosswise through the mass of roots, so as to reach across its entire diameter. With a stream of water from a garden hose or with numerous pails of water wash away the earth as completely as possible from the mass of roots and remove the root system entire. It may then be used for illustration in the schoolroom.

28. Pull exerted by roots. After root fibers or the taproots of herbaceous plants have attained their full length, in many kinds of plants a decided shortening of the root takes place. This shortening originates in the cellular portion of the cortex, between its outer layers and the central cylinder of the root, and it may amount to from 10 to 25 per cent of the length of the root before contraction. Because the epidermis does not contract, its outer surface often becomes much wrinkled, especially in the roots of bulbous plants. The shortening of the fibrous roots which spring from a taproot holds it firmly in place, as a derrick is held upright by guy ropes. Sometimes, as in the dandelion, the taproot shortens about as fast as the short stems which crown the root grow upward. In this way the rosette of leaves is kept firmly pressed against the ground, or it may even be drawn slightly into the earth. Grass plants on a lawn are injured or destroyed by being deprived of light by the rosette of dandelion or fall dandelion.

29. Effects of roots on the soil. If we dig up a spadeful of earth from a well-grassed meadow, or from a little inside the circumference of the circle formed by the roots of a tree, we shall find the soil bound together by the living roots or full of little, crooked, tubular channels left by the decay of dead ones. Thus the soil is in the one case, held together so as to prevent its becoming gullied and washed away by rains, and in the other case made more porous and easily penetrated by air and water. The latter effect is a very important one in the case of stiff clay soils, which when closely packed are almost waterproof.

The extensive washing away of soils when unprotected by a covering of plants, such as grass, shrubs, or forest growth, is one of the most serious calamities that can befall a country. It is especially formidable in hilly regions, which may become wholly uninhabitable if the forests are cut off and the turf on the hillsides is destroyed by too constant grazing and trampling of sheep or goats. Immense areas of land once valuable for timber and for grazing have thus been ruined throughout southern Europe, and the same process is under way in our own country all the way from New England to the Pacific coast region. One of the clearest ways in which the loss by washing away of the soil can be presented is by considering how the land is carried into the sea by great rivers. The delta of the Mississippi covers an area of more than 12,000 square miles. It consists of material brought down by the river in the form of mud, now forming a deposit of unknown thickness, probably averaging more than 500 feet. It is calculated that the river every year carries enough solid matter to form a layer one foot thick over an area of about 268 square miles. Remembering that this mud consists mainly of the choicest part of the rich soil of the Mississippi basin, it is easy to see that the land is robbed every year of the material to support enormous harvests[1] (see Chapter XXIV).

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[1] See "Forest Influences," *Bulletin 7*, Division of Forestry, U. S. Dept. Agr., 1893.

30. Relation of earth roots to air and water. The soil at moderate depths contains much air in its pores, the amount being largest in light loams and sand, and least in stiff clays. This air is essential to the health and growth of ordinary roots. Many kinds of plants growing in earth are quickly killed when transferred to a glass battery jar with a lead cover sealed on, if water enough is poured in through a thistle tube to fill the jar almost to the exclusion of air. In the same way, if water is backed up a stream when a dam is built across it, most of the trees that are surrounded by the pond formed by the retained water are killed. They have been drowned, and die for lack of air. Even the lower forms of green plants (Figs. 156–168) will soon die for lack of it, if kept in a tightly stoppered jar or bottle full of water. Most aquatic plants which have leaves or green stems exposed to the air — like pond lilies, some rushes, cat-tails, and so on — convey air down into the submerged parts by means of numerous

FIG. 19. Cypress trees (*Taxodium*) growing in a swamp

The conical "knees" growing from the roots and nearly always above water are thought to serve as channels to supply air to the roots

air passages, which lead from the leaf, through the stem, down into the roots (Fig. 360). It is supposed that "cypress knees," curious outgrowths from the roots of the American cypress (Fig. 19), absorb air, which passes down into the roots.

A supply of water is, as already suggested, even more evidently necessary for earth roots than is a supply of air. The appearance during a drought of fields planted with ordinary crops is familiar to most people. The dwarfed condition to which plants can be brought by a scanty supply of water is less well known. Many annuals, if given barely enough water to keep them alive, will flower and bear seed after reaching a height of hardly a greater number of inches than they would measure in feet under favorable conditions. When the water supply is wholly withheld from ordinary potted plants they soon wilt and die, as every one knows.

31. Water roots. Most aquatic perennials, like the cat-tails, arrowheads, pickerel weeds, pond lilies, and many grasses and sedges, form mainly earth roots. On the other hand, some plants not aquatics, as many willows, can develop roots indifferently either in earth or in water. A row of willows along a brook usually sends great numbers of roots into the earth, and also produces a multitude of fibrous roots which dangle in the water of the brook. Cuttings of Wandering Jew (*Zebrina*), geranium (*Pelargonium*), and many other common plants, root readily in water, and grow for a long time if supplied only with ordinary river or well water. The number of kinds of seed plants which float, and therefore produce only water roots (if they have roots at all), is rather small. Some of the commonest are the so-called "water hyacinth" and the little duckweeds (Fig. 357) so often seen on the surface of stagnant pools and streams.

32. Air roots. Roots may be produced by portions of the stem above ground, in the case of plants which root in the earth. Well-known examples of these are the brace roots of corn, often originating a foot or more above the earth and usually at length extending into the soil, and the tough, fibrous roots by means of which English ivy and poison ivy

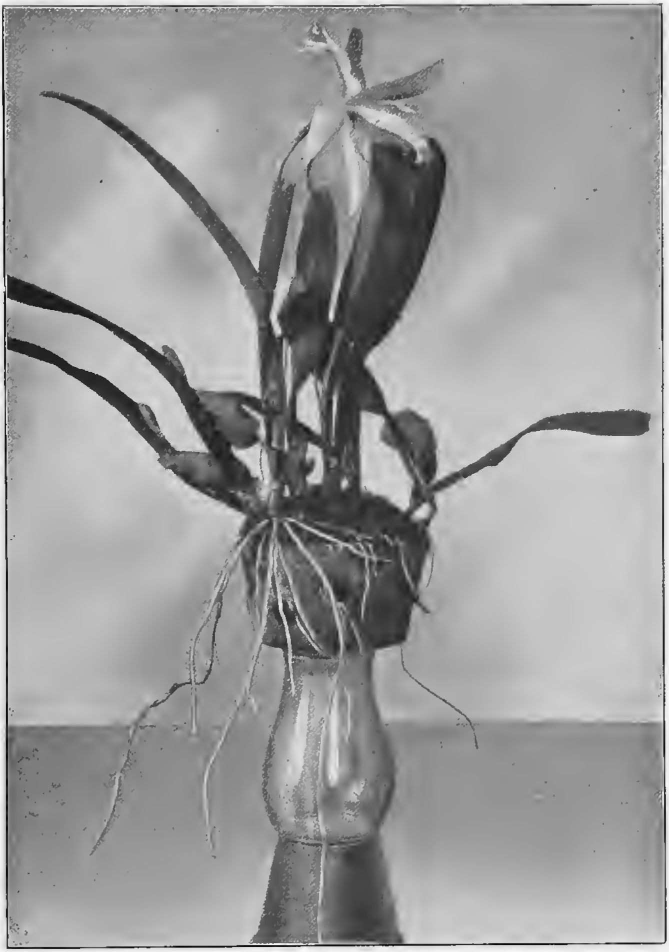

FIG. 20. Aërial roots of an orchid (*Cattleya*)

(Fig. 46) climb. Air roots are also borne by many kinds of air plants which do not root in the earth at all. Such plants are usually natives of moist, warm climates. Good examples of air plants are many orchids (Fig. 20), and some plants of the

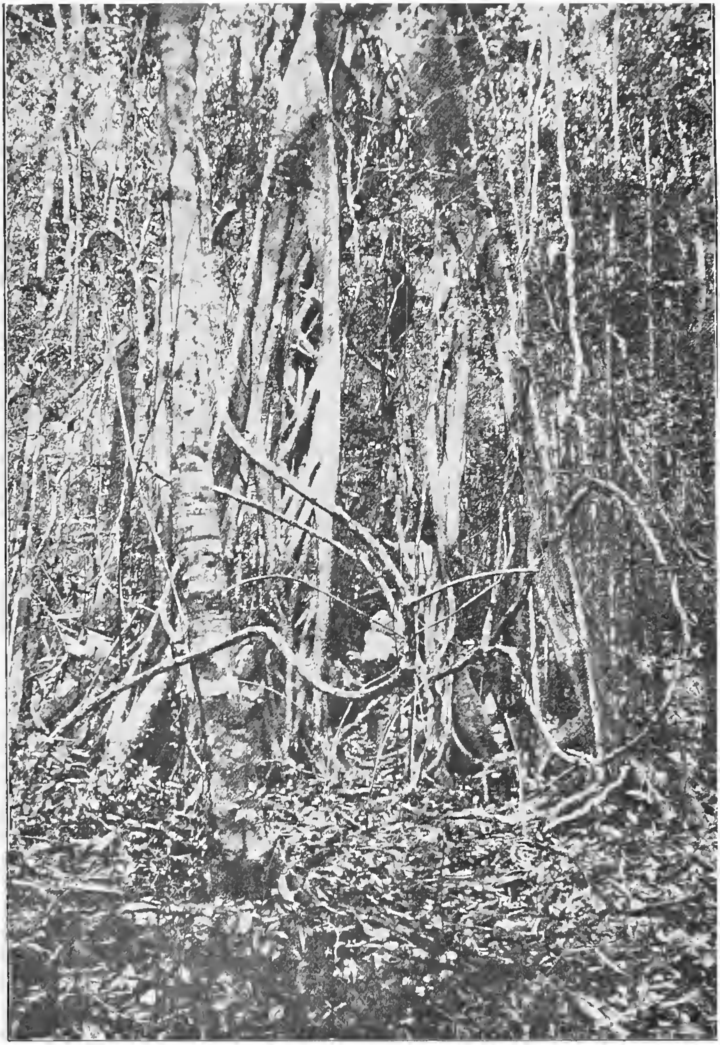

FIG. 21. Aërial roots of a wild fig tree and lianas in a tropical forest

Pineapple family. Aërial orchids frequently possess roots of peculiar structure, covered with a papery, absorbent layer which takes up water freely when exposed to rain or dew. One air plant, the Spanish moss (*Tillandsia*) (Figs. 367, 368), common in the Gulf States, has no roots, but it imbibes water freely by means of special absorbing hairs scattered over the surface of the plant. The *Tillandsia* is a characteristic feature of many Southern regions, often appearing as tangled, rope-like masses hanging from the trees.

33. Reproduction by means of roots. Roots are often capable of producing buds which may develop into new individuals and thus serve to propagate the plant. The sweet potato is a good instance of this, each root if buried in moist sand being capable of giving rise to several new plants (Fig. 22). Roses are propagated by root cuttings, and some trees, such as the silver-leaved poplar (*Populus*) and the black locust (*Robinia*), are very troublesome because of the readiness with which young sprouts (sometimes called suckers) spring up from the roots. Many bad weeds, such as the field sorrel (*Rumex*) and the Canada thistle (*Cirsium*), are reproduced by roots. In case of desirable plants that can be propagated either by pieces of root or by seeds, it is generally better to use root cuttings, as they will grow much faster.

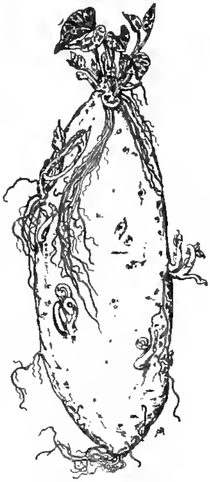

FIG. 22. Vegetative reproduction of the sweet potato

The potato was buried in moist sand and began to sprout, that is, to send out shoots from adventitious buds at various points. Each shoot may grow into a new plant. About half natural size

34. Duration of life and storage of food and water in roots. It is usual to divide plants according to their duration of life into three classes: *annuals*, living one year or less; *biennials*, living two years; *perennials*, living more than two years. The boundaries between these classes are not always definite;

for example, winter wheat is an annual, though it does not seed until the next summer after it is planted. And the cotton plant, the lima bean, the tomato, and the castor bean are instances of plants which with us are cultivated as annuals, but in warm climates live several years; the castor bean, indeed, grows there into a large, almost tree-like shrub. Very commonly plants which live for more than one year have food stored in their roots.

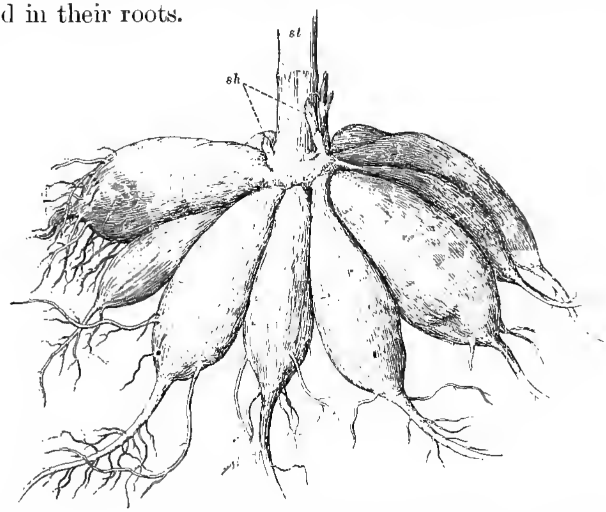

Fig. 23. Clustered, fleshy roots of the dahlia, with much stored plant food, in early spring

st, remains of last year's stem; *sh*, young shoots beginning to sprout from the upper ends of the roots. One fourth natural size

Such biennials as beets, carrots, and parsnips store up much food in the root[1] during the first summer's growth, and form a large tuft or rosette of leaves, but do not develop much stem above ground. During the second summer the stored food is consumed in the production of leafy stems, bearing flowers and fruit, and in the autumn the root appears quite withered and nearly dry.

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[1] The underground part of the carrot and the parsnip is part stem and part root.

Herbaceous perennials, like the dahlia (Fig. 23) and the common rhubarb, store food in the root during the summer, and consume part or all of it in the growth of the following spring. Trees and shrubs in temperate or cold climates store starch and other foods in the roots, as well as the stem, during the winter. It is the stored food in the root that enables such plants as rhubarb, the peony, some buttercups, sweet cicely, the dandelion, and many others to make a quick growth in the spring before the weather is warm enough for the manufacture of much plant food. The starch, sugar, and proteins which abound in many roots or root-like portions of plants make them valuable for food, as in the case of beets, turnips, carrots, parsnips, sweet potatoes, salsify, and in the cassava plant, from which tapioca is made.

It is frequently the case that desert plants store large quantities of water in their roots or in combinations of roots and underground stems, and are thus able to survive long periods without rain.

35. Roots in relation to other organisms. The roots of the higher plants often enter into complicated relations with plants of other species or with animals. Before discussing these relations it is necessary to state briefly what some of them are. A plant or animal which feeds in whole or in part on the substance of another living organism is called a *parasite*. Familiar examples of animals parasitic on other animals are fleas and ticks. The organism which supports a parasite is called the *host*. Organisms which live together in a mutually helpful way are said to be mutualists or sometimes are called *messmates*. Roots may be:

(1) Parasitic on other roots or stems.
(2) Hosts for parasitic roots.
(3) Hosts for parasitic animals.
(4) Messmates or mutualists with other organisms.

36. Parasitic roots. A good many of the higher plants feed altogether or partially on the sap which they draw from other living plants. Those which live entirely at the expense of the host are total parasites, while the others are partial parasites. The dodders (Fig. 351) are practically leafless, of a yellow-greenish or whitish color, and incapable of photosynthesis. The mistletoes and many other half parasites have green leaves and can do photosynthetic work, so that they may depend on the host only for water and mineral subtances, but make for themselves starch or other carbohydrates from the raw materials. Root parasites (Fig. 309) are often attached to the roots of the host at some distance from the stem of the latter, so that few but botanists recognize the real state of the relations between the two plants. The sucking roots of parasites, known as *haustoria*, are of peculiar structure and have the power of penetrating rapidly into the substance of the host. In the dodder, at any rate, this power is partly due to the presence of *ferments*, liquid or semi-liquid substances manufactured by the haustorium and capable of dissolving cellulose.

37. Partnership of roots and bacteria. Bacteria are exceedingly minute plants of very low organization (Fig. 150). Their forms and structure are shown in a general way by the figure. They differ greatly in their habits of life, as is shown in Chapter XI. Those which inhabit little tubercles on the roots of most *leguminous* plants (as those of the Pea family are called) are of the highest value to the farmer. The tubercles occur in the greatest abundance, 4572 having been counted on the roots of a single pea plant. Fig. 305 shows their mode of occurrence on the roots of red clover. Each tubercle contains multitudes of *root tubercle bacteria*, which are able to change the free nitrogen of the air, contained in the pores of the soil, into a soluble form in which it can be absorbed by the plant. Without the action of these or other bacteria or other agents to transform atmospheric nitrogen into a soluble form it is perfectly useless to the higher plants.[1]

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[1] It is certain that other bacteria besides those of root tubercles render nitrogen soluble, but the extent of their action is not fully known.

In order to ascertain how much nitrogen is produced by any given crop it is necessary to make chemical analyses of carefully selected and weighed samples of the clover, alfalfa, or other crop studied. In this way it was found in one series of experiments that a single crop of alfalfa yielded 95 pounds, red clover 102 pounds, and crimson clover 134 pounds to the acre. As about two thirds of this nitrogen is taken from the air by the plant, turning under by plowing any of these leguminous crops adds greatly to the available nitrogen of the soil. A ton of barnyard manure contains only about 10 pounds of nitrogen. Therefore an acre of alfalfa plowed under might add to the soil as much nitrogen as could be gained from 16 tons of manure, though the manure would add other desired substances to the soil. A crop of corn of 50 bushels per acre would remove from the soil (in both grain and fodder) about 74 pounds of nitrogen per acre. A wheat crop of 25 bushels per acre would remove from the soil about 48 pounds of nitrogen per acre. Experiments continued for a series of years upon worn-out land, treated year after year with lime and leguminous crops plowed under, show great gains in fertility. In one set of experiments lasting from 1902 to 1907 the soil which had been thus treated produced a little more than six times as large a crop of oats as a similar untreated area. On common prairie land in Illinois the value of the nitrogen gained by the root tubercles of a single crop of alfalfa was found to amount to $25.80 per acre, reckoning the nitrogen as worth the usual fertilizer price for it, 15 cents per pound. What part of this improvement is due to better cultivation is a matter still under discussion. The poorer the land is in nitrogen the more effective is this process of "green manuring" with leguminous crops. Provided the tubercle bacteria are present, clover can make a vigorous growth without any soluble nitrogen in the soil at the beginning.[1]

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[1] On the general subject of maintenance of fertility by plowing under leguminous crops, see Hopkins, Soil Fertility and Permanent Agriculture, chap. xvi, and Part III. Ginn and Company, Boston.

38. Partnership of roots and filaments of fungi. Many of the flowerless plants known by the general name of fungi form a dense network of very minute threads. Such a network is found in intimate association with the roots of many kinds of flowering plants. It is especially common on the roots of those which cannot manufacture plant food by photosynthesis, but it also occurs on other plants with green leaves, such as pines and beeches. On the roots of the beech the fungus filaments are found united into a sort of membrane, covering the tips of the young roots and extending back for a considerable distance (Fig. 24). In such plants as the heaths, blueberries, and their relatives, the fungus threads form little tangled masses inside the cells near the surface of the root and send out free ends into the surrounding soil. In any case the whole filamentous mass living in connection with the root is called a *mycorrhiza*. Roots provided with mycorrhiza usually form few or no root hairs, and it is supposed that the fungus threads to some extent perform the work of root hairs in absorbing soil water. The subject is not yet well understood, but it would seem that certain trees, such as pines and oaks, do not flourish as well when grown in a soil which does not develop a mycorrhiza upon their roots.[1]

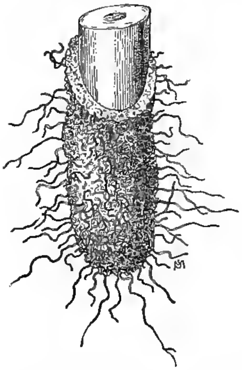

FIG. 24. Tip of a root of European beech, covered with mycorrhiza

The coating has been stripped off for a little way at the top to show the thickness of the mycorrhiza. Magnified 30 diameters. After Pfeffer

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[1] See "Experiments in Blueberry Culture," *Bulletin 193*, Bureau of Plant Industry, U.S. Dept. Agr.

CHAPTER IV

THE STEM AND THE LEAF

39. Stem and leaf as coworkers. In a general way it may be said that the stem and the leaf together do the work of making plant food from the raw materials (Sect. 17). In most of our commonest seed plants the stem is mainly important as the part of the plant body which bears leaves, maintains them in the most advantageous position to receive sunlight, carries to them water and dissolved salts from the earth, and carries away from the leaves the newly made plant food which is to serve for the immediate needs of the plant body or to be stored for use later on. The stem and the leaf are so intimately associated that it is often convenient to have a single name for the two together. The stem and its leaves collectively are known as the *shoot.*

40. Photosynthesis done by stems. In some practically leafless plants, such as the cacti, the photosynthetic work of the plant is all done by the stem, which is covered with layers of chlorophyll-containing cells. Stems flattened so as to expose a good deal of surface for photosynthesis are shown in Fig. 25 and still more expanded ones in Fig. 26. In the shrubs known as *switch plants* (Fig. 365), common in some regions where the summers are hot and almost rainless, the leaves (if there are any) are borne for only a few months of the year, usually in the spring. During the rest of the year photosynthesis is slowly carried on by the green layer of the bark, which is abundantly supplied with chlorophyll. Even among the trees and shrubs of temperate North America there are many species, such as the wahoo, box elder, sassafras, and some roses, which have much green bark on the younger twigs and probably accomplish a good deal of photosynthesis through these. As the twigs grow older the green layer is shut away from the light by the corky layer outside of it and soon dies. Most of our useful annuals of the farm and garden, such as corn, potatoes, tomatoes, squashes, and so on, have green stems which do photosynthetic work.

41. The stem raises leaves into the light. Many plants which cover the ground rather closely do not need to raise themselves much from the earth in securing their share of the light. Good examples of these are such familiar creeping plants as white clover, black medic (*Medicago*), moneywort (*Lysimachia*), and some species of wild everlasting (*Antennaria*). But very commonly plants compete for light against each other, as may readily be seen in almost any cornfield. When the corn is only a little way above ground it is necessary to keep it free from rank, quickly growing weeds by frequent cultivation. If this work

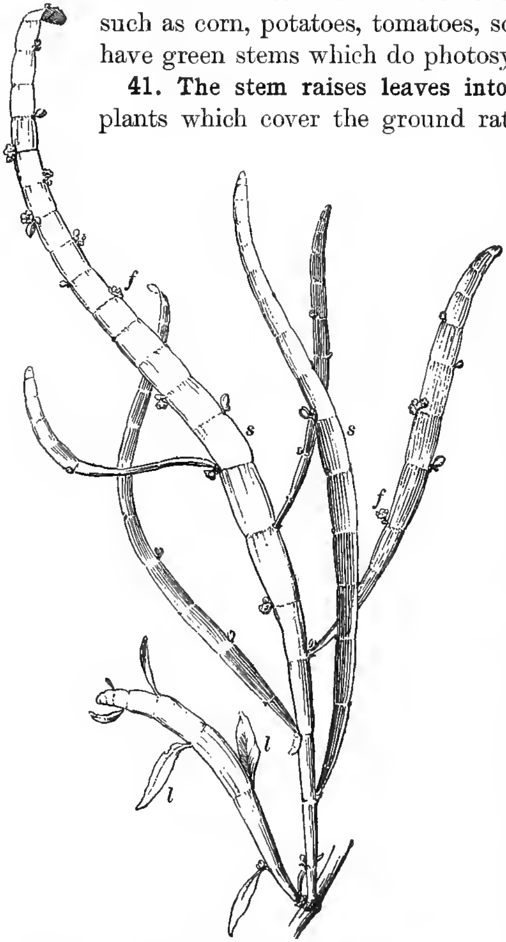

FIG. 25. Branches of *Muehlenbeckia*, a plant with flattened stems which do most of the photosynthetic work of the plant

f, flowers; *l*, leaves; *s*, stems. One half natural size is neglected, the young corn plants will be overshadowed and dwarfed and the crop greatly injured. But as soon as the cornstalks have lengthened enough to carry the spreading leaves above the tops of ordinary weeds and leave them in the shade, the corn plants are safe from further competition with these plants, though other species that can thrive in weak light may develop later. In the same way wild plants kill off other species by overshadowing them. Under a close thicket of dogwoods (*Cornus*), hazels, or buttonbush, hardly any smaller plants can grow, and the most successful competitors with the bushes are such climbers as the cat brier (*Smilax*, Fig. 49),[1] climbing false buckwheat (*Polygonum*), wild morning-glory, and climbing hempweed (*Mikania*). These support themselves on the bushes or other plants, and secure all the light they need by running along the tops of the supporting plants.

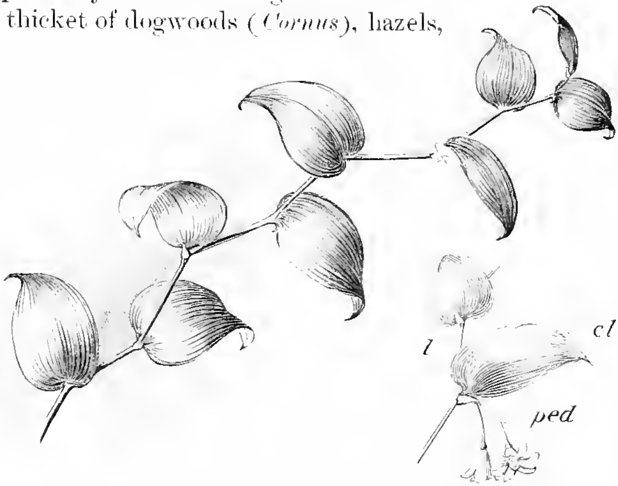

FIG. 26. Stem of "smilax" (*Myrsiphyllum*)

l, scale-like leaves; *cl*, cladophyll, or leaf-like branch, growing in the axil of a leaf; *ped*, flower stalk, growing in the axil of a leaf

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[1] This is not the familiar greenhouse plant shown in Fig. 26, which is usually called smilax by florists.

As a result of competition with each other to secure light, plant stems often become greatly lengthened. Any one who is observant and familiar with things out of doors must have noticed the different form (*habit* it is called by botanists) of such plants as giant ragweed (*Artemisia*) or hemp as they grow tall and little-branched when in dense clumps, or low and spreading when they stand singly. And full-grown trees such as pines are nearly branchless for most of their height, when growing in dense forests, but low and broad-topped with many lateral branches when growing alone in a pasture (Fig. 246). A tree growing on the edge of a patch of dense woods may develop the pasture habit on its exposed side and the forest habit on the side toward the woods, like the tree in Fig. 27.

Fig. 27. Pruning as an effect of shade

The large American beech in the foreground has developed no considerable limbs on the right, because, until it was well grown, another beech stood within fourteen feet of it, on that side

42. Danger from excessive height of stems. Wheat, oats, or corn plants are sometimes blown down by severe winds, and a field of grain in this condition is said to be "lodged." Large tracts of forest may also be greatly damaged by severe storms, particularly when the trees are loaded with sleet (Fig. 28), and the area covered with broken-down tree trunks is known as a "windfall." But neither tall grain nor forest trees can be blown down as easily when growing massed together as when standing singly, since every

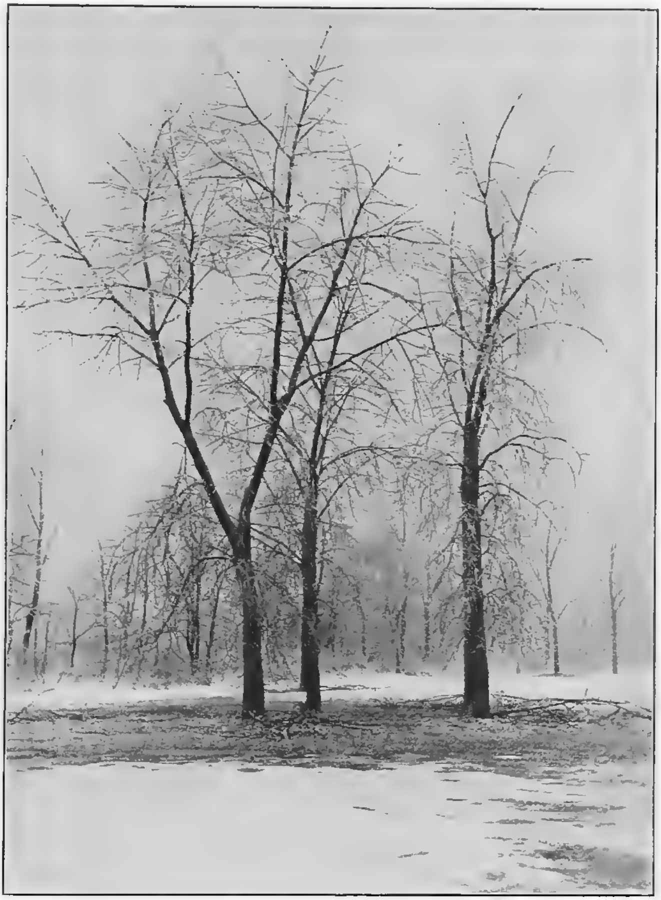

FIG. 28. Cottonwood trees on the day after a sleet storm

Many branches have been broken off by the weight of the sleet

individual in the interior of the field or forest is much sheltered from the wind by its neighbors, and all together present enough resistance partially to impede the wind. Scientific foresters in clearing the trees off a large tract begin on the sheltered side and cut toward the quarter from which severe storms usually come.

43. Growth in length. Under favorable conditions the younger portions of the stem for a good while increase continually in length. The rate of growth varies greatly in different plants: sunflowers and giant ragweed (*Artemisia*) may grow to a height of 10 or 12 feet, and climbers like gourds and hops to a length of perhaps 40 feet, in a single summer. On the other hand, pine seedlings during their first summer only grow to be from 1 to 3 inches high, and oak seedlings less than 5 inches. The growth per year for a time continues to increase and then diminishes. For example, the long-leaf pine (Fig. 261) grows only about three quarters of an inch the first year. For the first fifty years it makes an average annual growth of 14 or 15 inches; for the next fifty, 4 or 5 inches; and from one hundred years to extreme old age, about one and one-half inches. It usually lives about two hundred years.

The growth of the younger nodes of most plants is quite unequal, as may be learned from the study of a rapidly growing stem, such as the morning-glory.[1] It will also prove interesting to measure such plants as corn, broom corn, hemp, and pole beans, to determine whether they elongate more during the day or the night, and during warm or cool weather.

44. Internal structure of the young dicotyledonous stem.[2] The structure of the fully developed stem can best be understood by tracing its development from the time when the embryo begins to grow in the sprouting seed. That, however, is a rather difficult process to follow, so this brief account will begin with the stem already considerably developed.

In common language the dicotyledonous stem is said to consist of bark, wood, and pith. These regions are very distinctly

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[1] See Bergen and Davis's Principles of Botany, p. 17.

[2] See also Sects. 45–48. The stem of many gymnosperms (e.g. trees of the Pine family) in its general structure much resembles the dicotyledonous stem. For a general account of the stem structure of dicotyledons and monocotyledons see Coulter, Barnes, and Cowles's Textbook of Botany, chap. iv, A. ANGIOSPERMS.

seen in the youngest twigs of most of our dicotyledonous trees and shrubs, such as willow, poplar, sassafras, and elder. The early structure of dicotyledonous stems is in some ways best shown in the stems of woody climbers. Fig. 29 shows

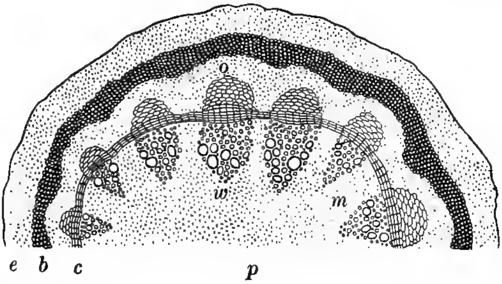

FIG. 29. Diagrammatic cross section of one-year-old *Aristolochia* stem

e, region of epidermis; *b*, hard bast; *o*, outer or bark part of a bundle (the cellular portion under the letter); *w*, inner or woody part of bundle; *c*, cambium layer; *p*, region of pith; *m*, a medullary ray. The space between the bard bast and the bundles is occupied by thin-walled, somewhat cubical cells of the bark. Considerably magnified

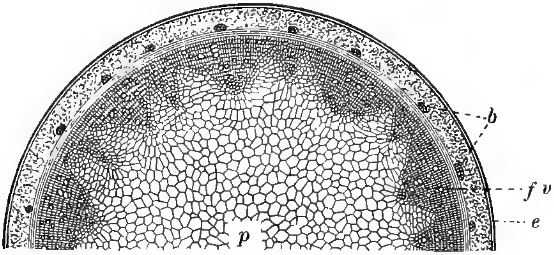

FIG. 30. Diagrammatic cross section of sunflower stem

p, pith; *fv*, woody or fibrovascular bundles; *e*, epidermis; *b*, bundles of hard bast fibers of the bark. Somewhat magnified. After Frank

the relative position of the structural components of the one-year-old stem of Dutchman's-pipe, as seen in a cross section. The outer cylinder (*e–c*) is bark; the central portion (*p*) is pith. Between bark and pith, extending both inward and outward from the cambium layer (*c*), are fibrovascular bundles (*o–w*), seven of which are shown in the figure. Each bundle consists of a cellular portion (*o*) which belongs to the bark system, and a fibrous and tubular portion (*w*) which belongs to the wood system. Briefly stated, the uses of some of the several parts are as follows: (1) The epidermis serves as a protective covering for the young stem, and to a considerable extent prevents it from becoming dried up.

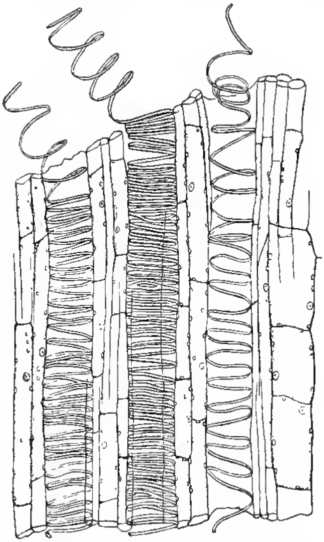

FIG. 31. Lengthwise section through the vascular part of a fibrovascular bundle of sunflower stem

The tubes with spiral markings (spiral vessels) are the principal channels for the conduction of water. Between and around them are thin-walled nucleated cells, containing much cell sap. Much magnified. After Frank

(2) The layers of cork cells soon formed close beneath the epidermis (not separately shown in the diagram) prevent loss of water and consequent drying up.

(3) The layers of green cells which at first directly underlie the epidermis (not shown in the diagram) are useful in the manufacture of plant food.[1]

(4) The fibrous cells of the hard bast (*b*) give toughness to the stem.

(5) The thin-walled tubes of the outer portions (*o*) of the bundles carry manufactured plant food in liquid form downward or toward the roots.

(6) The cambium layer (*c*) (shown proportionally thicker in the diagram than it really is) grows, and on its outer side it forms new bark, while on its inner side it forms new wood (see Sect. 47).

(7) The woody portions (*w*) of the bundles carry water upward or toward the leaves. The fibers which constitute a considerable portion of the wood part of the bundles both stiffen the stem and make it tougher.

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[1] See Sect. 40.

One-year-old stems of dicotyledonous plants which are not climbers usually differ in structure from the type shown in Fig. 29 mainly in having the bundles more or less completely joined into a continuous cylinder (shown in the cross section as a ring, Fig. 30).

45. Strengthening cells. There are several kinds of cells which give either toughness, stiffness (Sect. 46), or both of these qualities to the parts of the plant body where they occur. Only four of these kinds need be mentioned in this place. The two shown in Fig. 32 are commonly found in the cortex of dicotyledons. *Collenchyma cells* (*A*) are like the thin-walled cells of the pith, but are reënforced at the angles, just as some packing boxes have strips of board nailed fast on the inside of the box at the junctions of the sides. *Bast fibers* (*B*) are extremely slender tubes, with closed and pointed ends, much like a piece of thermometer tubing drawn to a point in a gas flame and thus closed. Collenchyma gives moderate stiffness to the parts in which it occurs, and is highly elastic, so that it does not hinder the growth of the stem which it incloses. Bast fibers are flexible but very tough, and therefore enable the parts of the root, stem, or leaf in which they occur to resist being pulled apart.

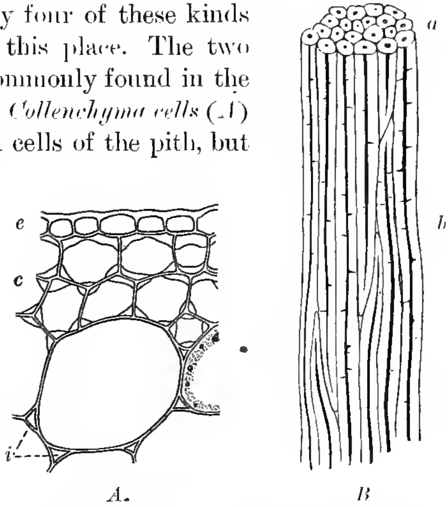

FIG. 32. *A*, collenchymatous and other tissue from stem of balsam (*Impatiens*); *B*, a group of hard-bast fibers

e, epidermis; *c*, collenchyma; *i*, intercellular spaces between large parenchyma cells; *a*, cut-off ends; *b*, lengthwise section of fibers. Greatly magnified. *A*, after Strasburger; *B*, after Tschirch

Two other kinds of cells which are important in giving strength to the plant body are shown in Fig. 33. *Tracheids* (*A*) form a considerable part of the fibro-vascular bundles and of the wood cylinders of dicotyledons. The slender thick-walled ones, known as *fiber tracheids* (*B*), greatly strengthen those parts of the plant in which they occur. There is considerable difference between wood fibers proper and tracheids in regard to the tissues with which they are generally associated, but the fibers do not differ much in form from the most slender tracheids. Generally, however, tracheids are a good deal stouter than wood fibers, they have rounded ends, and they show spiral or ladder-like markings or oval or nearly circular pits on their sides. Both wood fibers and thickened tracheids serve to stiffen and toughen the parts of the plants in which they occur.

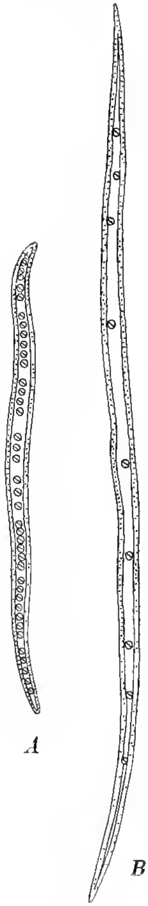

FIG. 33. *A*, tracheid; *B*, fiber tracheid of oak wood

Magnified about 125 diameters. After G. Müller

46. Mechanical arrangement of strengthening materials. Most people know, in a general way, that a metal tube is stronger than a solid rod of the metal, of the same weight per foot of length. So, too, a T-rail for steam or street cars, or an I-shaped girder for bridge or other construction, is much stiffer than one of simple rectangular section like an ordinary plank.

In many plants the stems and leaves show great economy of stiffening material, having the portions of rigid tissue so disposed as to act in the most advantageous way. Many dicotyledons and great numbers of monocotyledons, especially the grasses, have hollow, nearly cylindrical stems. Sometimes the main stem is not entirely hollow, but portions of it are, as in the case of the hollow flower stalk of the garden rhubarb and the dandelion. More frequently the stem is not hollow, but a large mass of very light spongy pith occupies the interior, as in corn, young twigs of elder (Fig. 34, *A*) and sumach, and in the entire stem of the sunflower.

The stiffness of the young stem may be due almost wholly to collenchyma, as in the balsam (Fig. 32) and the elder (Fig. 34, *A*), or it may depend largely on the presence of wood fibers and tracheids in the bundles, as in the sunflower (Fig. 30). Sometimes collenchyma and fibers coöperate, as shown in the flower stalk of *Eryngium* (Fig. 34, *B*). In the case of dicotyledonous trees the stiffness of the trunk, resisting the severest storms, is mainly due to the enormous number of tracheids and fibers in the wood of the annual cylinders.

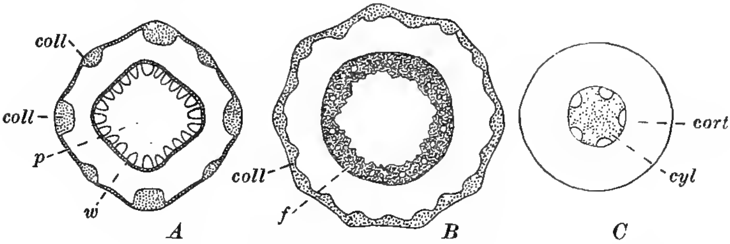

FIG. 34. Arrangement of strengthening tissue *A*, *B*, in stems; *C*, in the root

A, cross section of a young elder twig; *B*, cross section of flower stalk of *Eryngium*; *C*, cross section of a small root; *coll*, collenchyma; *cort*, brittle cortex; *cyl*, tough central cylinder; *f*, fibrous cylinder around a central hollow portion; *p*, pith; *w*, woody bundles surrounding the pith. After Strasburger

The stems of woody climbers need to be at once tough and flexible. Many such vines have, while young, the structure shown in the cross section of Dutchman's-pipe (Fig. 29), with the bundles arranged in a discontinuous series around the central pith and not united into a cylinder. This makes the stem flexible in the same way that a wire cable is more flexible than a solid metal rod.

Roots (except prop roots) do not need to possess much stiffness; it is necessary for them to be tough to resist lengthwise pulls, but laterally they are supported by the earth. Accordingly it is usual to find young roots with a fibrous central cylinder of comparatively small diameter, surrounded by a coating of much weaker tissue (Fig. 34, *C*).

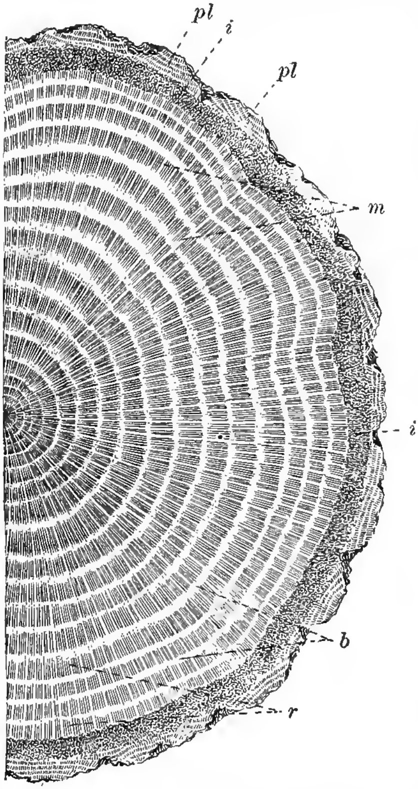

Fig. 35. Cross section of a stick of oak wood

m, medullary rays, running from bark to pith; *r*, "annual rings"; *b*, boundaries between "rings," porous from presence of many ducts; *i*, interior fibrous layers of dead bark; *pl*, hard plates of dead bark, splitting away from each other but attached to bark beneath. Reduced

47. Limited thickening of annual stems. In stems of large dicotyledons which die to the ground every year, such as sunflowers, ironweeds, hemp, giant ragweed, and so on, growth in thickness goes on throughout the summer. The outer cells of the cambium continually split up, by the formation of tangential partitions (parallel to the bark), and so form new layers of bark. The inner cells of the cambium, in a similar way and to a still greater extent, form new wood, and thus the stem goes on increasing in thickness. But in such plants as those just mentioned the activity of the cambium is strictly limited. After it has given rise to a certain amount of new tissue, growth stops and the stem dies down to the ground. The death of annual stems in the autumn is often thoughtlessly supposed to be due to the arrival of cold weather, but it occurs just as certainly, and often after a briefer period of growth, in regions where there is no cold winter.

48. Annual thickening. In stems such as those of dicotyledonous trees and the trees of the Pine family and other cone bearers, which live for many years, the cambium forms a new layer of bark and of wood every year.[1] These annual layers are usually more noticeable in the wood than in the bark, because the wood cylinders thus formed remain closely joined together (Fig. 35). The newer lighter-colored portions of the wood are known as *sapwood*, and the older portions, often darkened by the deposit of coloring matter, are known as *heartwood*. Not infrequently the heartwood decays and leaves the tree hollow.

(1) How old is the stick of wood shown in Fig. 35? (2) Did it grow equally fast during each year of its life? Discuss this question. (3) Why is the name "annual rings" not an accurate one? What are they really? (4) Is each year's growth uniform all round the stem? (5) Had this stem any branches in the portion shown by the section? How could the age of the stem, at the time when a branch began, be known (Fig. 37)?

The hardwood trees show great differences in the rate at which their trunks increase in thickness. Poplars, basswoods, willows, or red oaks, growing in good soil and unshaded, may for forty or fifty years form annual rings as much as three eighths of an inch thick. But old beeches and sugar maples in the forest, after they have passed the hundred-year limit, often grow not more than about one sixteenth of an inch per year. When very old, though still sound, they may grow only about one twenty-fifth of an inch per year.

Two of the most important of our coniferous or needle-leaved timber trees are the white pine and the long-leaf pine. A white-pine tree, overtopping most of its fellows in the forest, is, on the average, at ten years 0.9 inch in diameter,

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[1] In the tropical regions, where there is no marked change of seasons, the wood often grows rather evenly all the year round.

at one hundred years 17.2 inches, and at two hundred years 31 inches. The average thickness of the "annual rings" during the life of the tree throughout its second century is therefore about one fourteenth of an inch. In the Southern long-leaf pine, growth is slower. The increase in thickness of a tree two hundred and twenty years old and 17¾ inches in diameter was only one inch during the last forty years, — or one fortieth of an inch per year.

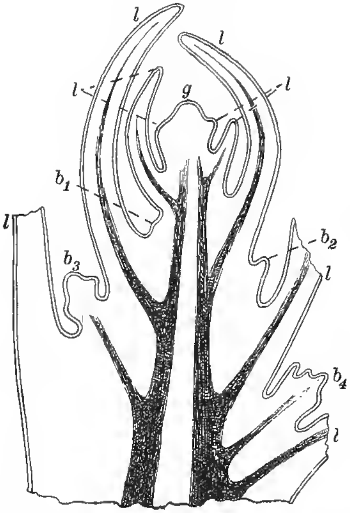

FIG. 36. Diagrammatic section through the growing tip of a dicotyledonous shoot, showing origin of branches

g, the growing tip of the shoot; l, leaves, those at the upper part of the shoot the youngest; b_1, b_2, b_3, b_4, branches of various ages, arising in the axils of the leaves. Note that only the older leaves and branches have fibrovascular bundles, connecting with those of the main portion of the shoot (all deeply shaded in the diagram). After Luerssen

In successful white-pine trees (that is, the taller and only slightly shaded ones of a forest) the total amount of wood formed in the trunk per year is, at fifty years, about one fourth of a cubic foot, at sixty to seventy years one cubic foot, at one hundred years one and one half cubic feet.[1]

49. Origin of branches. The branches of dicotyledons begin as little elevations or rounded outgrowths from the axis of the leaf bud, which often terminates the stem.[2] The extreme tip of the stem is the *growing point* (*g*, Fig. 36). This and much of the neighboring region is made up of cells which

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[1] See "The White Pine," *Bulletin 22*, Division of Forestry, U. S. Dept. Agr.

[2] Buds are treated more in detail in Chapter VI, but it seems best to say a few words in this place about the relation of the beginning branch to the axis from which it grows.

are rapidly dividing to form new ones, or, if not dividing, will begin to do so whenever they are placed under favorable conditions. Just back of the growing point appear little protuberances (*l*) which are to develop into leaves. Further along on the stem, each just forward of a rudimentary leaf, are still more rudimentary branches (b_1, b_2, and so on). In their youngest condition neither leaves nor branches contain any fibrovascular bundles, but these soon appear, as shown by the heavily shaded areas in the figure. Once equipped with bundles for the transportation of water and food materials, the growth of the young branch into a stem like that from which it sprang, with bark, wood, and pith of its own, is comparatively rapid. Branches of trees, being structurally of the same nature as the stem, form "annual rings," just as the main trunk does. The wood of the branch cuts across the "annual rings" of the trunk and forms a knot (Fig. 37).[1]

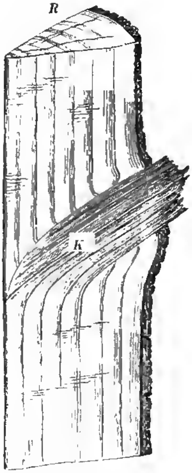

Fig. 37. Formation of a knot in a tree trunk

R, cut-off end of stick, showing annual rings; *K*, knot, formed by growth of a branch

50. Internal structure of the monocotyledonous stem. In the very young monocotyledonous stem of seedlings the fibrovascular bundles are constructed like those of dicotyledons, with the wood elements on the one side and the cortical elements on the other, as in Fig. 29. But in the full-grown stems of most monocotyledons the bundles have their vessels and other wood elements arranged in a hollow cylinder inclosing that part of the bundle which corresponds to the portion shown outside of the cambium ring in Fig. 29. In the adult monocotyledonous stem (when it is solid) the bundles occur scattered all through the pith, as shown in a section of

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[1] Knots may also be produced by injuries, but most of those found in ordinary lumber were caused by branches.

asparagus or corn stem (Fig. 38). No such complicated bark as that of woody dicotyledons is found in monocotyledons.

51. Growth in thickness of the monocotyledonous stem. The very young stem of monocotyledons may for a time increase considerably in diameter by the formation within it of new bundles. But in monocotyledons all the cambium becomes changed into other tissues, so that none is left (as it is in dicotyledons) to develop new tissue. In monocotyledons the bundles are said to be *closed*, while those of dicotyledons in which active cambium remains are said to be *open*. Most monocotyledonous trees, such as the palms, cannot form annual rings of wood. A few tree-like monocotyledons have trunks which continue for many years to increase in thickness, but the thickening of the trunk takes place in a manner wholly

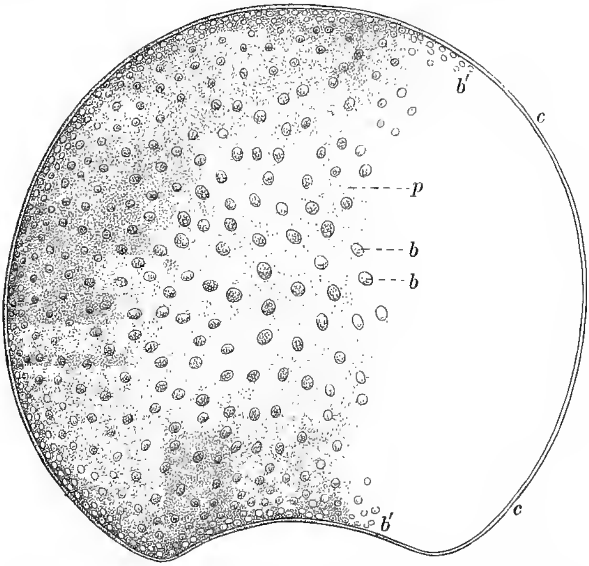

FIG. 38. Cross section of a corn stem (monocotyledonous)

c, cortex; *b′*, small fibrovascular bundles near the cortex; *b*, large bundles in the interior of the stem; *p*, pith-like material between bundles. About one and one-half times natural size different from that of dicotyledons. Many monocotyledons, such as the rattans, are remarkable for the extraordinary length and slenderness of their stems, which often scramble for hundreds of feet over the tropical forest.

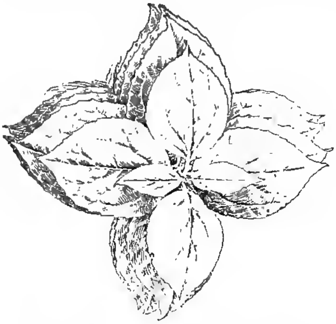

FIG. 39. Top view of vertical shoot of "syringa" (*Philadelphus*)

The leaves are arranged in pairs and each pair overlies the spaces between the pair below it. One third natural size

52. Arrangement of leaves upon the stem. A glance at any leafy twig usually suffices to show that the leaves do not spring from it haphazard but are definitely arranged. The commonest methods of leaf arrangement are the *opposite plan*, in which the leaves spring from the nodes in pairs (Figs. 39 and 40), as in the maples, the ashes, the mints, and many other plants; and the *alternate plan*, in which the leaf origins form a spiral about the stem, as in

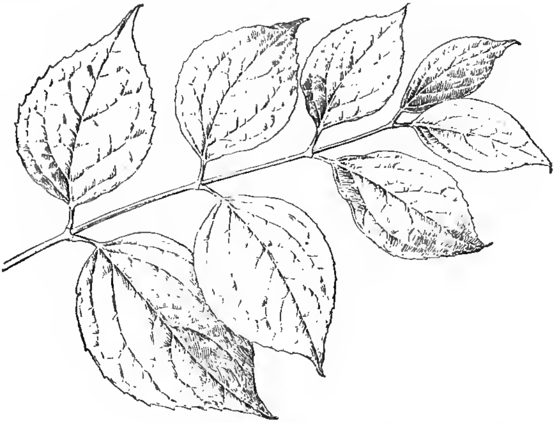

FIG. 40. Top view of a horizontal shoot from the same shrub shown in Fig. 39

The leaves spring from the branch in the same order as do those of the vertical branch, but by a twisting of the leafstalks the blades are made to lie nearly in a horizontal position and thus secure abundant illumination. One third natural size oaks, corn, and most kinds of hard-wood trees and of herbaceous seed plants. There are many varieties of spiral arrangement, the simplest being that of corn and other grasses, in which the second leaf is on the opposite side of the stem from the first, and the third is directly over the first. More complicated is the spiral of our common fruit trees (Fig. 41); and yet more complicated those of pines (Chapter XVIII), of houseleeks, and of many other plants.

FIG. 41. Alternate arrangement of leaves
An apple twig in the autumn

53. Arrangement on vertical stems in relation to overshadowing. On a vertical stem usually *no leaf directly overlies the one next beneath it.* In the opposite arrangement overshadowing is partially prevented by having the leaves of each pair overlie the spaces between the two leaves directly below them (Fig. 39). In the various spiral arrangements the third, the sixth, or the ninth leaf, and so on, comes directly over the first.

Since every foliage leaf usually bears in its axil a leaf bud which may develop into a branch, it follows that *branch arrangement must depend upon and resemble leaf arrangement.*[1] It is clear, therefore, that the branches cannot usually directly overlie each other. This is plainest in the case of opposite leaves and branches, but it is fairly evident in many other cases.

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[1] Branch arrangement is often obscured by the dying of most of the branches (Sect. 60).

54. Leaf positions on horizontal stems, and overshadowing. If a rapidly growing plant, as a sunflower, is bent over so as to lie flat on the ground, its younger leaves soon readjust themselves to the new position. Horizontal branches of trees and shrubs are very different from vertical shoots as regards the position of the leaf blades with reference to the stem. Though the opposite or the spiral arrangement of the leaf origins is the same, a twisting of the stem, or a lengthening, or twisting, or other change of position of the leafstalks usually occurs. This comes about in such a manner as to put the leaves in a favorable position to receive the sunlight (Fig. 40). Prostrate stems, like those of pumpkins, squashes, cucumbers, poison ivy, English ivy, and a host of others, when lying on the ground, arrange their leaves much as do horizontal branches of trees. Trees that have fallen in such a way as to leave the roots in the soil may have one or more branches assume the form of a tree.

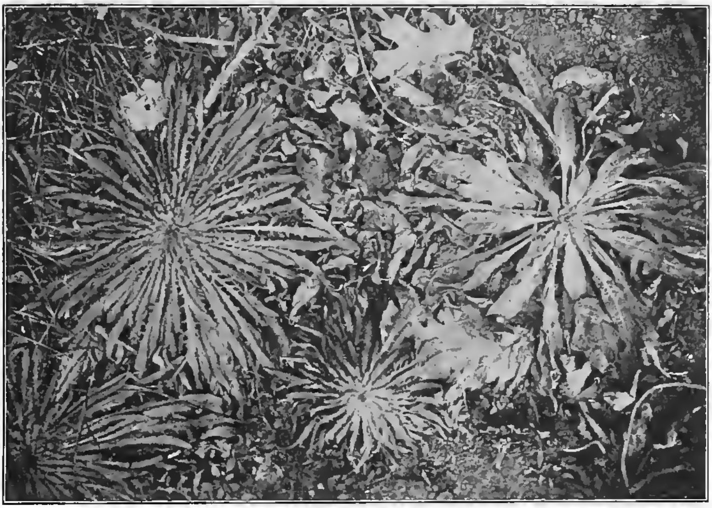

FIG. 42. Rosettes of evening primrose

Two species are shown: *Œnothera rhombifolia* on the left, and *Œ. biennis*, a very widely distributed species, on the right. Photograph by W. J. G. Land

55. Leaves of apparently stemless plants. Many plants have a stem so short that they are commonly spoken of as stemless. Most of these are perennials, such as the Iceland poppy, the common plantain, the true primroses (*Primula*), and the dandelion. There are also numerous biennials, such as the parsnip, the carrot, some species of wild lettuce, many evening primroses (*Œnothera*), and other plants, which form a tuft of leaves close to the ground the first year and then send up a leafy stem which flowers and fruits the second year. Such a tuft of leaves as that of the dandelion or the evening primrose (Fig. 42) is called a *rosette*, and plants in which the apparently stemless condition, with a cluster of radiating leaves, is permanent are known as *rosette plants*. Many of these are natives of alpine regions, and some, such as the century plant (*Agave*, Fig. 62), are found in hot, dry climates. Quite generally the shape of the leaves in rosette plants secures economy of

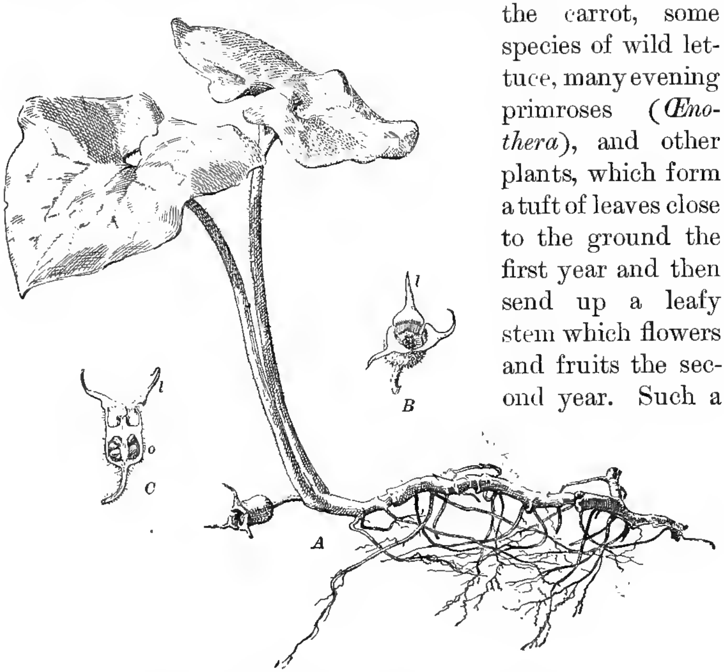

Fig. 43. Wild ginger, an apparently stemless plant

A, the entire plant, with running rootstock; *B*, top view of flower; *C*, lengthwise section of flower; *l*, limb of calyx; o, ovary. Reduced light, as they are either narrowed at the base or borne on long leafstalks, so that they do not overlap and shade each other at the bases. The leaves of the century plant are broad at the base, but this portion is pale and much thickened and does hardly any photosynthetic work, serving rather as a storehouse for plant food. At flowering time this food is removed, the leaves droop, and after the seeds are ripe the leaves die (Fig. 63).

FIG. 44. Leaf mosaic of a begonia

The leaves are so disposed that little shading of one leaf by another occurs

FIG. 45. Mosaic formed by leaves of unequal size

Top view of a branch of deadly nightshade. After Kerner

56. Leaf mosaics. Any combination of leaves, whether found in rosette plants or on longer stems, in which the space is very fully occupied by leaves, with few spaces horizontally between them, is called a leaf mosaic (Figs. 44 and 45). Walls covered with Japanese ivy furnish beautiful examples of leaf mosaics on a large scale, and many of our common house plants illustrate the same phenomenon. In any leaf mosaic many of the leaves occupy a very different position from that which they would have if borne on a vertical stem.

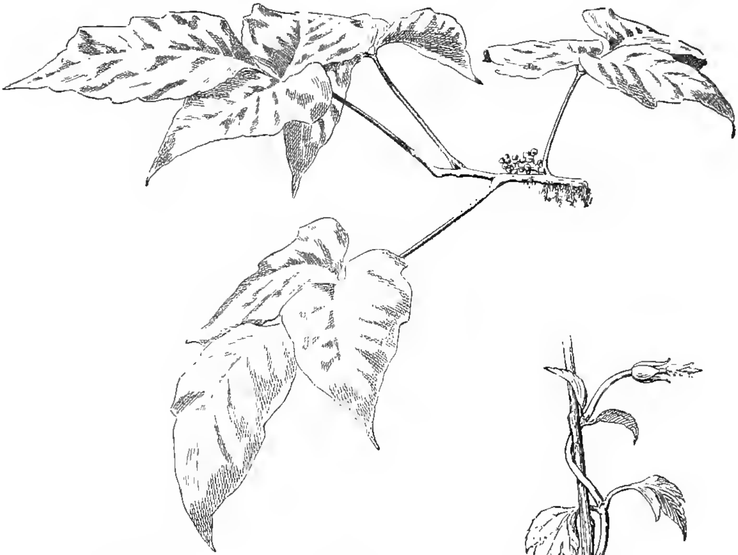

Fig. 46. Poison ivy, a root climber
Reduced

Fig. 47. Twining stem of hop

57. Obtaining better illumination by climbing. While the "stemless" plants and low mosaic formers utilize light very advantageously by the disposition of their leaves, many plants get an increased light supply by climbing. On account of the great height and dense growth of tropical forests, climbing plants or *lianas* reach their greatest development in those regions, often running hundreds of feet to emerge at last into the blazing sunlight above the tree tops.

Climbers are, however, quite generally distributed, and many are familiar plants of our own flora. They may be roughly classed into (1) scramblers, (2) root climbers, (3) twiners, and (4) tendril climbers.

Scramblers sprawl among and over the tops of bushes and thickets. Examples are some kinds of asparagus, our common climbing rose, and cleavers (*Galium Aparine*).

FIG. 48. Woodbine or Virginia creeper, a tendril climber

Reduced

Twiners raise themselves by winding the stem about any slender upright support that offers itself. Well-known examples are pole beans, morning-glories, and the hop. The details of the process by which twiners wind themselves about a supporting object cannot be very briefly stated. If carefully watched, the growing tip of the shoot will often be found to describe revolving movements like those of the hands of a watch. When the movement is arrested by contact of the shoot with an object not too large for the climber to twine about, the resistance which the young moving stem encounters causes it to wind permanently around the resisting object (Fig. 47). Usually the direction of the coils for any given plant is the same.

Tendril climbers attach themselves to the stems or branches of other plants or to inanimate objects by means of special, slender, thread-shaped, leafless organs called *tendrils*. These are modified leaves or parts of a leaf, as in the pea (Fig. 306); or modified branches, as in the grape, the Virginia creeper (Fig. 48), and the passion flower. When a living and active tendril comes into contact with a support, this contact causes growth to take place more rapidly on the exterior side of the tendril (that side which does not touch the foreign object), and thus the tendril is made to coil about the support. The sensitiveness of some tendrils is almost inconceivably great. Those of the star, wild, or bur cucumber (*Sicyos*) are stimulated to curve by a moving weight of $\frac{3}{1000000}$ of a grain, or one eighth of the smallest amount which can be perceived by the most sensitive part of the human skin (the face). After a tendril has become attached the free portions are also thrown into coils and thus the plant is drawn closer to the support. As a result of its attachment the tendril becomes stronger and often considerably thicker. In some plants, as the Virginia creeper, the tendrils are enabled to fasten

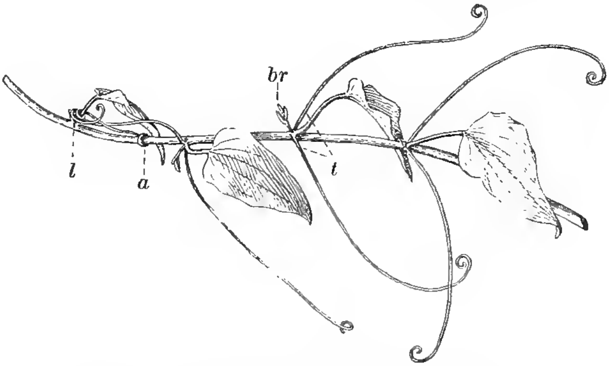

FIG. 49. A tropical *Smilax*, a tendril climber

a, tendril coiled about a portion of the stem; *l*, tendril coiled about a leafstalk; *br*, a young branch; *t*, young unattached tendrils

FIG. 50. An English ivy (*Hedera*) grown in front of a south window

WW, the line of the window casing; all to the right of this is unlighted wall. The tips of the shoots (*t*) avoid the light; the young leaves (*l*) have assumed no definite position; the mature leaves are nearly at right angles to the light coming from the direction of the arrow; *r*, aërial roots themselves to flat surfaces, as of stones or bark, by developing disks which act as suckers. These may stick so fast to the supporting surface that the tendril can be broken without tearing them away.

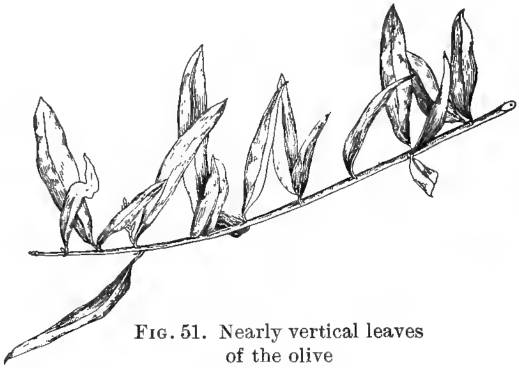

FIG. 51. Nearly vertical leaves of the olive

58. Leaf positions avoiding excessive illumination. While the leaves of plants growing in the shade often suffer from lack of sunlight and are usually so arranged as to utilize most fully what light there is (Fig. 50), it is possible for leaves in exposed situations to have too much light. It seems certain that the most powerful sunlight may injure the chloroplasts and therefore cripple the power of the leaf to do its work of photosynthesis.

Compass plants, such as the common prairie species (*Silphium*) and the prickly lettuce, have leaves somewhat erect, with edges directed nearly north and south, thus securing good illumination during the cooler morning and evening hours, but presenting the leaves nearly edgewise to the sun at noon. Many other plants maintain some or all of their leaves in a nearly vertical position, but with the edges not directed north and south. In the olive (Fig. 51) many leaves point nearly upward, while in the commonest species of *Eucalyptus* the leaves hang vertically downward.

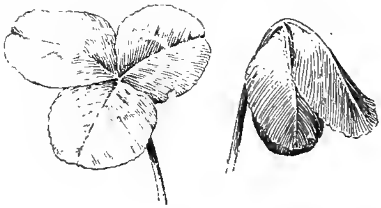

FIG. 52. A leaf of red clover

At the left, leaf by day; at the right, the same leaf at night. Natural size

In a great number of trees the young leaves from recently opened buds stand erect or hang straight down. In one tropical species[1] it is estimated that these young drooping leaves do not get more than $\frac{1}{500}$ as intense illumination as is received by the most exposed of the mature leaves.

59. Daily movements of leaves. It is common to find leaves assuming different positions during different portions of the day, or even whenever (as from the long continuance of clouds over the sky) the intensity of the sunlight is much altered. These daily changes of position are particularly frequent in plants of the Pea family, and many of these have a special cushion-like organ, the *pulvinus*, at the base of the leafstalks or of the leaflets, which produces the movements. Sometimes, as in Fig. 52, there are only two principal positions assumed during the entire twenty-four hours, one for the day, the other for the night. In other cases there are at least three well-defined positions, as in the case of the black locust leaf. In this the leaflets droop at night, remain nearly horizontal in ordinary daylight, and stand erect in full sunlight.

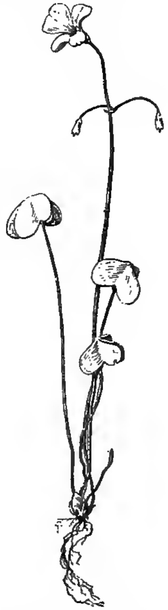

FIG. 53. The purple wood sorrel, with the leaves in the nocturnal position

One third natural size

It is certain that the plant gains some advantages from the change from horizontally placed to vertically placed leaflets, and the reverse. The horizontal position is (as already stated) favorable for photosynthesis in moderate light, and the vertical position hinders undue absorption of intense sunlight by the chloroplasts. What benefit the plant gets from the assumption of the night position by the leaves, and of how much importance this is, are questions as yet unsettled.

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[1] *Amherstia nobilis*, from Burma.

60. Self-pruning of leaves and twigs. Many trees and shrubs begin to shed some of their leaves even in the spring, very soon after the leaves are well grown. Examples of this are the lilacs, the syringa (*Philadelphus*), the cottonwood, the horse-chestnut, the box elder, and some lindens. Still more common is the loss of leaves during the summer, which may amount to 30 per cent of the total number of leaves. This leaf fall, coming long before the leaves are cast off in the autumn as a preparation for winter, affects mostly the leaves inside the crown of the tree, which have such scanty light that they cannot accomplish much photosynthesis.

Leaves, twigs, and even larger branches which are not getting an adequate supply of light or of water are pruned away by the tree. Were it not for this, the dense growth in the interior of the tree top and along the trunk would soon render further branching mechanically impossible. What one sees on looking up along the trunk into the top of a large tree is mainly dead or dying branches, with few leaves. It is this self-pruning and pruning by neighboring trees which makes the straight trunks, free from knots and most valuable for timber, in trees grown in woodlands, where they stand moderately close together. In some instances, as the so-called snap willows, the cottonwood, and the large-toothed aspen, live twigs fall very freely from the tree during wind or snowstorms, or when it is loaded

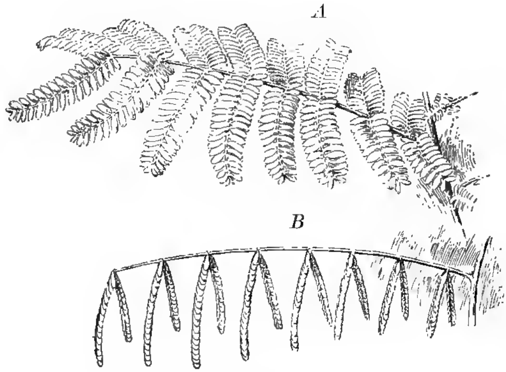

FIG. 54. A leaf of acacia

A, as seen by day; *B*, the same leaf at night. After Darwin with sleet (Fig. 28). These may be blown over crusted snow or floated along by brooks or rivers near which the trees grow, and doubtless often lodge in spots where they take root and grow into new trees.

61. Aërial, floating, and submerged leaves of water plants. Many plants which grow rooted under water have only aërial leaves. To this class belong many arrowheads, the cat-tails, wild rice, pickerel weeds, and other familiar species. A few common plants like the pond lilies and Victorias have floating leaves only (Fig. 55). Some water crowfoots and pondweeds have all their leaves submerged, while other species of these plants and some arrowheads have part of their leaves exposed to the air and others wholly under water.

FIG. 55. *Victoria regia* and other tropical and sub-tropical water lilies at the nurseries of Henry A. Dreer, Philadelphia

The Victorias have the largest known floating leaves, sometimes six feet in diameter and, like rafts, capable of supporting large water birds

Submerged leaves are often made up of many thread-like divisions, apparently to enable them to present as much surface as possible to the water, in order that they may absorb from it the gases dissolved in it. Their shape somewhat resembles that of the gills of fishes, and the thread-like divisions of the leaf and the gill have both to do the work of absorbing dissolved gases.

62. Leaves in relation to water supply. The form and size of leaves are frequently dependent on the water supply which the plant receives. In many plants which grow in moist soil or even in swamps the leaves are large and often entire, as in the *Cypripedium*, skunk cabbage, white hellebore, papaw, and the magnolias.

In very dry soils or where the rainfall is scanty or lacking during a considerable part of the warm months, there occur many plants whose leaf surface is very small, as in some Euphorbias, aloes, and heaths (*Erica*); or is even practically wanting, as in most cacti (Fig. 65). This reduced leaf surface evidently fits plants admirably to resist death from excessive transpiration during droughts.

When the soil temperature is nearly at the freezing point most plants are unable to absorb much water by their roots. It is probably mainly due to this fact that our ordinary *winter deciduous* trees owe their habit of shedding the leaves at the approach of winter. If their actively transpiring leaves were to remain at work while the ground was almost or quite frozen, the tree would suffer a fatal loss of water. Winter deciduousness is not a perfectly definite phenomenon, always setting in at precisely the same season. For example, the common Japanese honeysuckle, which is deciduous in the late autumn or early winter in the Northeastern States, is almost or quite evergreen in the South, and the trumpet honeysuckle is deciduous in the North and perfectly evergreen in the South. Such deciduous trees as the American tulip tree (*Liriodendron*) and the English oak become irregularly evergreen in the very uniform climate of West Java; that is, they show in December and January (on separate boughs) a state of things corresponding to their winter, spring, and summer condition in their native countries. The process of shedding the leaf is a somewhat complicated one, being brought about by the formation of a waterproof layer of tissue at the base of the leafstalk, thus cutting the leaf off from communication with the stem. Before this is formed, the plant food in the leaf has usually been conveyed into other parts of the plant, so that when the leaf falls it takes with it little of value.

FIG. 56. An evergreen rhododendron, typical of leathery-leaved non-deciduous dicotyledons, in very early spring

A deciduous rhododendron (azalea) is seen leafless in the foreground

Photograph by Robert Cameron

Some trees and many shrubs in countries like the Mediterranean region and California, where the hotter months are nearly rainless, are *summer-deciduous*, losing almost or quite all of their leaves at the beginning of summer. Twigs in this leafless summer condition have been found to lose only about $\frac{1}{36}$ as much water in a given time as they do when in full leaf.

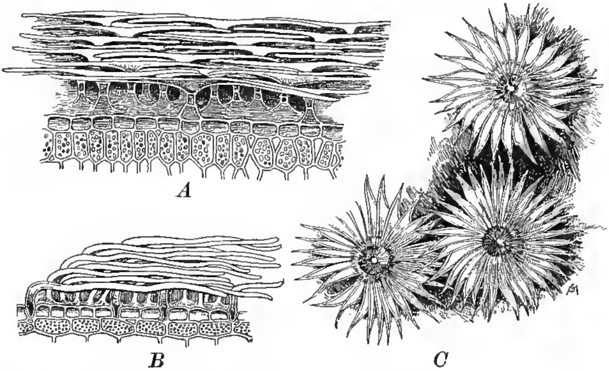

FIG. 57. Hairs which protect leaves from excessive loss of moisture

A, T-shaped hairs of wormwood; *B*, silky hairs of *Convolvulus*; *C*, shield-shaped scaly hairs of *Elæagnus*. All considerably magnified. After Kerner

63. Hairs and other coverings of the leaf surface. The leaves of many kinds of plants are covered with a layer of wax or of a varnish-like material; some are coated with a deposit of lime salts, and all of these substances appear to hinder excessive loss of water from the leaves. A similar purpose is subserved by a

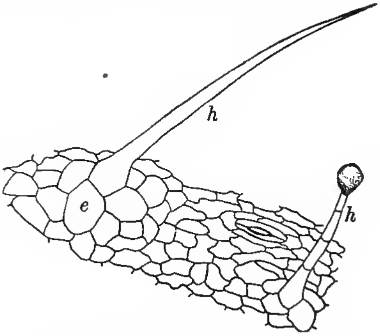

FIG. 58. Part of epidermis of geranium (*Pelargonium*), surface view

h, hairs, the one at the left consisting of one cell, the one at the right several-celled and bearing a gland at its tip; *e*, stout cells of the epidermis, which serve to support the hair. Between the hairs a stoma is seen. Considerably magnified clothing of dry hairs, which often assume very curious forms (Fig. 57). These may completely cover one or both surfaces of the leaf (usually the lower one). Such hair-clad leaves are very commonly found on mountain and desert plants and on those which grow in regions with a long and rainless summer, and it has been experimentally proved that the hairs greatly lessen evaporation from the leaves. Speaking of the flora of the summer-dry Mediterranean region, the distinguished Austrian botanist Kerner says: "The trees have foliage with gray hairs; the low undergrowth of sage and various other bushes and semi-shrubs . . . as well as the perennial shrubs and herbs growing on sunny hills and mountain slopes, are gray or white, and the preponderance of plants colored thus to restrict evaporation has a noticeable influence on the character of the landscape. He who has only heard from books of the evergreen plants of the Greek, Spanish, and Italian floras, feels at the first sight of this gray vegetation that he has been in some degree deceived, and is tempted to alter the expression 'evergreen' into 'ever gray.'"

Hairs which contain liquid, like the gland-bearing one in Fig. 58, do not serve to prevent evaporation, but are sometimes of much use for other purposes, as in carnivorous plants (Chapter XXI).

CHAPTER V

UNDERGROUND STEMS; STORAGE IN STEMS AND LEAVES; REPRODUCTION

64. Characteristics of underground stems. The popular notion of what a stem is, includes the idea that it is an aërial part of the plant. It is easier to recognize as roots such structures as the aërial roots of corn and of poison ivy than it is to recognize as stems the thickened underground portions of iris, jack-in-the-pulpit, dragon-root, trillium, or potato. Frequently, like aërial stems, underground stems are divided into nodes and internodes; and many of them bear scales which represent leaves, and produce buds in the axils of these scales. Such buds are well shown in the underground stems of some grasses. Dicotyledonous underground stems usually have distinct bark, wood, and pith, while most dicotyledonous roots do not have pith, though some do.

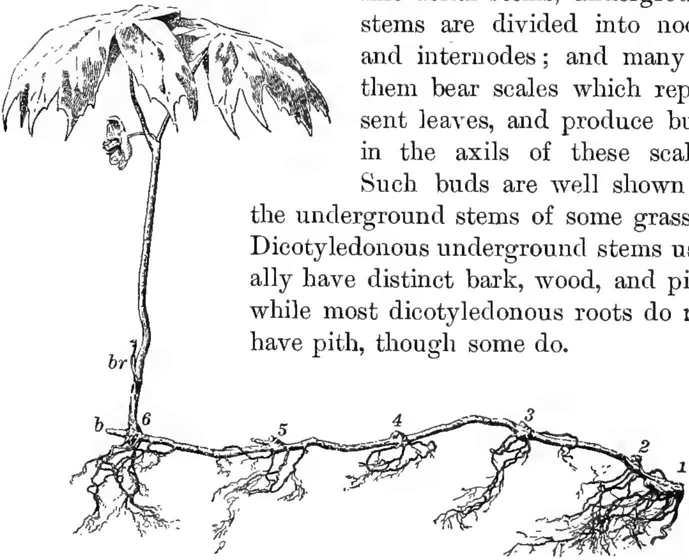

Fig. 59. A May-apple plant, showing the history of the rootstock

1 is the oldest surviving portion of the rootstock; *2* is a year younger; *3* a year younger than *2*, and so on. At each figure the cluster of roots marks the position of the base of the upright stem for that year, as is shown at *6*. *b*, bud for the new year's growth; *br*, bract at the base of the present stem. One sixth natural size

Some of the principal forms of underground stems have for convenience been given special names. The elongated forms like that of the May apple (Fig. 59), mints, couch grass, and many other plants, and some stouter kinds like that of trillium and Solomon's-seal (Fig. 60), are known as *rootstocks* or *rhizomes*. The very short shoots with disk-like stems and a covering of scales, familiar in some lilies, the hyacinth (Fig. 61), and the onion, are called *bulbs*. Much like bulbs, except that the stem is more developed and that the scales are almost lacking, are *tubers*, like those of the Jerusalem artichoke (Fig. 67), the potato, and the crocus.[1] The potato is a particularly good tuber for study, as it has well-defined nodes and internodes; the buds ("eyes") are arranged in a distinctly spiral manner, and are borne in the axils of little scales which represent leaves, and not infrequently the tuber is considerably branched.

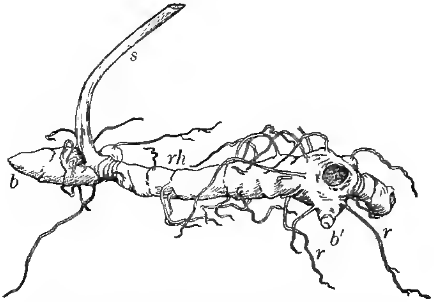

FIG. 60. Rootstock of Solomon's-seal

rh, rhizome or rootstock; *b*, *b′*, buds; *r*, roots; *s*, stem. The scar where an old stem was attached is seen just above *b′*

65. Aërial outgrowths of underground stems. Some underground stems produce a leafy aërial stem, while others send up leaves but have no stem above ground. A good example of the former class is the lily or the Jerusalem artichoke; of the latter, the ferns of temperate regions, many grasses, wild ginger (Fig. 43), and some of the commonest violets (Fig. 124). In any case the aërial parts of herbs, in cold or temperate climates, usually die to the ground at the beginning of winter. In regions with a long, rainless summer they frequently die soon after the end of the spring rains. The buried

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[1] Such very short underground stems as that of the jack-in-the-pulpit and the crocus are often called *corms*.

part of the plant body, with its terminal bud or sometimes lateral buds, is comparatively safe from extremes of cold or dryness, and serves to carry the life of the plant over from one growing season to another.

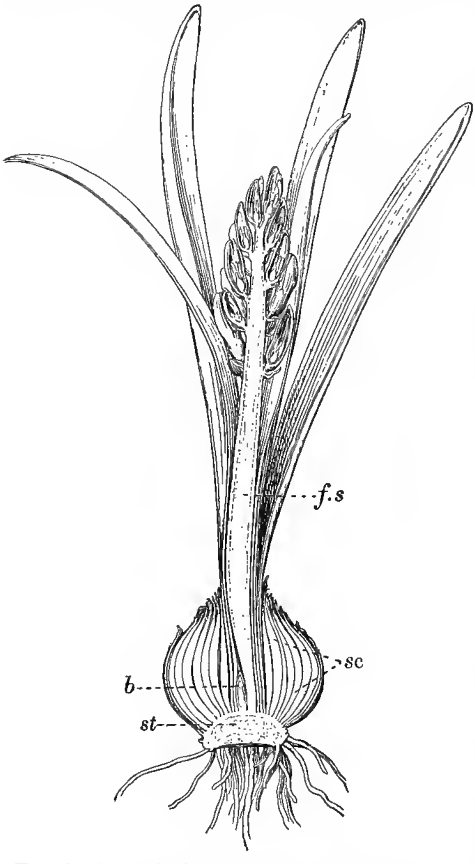

FIG. 61. Lengthwise section through a young hyacinth plant

st, the cushion-shaped stem at the base of the bulb; *b*, the young bulb from which the next year's growth would proceed; *sc*, bulb scales; *f.s*, flower stalk. Reduced

66. Water storage in stems. All living stems of plants contain water, and in the case of plants exposed to long periods of drought the water stored in the stem may be absolutely necessary to tide over the rainless months. Some cacti and other succulent desert plants contain enough water to make it possible for men and other animals to drink from them when they are cut open. The amount of water stored in some desert plants is sufficient to carry on growth and reproduction for ten years or more without renewal from outside sources. The trunks of certain South American trees are so swollen as to constitute something like aërial tubers, and great numbers of desert plants have bulbs or rootstocks much exceeding in bulk the rest of the plant body, and containing large quantities of water, protected from evaporation by heavy exterior layers of cork.

67. Water storage in leaves. Many of the most striking examples of succulent or fleshy-leaved plants occur among species which are natives of dry countries or of regions where there are long rainless periods. The century plants (*Agave*) (Fig. 62), ice plants (*Mesembryanthemum*), aloes (*Aloë*), and *Echeveria* are good instances of this kind of leaf. The leaves are sometimes cylindrical or prismatic, thus offering little surface for evaporation, and contain great quantities of water in the form of a thin mucilage, not easily dried up. In many such leaves the water is largely stored in special layers of the epidermis, while in others the water-storage tissue is in the interior of the leaf. During droughts fleshy leaves gradually lose their firmness and become flabby in the same way as the leaves of the purslane do when the plant is hoed up and left on the surface of the ground. In this case the plant may live for weeks and then take root and grow again after the first rain.

Sometimes plants which grow in moist soil have leaves with water-storage layers. The oleander, for instance, grows along water courses but is exposed for months to very dry, hot air, during the nearly rainless summers of the Mediterranean region. The common rubber plant (*Ficus*), which in India grows to be an immense tree, is one of the most familiar examples of water storage in the leaves of a species growing in moist soil. Such leaves are able to withstand the great changes of temperature and moisture in the air of the tropics during every twenty-four hours, the air for two thirds of the time being almost saturated with moisture, while during the remaining hours the moisture is relatively low and the temperature under a nearly vertical sun extremely high.

Plants with fleshy leaves are often found in cool, damp climates, but they usually grow on rocks or in other situations where the water supply is at times nearly or quite cut off.

68. Air storage in stems and leaves. In many marsh and water plants very extensive supplies of air are stored in the interior of the roots, rootstocks, the ordinary stems, and the leaves. This stored air constitutes what has been well called an inner atmosphere, by means of which the respiration of the plant is much aided, especially at times when the whole plant body is temporarily submerged. In those marsh or water plants which have the most extensively developed air passages and cavities they form a complex system which extends all the way from the stomata to the tips of the roots. Often a large part of the bulk of the plant body is occupied by such air cavities, surrounded by slight walls of solid material. In the leaves of *Pistia*, a floating aquatic belonging to the Arum family, 71 per cent of the volume is occupied by air spaces, while in ordinary land plants these spaces may occupy less than 7 per cent of the total volume of the leaf.

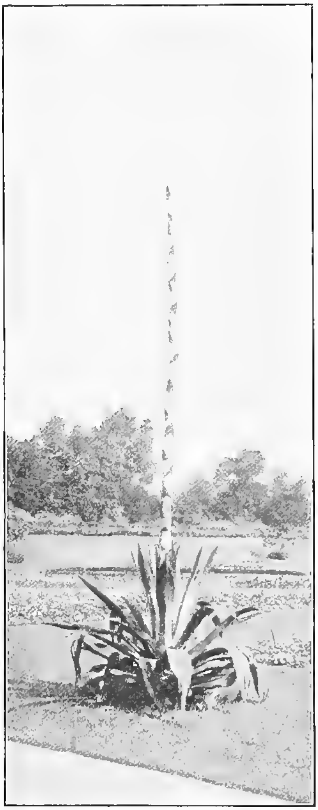

FIG. 62. A century plant, nearly ready to blossom

The flower stalk considerably developed and the outer leaves beginning to shrivel and droop from loss of food transferred to the flower stalk. Photograph by G. D. Fuller

An important mechanical use is often subserved by stems or leaves inflated with air, in buoying up the plant, as is well shown by the duckweeds, the water hyacinth (*Eichhornia*), and the water chestnut (*Trapa*). Many seaweeds, as the rockweed, are thus buoyed up.

69. Storage of food. Aërial stems contain plant food, often in great quantities. In the trunks of trees this food is present in various forms, — as starch, sugar, oil, and proteins. Many kinds of sapwood turn deep blue or black if tested with iodine for starch in the autumn. During the winter much of this starch is often converted into sugar or oil. The presence of proteins in wood is so general that the cheaper grades of white paper, largely made of wood pulp, at once turn yellow on being moistened with nitric acid (protein test). When thus tested, paper made wholly of cotton, or of linen rags, shows little change. The plant food stored in wood is most abundant in the younger portions (sapwood), and above all in the cambium layer.

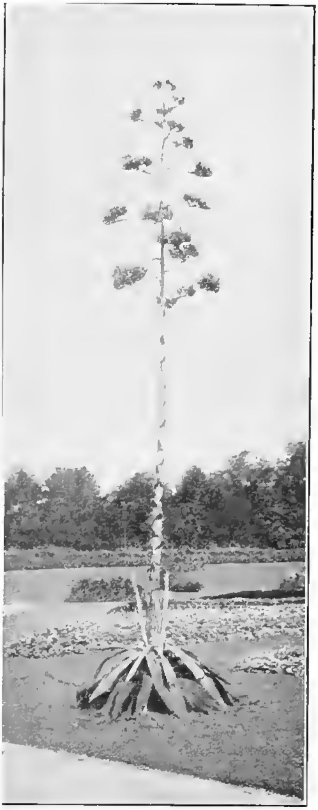

Fig. 63. The century plant of the preceding figure as it appeared nearly two months later

The leaves have given up their stored food to the flowers and flower stalk and are now withered and valueless. Photograph by G. D. Fuller

Underground stems often contain large quantities of stored food, and are thus useful in tiding over the period of the year when no food can be made, just as they have already (Sect. 66) been shown to be of service in storing water. There are many shade plants — such as trilliums, dogtooth violets (Fig. 66), wild ginger (Fig. 43), May apple (Fig. 59), and others — which leaf and blossom early in the spring and do a large part of the storing of food for the next season in their rootstocks, tubers, or bulbs, before the trees under which they grow are in full leaf, so as to shut out the abundant light necessary for photosynthesis.

Fleshy leaves often contain much stored food, as in the familiar century plant (Figs. 62 and 63). This receives its name from the commonly received idea that it must store food for a century before it can blossom. In hot climates, however, such as that of Arizona, near Tucson, it flowers at the age of fifteen years or but little more. By the end of the flowering season the leaves have lost more than 90 per cent of their weight, which has been expended in producing the immense flowering shoot. This may reach a height of over 33 feet and a weight of some 500 pounds. Its average growth in height during the month of most rapid elongation has been found to be about five and one half inches a day. Not only the plant food, but also nearly all of the water for this rapid growth is furnished by the leaves.

70. Food for reserve stores brought from elsewhere. In all plants of high organization the reserve food is carried from the cells in which it was manufactured into other cells. In plants with fleshy leaves, like the houseleek, the century plant, the common purslane, and many others, the greater part of the stored starch and other nutritive materials has only been carried from the outer portions of the leaf, where photosynthesis and other manufacturing processes go on, into the leaf interior. The distance traversed may be only a small fraction of an inch. But in case much of the food is stored in underground parts of the plant it may have been carried for long distances, in large trees even much more than a hundred feet.

71. Form in which plant food is carried. As is suggested in Sect. 17, the first visible product of photosynthesis in most plants is starch. This is deposited in or about the substance of the chloroplasts, during their exposure to daylight, in the form of very minute grains. In the course of the night these disappear, so that testing a leaf with iodine[1] shortly before

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[1] This turns starch grains blue or almost black.

daylight usually gives no result. However, in case the leaf is cut off from the stem before nightfall, it responds readily to the iodine test for starch in the morning. This, of course, shows that the starch made during the day had no outlet and therefore remained in the leaf cells where it was formed. Very generally starch carried away from any part of the plant body to another part is first changed to sugar and travels in the form of a very weak solution of sugar in water. On its arrival at the storage region (as in the case of the potato plant at the tuber) the dissolved sugar is reconverted into starch by the action of minute colorless corpuscles of protoplasm known as *leucoplasts*. The starch grains deposited for storage (Fig. 64) are many times larger and show a far more definite structure than those formed in the chloroplasts during photosynthesis.

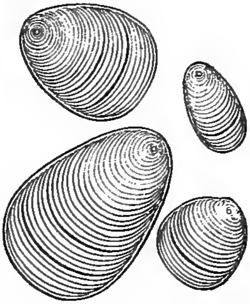

Fig. 64. Starch from rootstock of *Canna*. Magnified 300 diameters

72. How plant food is carried; diffusion. If a little molasses is poured into a straight-sided jar and water is carefully added, a disk of porous paper being first laid on the surface of the molasses to prevent instantaneous mixing, the water will for a considerable time appear clear and colorless. Only after some hours will the molasses rise and mingle much with the water, or the latter perceptibly thin the molasses. This process by which two liquids in contact become mixed by the interchange of inconceivably minute portions (molecules) of both liquids is called *diffusion*. The interchange of diffusible liquids through a membrane without visible pores, such as an ordinary cell wall, is called *osmosis*. Ordinarily in osmosis the stronger flow is from the less dense to the denser liquid. In the case of the starch-loaded leaf (Sect. 71) it is evident that, as fast as the starch grains temporarily deposited in the chloroplasts are changed into sugar, some of the sugar in the denser cell sap thus produced will pass on to the more watery sap of adjacent cells. From these cells in turn portions of sugar will pass on to other more distant cells. In a similar way, when a potato tuber is planted and begins to sprout, the sugar formed from the reserve starch in the potato will pass into the more watery sap contained in the sprouts. This sap is constantly losing sugar that is used as building material for the young growing stems and leaves, and its strength can be maintained only by the addition of new portions of sugar coming from the tuber.[1]

73. Channels by which plant food is carried. Many kinds of living tissue serve as channels for the conveyance of food from one part of the plant body to another. The main route for the transportation of food in flowering plants is through special tubular cells forming the *sieve tubes*, so called from the perforated plates which are found at the ends or along the sides of the nearly cylindrical cells of which the tubes are built up. These sieve tubes in dicotyledons occupy a region of the stem immediately outside of the cambium, as shown at *o* in Fig. 29. The fact that most of the plant food prepared in the leaves is carried down through the sieve layer of the bark is well shown by the behavior of a willow cutting from which a ring of bark has been removed. If the cutting is stood with its lower end in water but with the girdled part out of water, enough constructive material will pass down through the sieve layer to send out roots from the upper edge of the ring, but few or none will appear at its lower edge. Water meantime is freely carried upward through the sapwood. In early times the process of clearing woodlands for farming purposes was made less laborious by girdling the trees, which soon died and at length fell and were burned. Would the girdling process be more effective if a good deal of the sapwood were removed from the ring as well as the bark? Explain.

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[1] It is not possible here to go into details concerning the transportation of other kinds of plant food than starch and the sugars. That of proteins is especially difficult to trace.

FIG. 65. Prickly-pear cactus

It seems certain that a good deal of the transportation of food substances inward from the sieve tubes toward the center of the stem is done by the medullary rays (Fig. 35, *m*).

74. Stems as sources of animal food. The life of men and of many species of the lower animals is largely sustained by vegetable food obtained from the stems of plants. Cane sugar and maple sugar are respectively derived from the stem of the sugar cane and of the maple tree. The sugar maple is tapped for its sap for sugar-making in early spring. The flow of sap is most abundant during moderately warm days succeeding freezing nights. A single tree usually yields from 30 to 50 or more quarts of sap, from which 3 or 4 pounds of sugar can be made. One tree has, however, been known to yield 23 pounds of sugar in a single season. Asparagus, cabbage, and a few other vegetables consist of aërial shoots. Sago is made from the starchy pith of East Indian palms and West Indian cycads. Potatoes, onions, and Jerusalem artichokes are well-known examples of underground stems used as food. Many familiar animals — such as rabbits (more properly called hares), deer, and moose — live largely by browsing on the twigs of trees and shrubs. In pioneer times it was sometimes necessary to feed to horses cottonwood and other twigs in winter for lack of hay. Young cornstalks with the leaves (corn fodder) form an important article of horse and cattle food, and the preparation of fermented cornstalks known as ensilage is widely used. The stems of prickly-pear cactus (Fig. 65) deprived of their thorns (or of thornless varieties of this cactus), are used as food for cattle in the semi-desert regions of the Southwest.

75. Reproduction by portions of the stem. The number of seed plants which are naturally reproduced by means of portions of the stem is very large, and there are many others which are artificially propagated by this means. Some of the principal varieties of reproduction by pieces of stem or special shoots for the purpose are:

(1) By aërial bulblets.
(2) By underground bulbs, rootstocks, tubers, and so on.
(3) By offsets, stolons, and runners.
(4) By broken-off branches (Sect. 60) or cuttings ("slips").

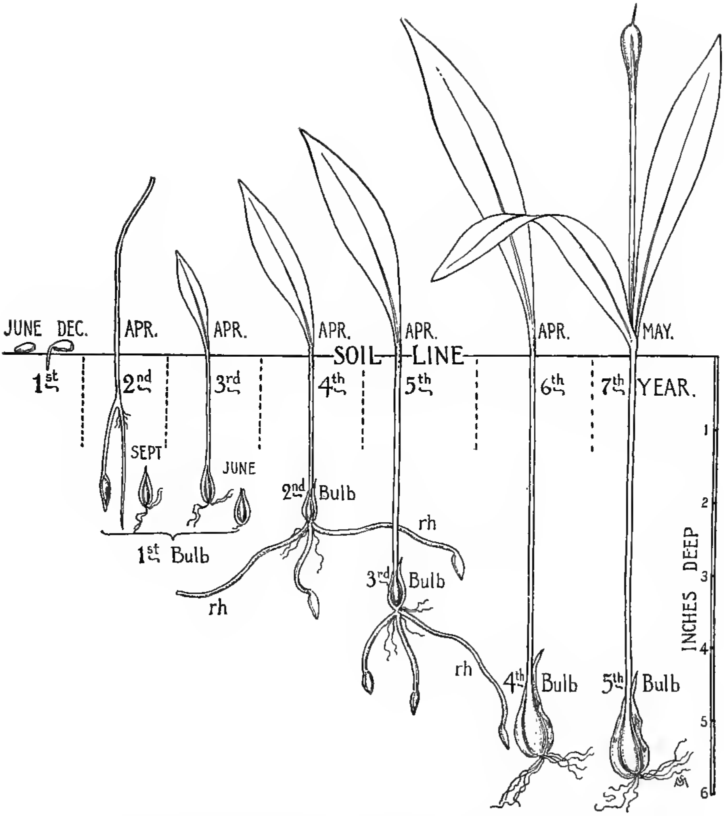

Fig. 66. Steps in the development of the yellow dogtooth violet (*Erythronium americanum*) from the seed to the seventh year

The diagram for the most part explains itself. The student should note that the seed begins to germinate late in the first year, becoming a seedling early in the second year. The cotyledon of the seedling accomplishes enough food making by photosynthesis to enable the plant to form a small bulb. This is maintained without much increase in size throughout the third year. During the fourth, the fifth, and the sixth years the increasing size of the leaf permits the production of larger and larger bulbs, until in the seventh year enough plant food has been accumulated in the bulb to send up two leaves and produce a flower and fruit. The third bulb may repeat itself indefinitely, not gaining much in depth. In this case the interval between germination and flowering would be more than six years (the time indicated in the diagram). Each well-developed bulb may (in this species) form runners, *rh*, which bring about vegetative reproduction, the small bulb at the end of each growing into a new plant. Modified after Blodgett

76. Reproduction by bulblets and by underground stems. Many plants bear small aërial bulbs or tubers on some portion of the stem and are commonly reproduced by these. Familiar examples among cultivated plants are the onion and the tiger lily. The bulblets known as "onion-sets" are for sale at every seed store, and in some parts of the country are almost exclusively planted by onion growers, while in other sections the seed is more generally planted. The black bulblets of the tiger lily are borne in considerable numbers along the stem, in the leaf axils, and may be found on the ground, rooting in the late autumn and the following spring. Some of our wild plants, including certain ferns, are propagated by bulblets.

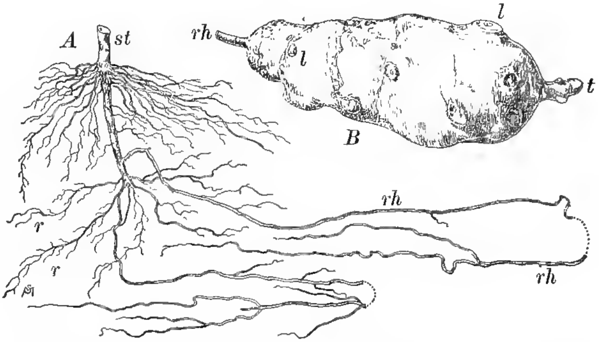

FIG. 67. Roots, rootstocks, and a tuber of the Jerusalem artichoke (*Helianthus tuberosus*)

A, base of a plant with two long rootstocks, about one twelfth natural size; *B*, a full-grown tuber, beginning to sprout, slightly reduced; *st*, aërial stem; *r*, roots; *rh*, rootstocks; *l*, lateral buds of tuber; *t*, terminal bud of tuber. *A*, modified from report of Kansas Agricultural Experiment Station

Underground stems of various kinds are so common as means of reproduction that only a very few of them need be mentioned. Some of the worst weeds are those which have running rootstocks, like the couch grass or quack grass and the Canada thistle, which may be cut up by the hoe and produce a new plant from every node; and the nut grass (*Cyperus*), which produces many little tubers. Among cultivated plants a great number of the earliest blooming herbaceous kinds, such as squills, hyacinths, tulips, crocuses, and snowdrops, are grown from bulbs or other forms of underground stem. The commonest of all instances of propagation by this kind of stem is that of the potato, which is never grown from seed except for the production of new varieties. As every farmer and market gardener knows, each potato will produce as many new plants as it has buds ("eyes"); though it is better not to cut the potato into too small pieces for propagation, or the plants will grow slowly at first.

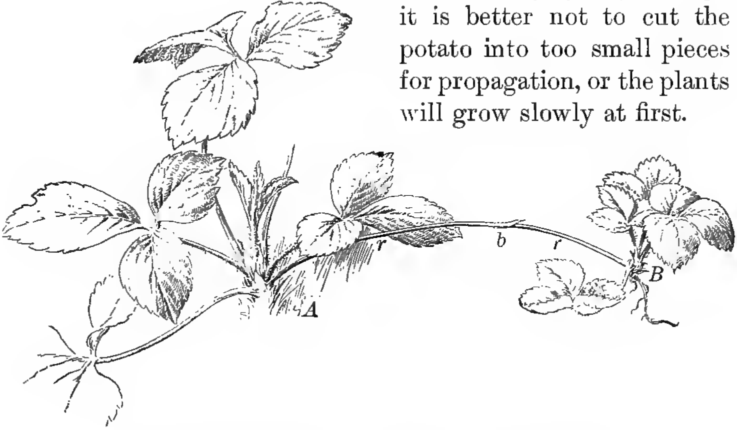

FIG. 68. Propagation of the strawberry plant by runners

A, the parent plant; *B*, the young plant; *r*, runner; *b*, bract. Half natural size

77. Reproduction by offsets and similar branches. An *offset* is a lateral branch for vegetative reproduction, usually rather short, as seen in the cardinal flower and the houseleek. Sometimes the offset ends in a leafy rosette; in any case the branch readily takes root and begins life as a new individual.

A *stolon* is an ordinary branch which roots at or near the tip and so forms a new plant, as is often seen in the black raspberry. A *runner* is a very slender stolon, leafless except near the tip, where it roots and grows into a new plant, as in the strawberry (Fig. 68), the silverweed, and other cinquefoils.[1]

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[1] The word *runner* is also used, for lack of a better term, for the slender underground stems shown in Fig. 66.

78. Reproduction by detached branches. A few words were said in Sect. 60 about how some trees, such as snap willows, are reproduced by broken-off twigs, rooting like cuttings.

A good many water plants, such as the common bladderwort, produce leafy buds or branch tips (Fig. 362) which become detached from the parent plant. In late autumn the latter usually dies, and in the spring new individuals arise from the buds which have lain dormant all winter at the bottoms of the ponds or slow streams where they grew.

Numerous woody plants, such as willows, grapevines, currant bushes, gooseberry bushes, and geraniums, and some herbaceous plants such as the hopvine and the Wandering Jew, are usually grown from cuttings. Many others, such as the French marigold and the garden portulaca, not usually thus grown, may be readily propagated by cuttings. In the case of woody plants the cutting should be taken from well-matured twigs of the previous season. In order to avoid too much loss of water and consequent wilting, leafy cuttings are often kept covered for a short time with a tumbler or bell glass.

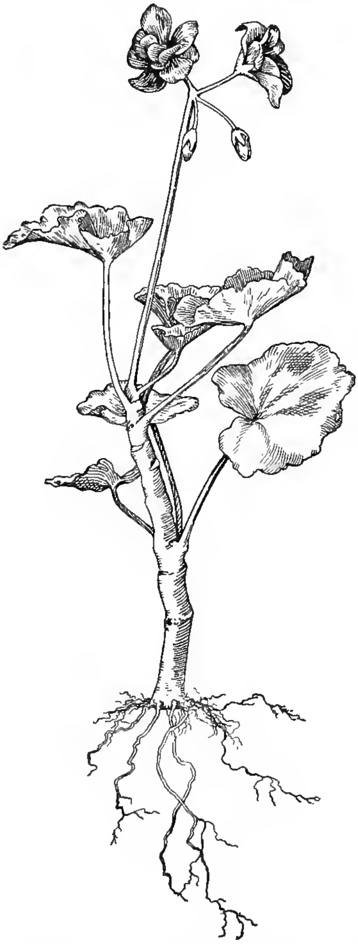

Fig. 69. A geranium cutting, showing growth of many young roots which spring from a node near the cut end

Layering is a modification of reproduction by cuttings, and consists in bending down a living branch and covering it for part of its length with earth, so as to form a sort of artificial stolon. Some trees and shrubs, such as the apple, pear, plum, and quince, are much easier to grow by layering than by making cuttings, and they root more readily if the shoot is deeply notched or has a ring of bark removed on the buried portion.

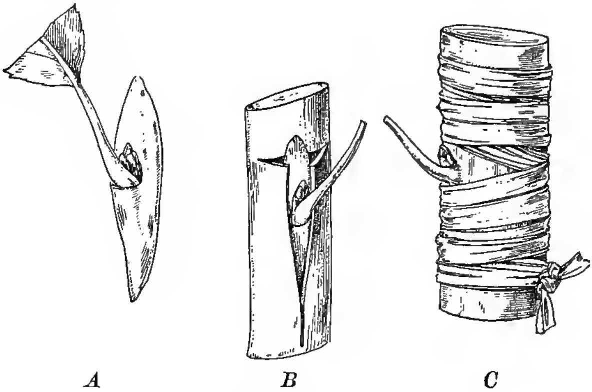

FIG. 70. Propagation by budding

A, a bud cut from a tree of the desired variety, with a piece of the underlying bark; *B*, the bud inserted in a T-shaped slit in the bark of the stock; *C*, the same, with the bark bound in place by strips of raffia (a fibrous material obtained from the leaves of the raffia palm). Modified after Percival

79. Budding and grafting. The process of *budding* consists of detaching an uninjured bud from the stem of one plant and inserting it under the bark of the stem of another plant (Fig. 70). Peaches and cherries are familiar examples of trees commonly propagated by budding. The operation should be performed at a season when the cambium layer is active, so that the transplanted bud will at once unite with the wood of the stem into which it is set. In the case of peaches the young seedling trees grown from seeds planted the same spring are budded in June or September. Those budded late do not grow much until the next season, but then make rapid progress. As the top of the seedling is cut off not far above the bud, all further growth of the shoot partakes of the quality of the bud; and the fruit borne by the tree, when it is large enough to bear, will be of the kind characteristic of the tree from which the bud was taken.

FIG. 71. Grafting

At the left scion and stock are shown ready to be united; at the right they are joined and ready to cover with grafting wax. After Percival

Grafting is removing a piece of stem with its buds from one plant and inserting it into a portion of stem of another living plant so that the cambium layer of each will be in contact with that of the other (Fig. 71). The plant into which the stem is inserted is called the *stock*, and the portion of shoot which is set into the stock is called the *scion* or *graft*. There are many kinds of woody plants which may readily be grafted, but the process is of practical importance mainly for the grower of apples and pears. Various plans are adopted in different fruit-growing regions. One of the commonest methods for the propagation of apples is root grafting. Seedling trees a year old are dug in the autumn and the roots grafted with one-year-old scions of desired varieties of apples, each cut to the length of about six inches. The grafted roots, wound about the joined surfaces with waxed cord, are packed in sand in a cool and not too dry cellar and left until spring. By that time the cambium layers of root and scion have united and the roots are ready to plant. *Tongue grafting* is practiced either with young seedlings or with twigs of larger trees (Fig. 71) in the spring. *Top grafting* consists in cutting off limbs one or two inches in diameter, splitting the portion remaining attached to the tree for a short distance, and inserting at each part of the split, where it crosses the cut surface, a small scion, and then covering all exposed parts well with grafting wax. Root grafting has the advantage that it results in a tree with trunk and branches wholly of the desired variety of apple. Tongue grafting of small branches does not interrupt the growth of the tree and is done with very little trouble. Top grafting is mainly resorted to in order to renew old trees that are not bearing the desired variety of apple.

The main object of budding and grafting is to propagate the varieties of fruit which the horticulturist desires. This cannot be done merely by growing seedling trees, since every seedling of hundreds grown from any valuable kind of apple or pear may differ from all the others of the same lot and not one of them be worth cultivating.

Grafting often succeeds on plants of different species,[1] as the peach on the plum, the apple on the pear, and the pear on the quince. Sometimes it succeeds between different genera[1] of the same family,[1] as the tomato on the potato and the Spanish chestnut on the oak.

Many technical details must be attended to in order to bud or graft successfully, and these are best learned from a practical horticulturist.

80. Reproduction by leaves. Not very many plants can reproduce themselves by means of their leaves. The best-known examples are begonias, which are largely propagated by cutting off leaves, slitting them, and then laying them on moist sand under a bell glass until buds and roots are produced at one or more points of the cut surface. A not uncommon greenhouse plant of the Live-forever family, the *Bryophyllum*, is still more easily propagated, as the leaflets readily produce buds and roots at the notches along their margins when placed on moist earth.

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[1] For the definition of the terms "species," "genus," and "family," see Chapter X.

CHAPTER VI

BUDS AND BRANCHES

81. Naked buds and scaly buds. When people who are not botanists speak of buds, as, for example, in referring to the signs of leafing or flowering of fruit trees in the spring, they always mean the scaly *winter buds* or *resting buds*, such as are familiar on most of our hard-wood trees and shrubs (Figs. 72–86). This is, however, a narrow view of the meaning of the term. Herbs like our common garden annuals, such as the bean, the pea, the cucumber, and the morning-glory, are as well provided with buds in proportion to their size as are ordinary trees. In the tropical rain forest, where the temperature is always high and there are violent rains almost daily, there are few scaly buds. Most of the trees in such regions have *naked buds* like those of the common greenhouse hydrangea (*Hydrangea Hortensia*) or the geraniums (*Pelargonium*).

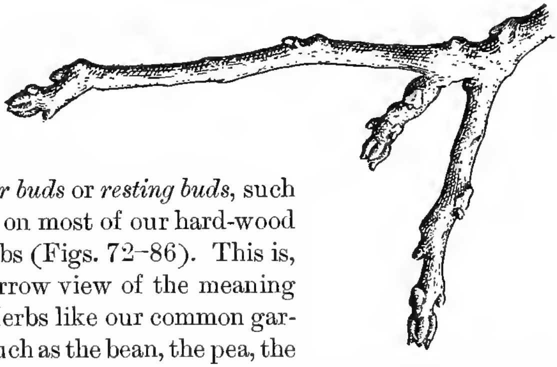

FIG. 72. Twigs of black walnut with buds in winter condition

Two thirds natural size

Generally speaking, scaly buds occur in woody plants which grow in cold or temperate climates, where such buds are well suited to resist the sudden winter changes from heat to cold, and the reverse. Some of our common trees and shrubs have buds which are only slightly protected by scales, but these buds are usually small, and often more or less hidden under the bark, as in the syringa (*Philadelphus*) and the *Ailanthus*.

82. Nature of the bud and its coverings. *A bud is an undeveloped shoot;* or, in other words, a bud is a group of undeveloped parts which, under favorable circumstances, will grow into some kind of stem and leaves. If it is a *leaf bud*, like the majority of the buds on most forest trees familiar to us, it will grow into a leafy branch or continue the growth of the main stem at its tip. If it is a *flower bud*, it will grow into that kind of specialized branch which we call a flower. If it is a *mixed bud*, it will grow into one or more flowers and will also develop some ordinary leaves.

The scales which cover buds are often dwarfed and otherwise modified leaves or leafstalks, as is well shown in some buckeyes in which the opening buds present a series of gradations between mere scales and foliage leaves (Fig. 73). In other cases, as in oaks, beeches, lindens, and magnolias, the scales represent the appendages (*stipules*) found at the bases of many leaves.[1] Frequently bud scales are covered with a dense layer of hairs or down, and sometimes, as in the balm-of-Gilead poplar, they are cemented together by a resinous varnish. These coatings on the scales of materials which do not readily conduct heat increase their value as a protection against sudden changes in the weather during the colder months.

FIG. 73. Dissected bud of sweet buckeye, showing transitions from bud scales to leaves

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[1] See Kerner-Oliver, Natural History of Plants, Vol. I, pp. 351–353. Henry Holt and Company, New York.

83. Position of buds. Buds are either *terminal*, growing from the tip of the stem; or *lateral*, growing from its side (Fig. 74, *lat*). The plumule (Fig. 126) is the first terminal bud of the young seedling. Commonly the terminal bud is stronger than any of the lateral ones, and makes more rapid growth than they do.

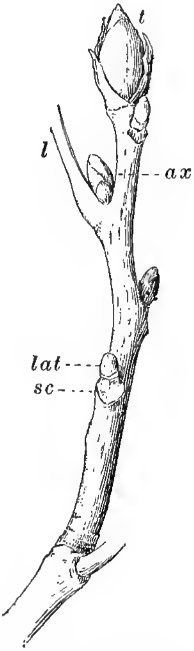

FIG. 74. Twig of hickory in winter condition

sc, scar of last year's leaf; *lat*, a lateral bud; *l*, a last year's leafstalk; *ax*, a lateral bud in the axil of the leafstalk; *t*, terminal bud. Reduced

Lateral buds are usually *axillary;* that is, they arise from the *axil*, or angle, formed by the leaf with the stem, as shown in Fig. 74, *ax*. Many plants also produce *accessory* buds; that is, buds a little outside of the leaf axil, which may either stand above the axillary bud, as in the butternut, or on either side of it, as in the box elder (Fig. 75).

Adventitious buds are those which spring, without any definite order, from roots, stems, or leaves. These are often of great value in propagating plants by means of cuttings or layers.

84. Form of trees dependent on growth of buds. If the uppermost bud of the main stem of a tree continues year after year to be stronger than any other bud, the general form of the tree becomes roughly conical, as is well shown in the pine tree (Fig. 246), and in firs, spruces, and the European cypress. If, on the other hand, some of the branches grow in length as fast as the main trunk, the tree will become round-topped and spreading, like an apple tree, an elm, or most of our hard-wood trees, when they grow in open ground.

Not uncommonly the terminal bud of most branches is a flower bud, as in the magnolias, or no terminal bud is developed, as in the lilac. In these cases the main branches cannot run out from the trunk for long distances, remaining much larger than any of the branchlets, as they do in the spruces and in many pines (Fig. 329). Why can they not? Such trees are round-topped, with many forking branches.

85. Competition among buds and branches. Of all the buds yearly produced by a medium-sized tree only a small proportion can survive even for a year or two, and a much smaller proportion still can grow into branches. The killing-off process is mainly one of light-starvation. Looking up into the crown of a tree along a line nearly parallel to its trunk, one is able readily to see that the tree top is not a rather dense mass of leaf-covered twigs, as it appears to be when looked at from without. It is more nearly a hollow cone or (in the case of very round-topped trees) a hemisphere, like an open umbrella, the main branches answering to the ribs of the umbrella. The interior portion of the tree top is too much shaded for rapid growth of buds or young twigs, and parts of it are dark enough to kill them outright, since their growth depends upon the plant food which they can make by photosynthesis.

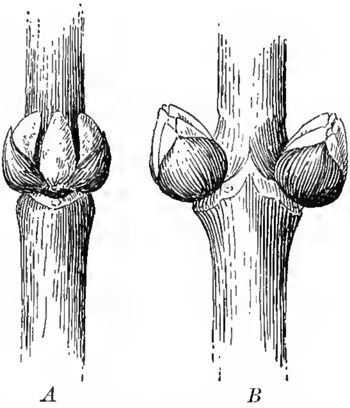

Fig. 75. Accessory buds of box elder (*Acer Negundo*). Magnified

A, front view of group; *B*, two groups seen in profile

Some simple counts and calculations may serve to make clearer the fact of competition and consequent death of the interior members of the tree top. On a well-grown box-elder tree, perhaps twenty-five years old, the condition of the lateral twigs springing from six-year-old portions of the smaller branches was carefully noted in March. On the branches most fully exposed to the sun, on the south side of the tree, the number of lateral twigs on the six-year-old portions of the branches ranged from 0 to 9 and averaged 3.2.[1] On the north side of the tree, and somewhat inside its circumference, only

FIG. 76. Development of leaf bud of pear

A, a leaf bud of pear in autumn; *B*, a leafy shoot derived from *A*, as seen in the middle of the following summer, with flower bud at tip; *C*, the fruit spur (*B*) in autumn, after the falling of the leaves. After Percival

FIG. 77. Fruit bud of pear (same as *C* of Fig. 76), showing its development

A, opening in spring; *B*, later, developing flowers and leaves; *C*, later still; only one flower has produced a fruit, the rest having fallen off. Below it, is a lateral bud which will continue the spur next year. After Percival

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[1] Average of ten counts.

one branch out of ten had any live twigs. The sunlighted branches, then, had 16 times as many twigs on the portions counted as the shaded ones did. A similar study of a large thorn bush (*Cratægus*) gave for the ten sunlighted branches 74 live twigs and for the shaded ones only 2, or 37 times as many for the sunny side.[1] A study of the relative amount of growth of the tips of branches during the year preceding the observations showed that those on the sunny side of the thorn grew 21 times as fast as those on the shady side.[2]

86. Definite and indefinite annual growth. In such trees as the hickories, walnuts, butternuts, elms, poplars, and so on (Figs. 72, 74, 82), the branches usually produce vigorous, well-matured buds at their tips; that is, they form *definite shoots*, and each terminal bud develops promptly in the spring. But some trees, like the honey locust, and such shrubs as sumachs, roses, raspberries, and blackberries, form *indefinite shoots*, which grow until their tips are killed by the frost. Trees of this sort necessarily have a top much broken up into minor branches. Why?

87. Fruit spurs. A fruit spur is a short fruit-bearing twig borne on the side of a branch (Figs. 76 and 77). Apple, pear, plum, and cherry trees afford capital examples of the production of fruit spurs. At the tip of the spur a flower bud (or a mixed bud) is borne, and this usually develops into a cluster of flowers, one or more of which may mature into fruit. In the apple and pear (Fig. 77), though the flower bud contains a good many blossoms, only one fruit is generally produced from each bud. In cherries a single bud produces a cluster of fruits. Why?

If the terminal bud of the spur contained leaves as well as flowers, a leaf bud is likely to grow in the axil of one of the leaves and thus provide for the growth of the spur during another year. This process may go on for a good many years.

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[1] Comparing three-year-old portions of branches.

[2] The illumination in the shade (measured by "solio" photographic printing paper) was, for the box elder, about one twentieth and for the thorn about one eightieth that of the sunny side at noon in early July.

Evidently when the spur produces a terminal bud containing flowers it cannot grow straight ahead but must turn aside slightly. Since a large part of the plant food carried into the spur is used in producing the flowers and fruit, it is clear that a fruit spur cannot grow as rapidly as an ordinary twig. A little study of an old fruit spur will show that of the scars left by the flower buds

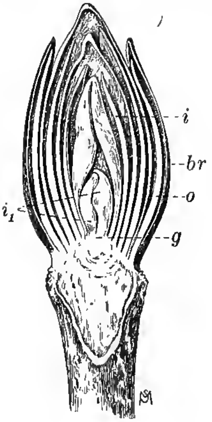

Fig. 78. A lengthwise section of bud of thorn tree (*Cratægus*)

br, brown outer bud scales; *o*, pale bud scale; *i*, innermost rudimentary leaves; *g*, growing point at apex of twig, consisting of cells in a condition to sub-divide and multiply rapidly at the beginning of the growing season. Somewhat magnified

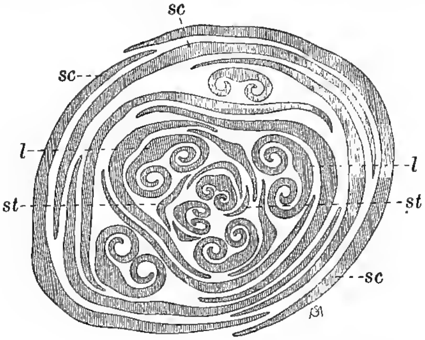

Fig. 79. Cross section of a poplar bud

sc, bud scales; *l*, leaves; *st*, stipules. Magnified 15 diameters. After Strasburger

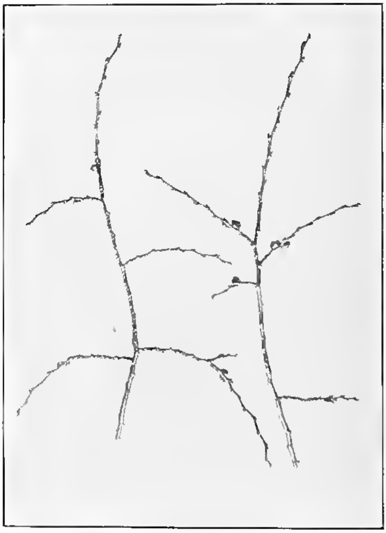

Fig. 80. American elm, March 11

The large buds are flower buds, the smaller, more numerous ones, leaf buds. Reduced

Fig. 81. American elm, April 3

The flower buds seen in Fig. 80 are fully opened. Reduced some are much larger than others. The large scars mark seasons when the fruit matured, and much smaller ones show that it dropped before it was full grown. Do fruits generally mature on any given fruit spur two years in succession?[1]

88. Structure of leaf buds. Scaly winter leaf buds consist, as shown in Figs. 78 and 79, of (*a*) one or more outer layers of scales; (*b*) rudimentary leaves; (*c*) a central axis, at the tip of which is the *growing point* (Fig. 36), a region of cells capable of rapid sub-division, by means of which the elongation of the shoot is produced.

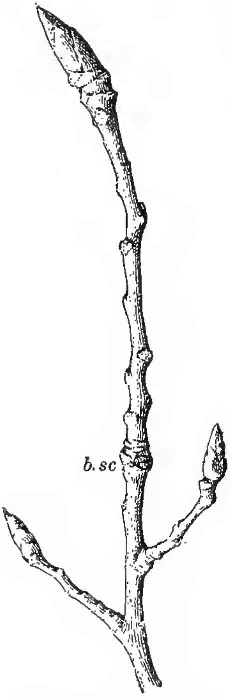

FIG. 82. Twig of cottonwood with buds in winter condition

b.sc, bud-scale scars. Two thirds natural size

FIG. 83. Cottonwood twigs, April 15

The flower buds (developing into catkins) are fully open, but the leaf buds are still closed. Reduced

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[1] See Bailey, Lessons with Plants, Part I. The Macmillan Company, New York.

The rudimentary leaves are stowed in the bud in a wonderfully compact manner. There are several plans of arrangement, all of which have received technical names. The mode of arrangement is best shown in a cross section of the bud like that represented in Fig. 79.

FIG. 84. Cottonwood fruits, April 28

Reduced

In mixed buds, as a rule, the flowers are inclosed by the leaves and usually develop earlier than the leaves (Fig. 83).

89. Opening of buds. Winter buds are not absolutely inactive during the colder months. Often a gradual increase in the size of the bud can be noted for many weeks before it gives any other external sign of getting ready to open. This swelling is caused by the growth and development of the leaves or other contents of the bud. When the bud actually begins to open, the scales spread apart and allow the contents to emerge; sometimes they promptly fall off. It is this time when the flowers are beginning to open that is a particularly anxious one for the fruit grower. Peaches, for example, often begin to blossom before the last freezing nights of the season are over, and the entire crop may often be cut off by a single very cold night. For this reason peach-growing in the North is safest in regions, like the east shore of Lake Michigan, where the spring is usually rather late in coming. A curious instance of the importance of the season at which frosts occur is found in European olive culture. In the Crimea, on the north shore of the Black Sea, the temperature during most years sinks a good deal lower than it does in southern France. Yet in Languedoc the olive culture fails, while in the southern Crimea it succeeds, because in the former region severe frosts occur in January, just when the olive buds are opening, while in the latter region the coldest month is often March or April, after the young olive leaves are fairly well grown and are not easily injured by cold.

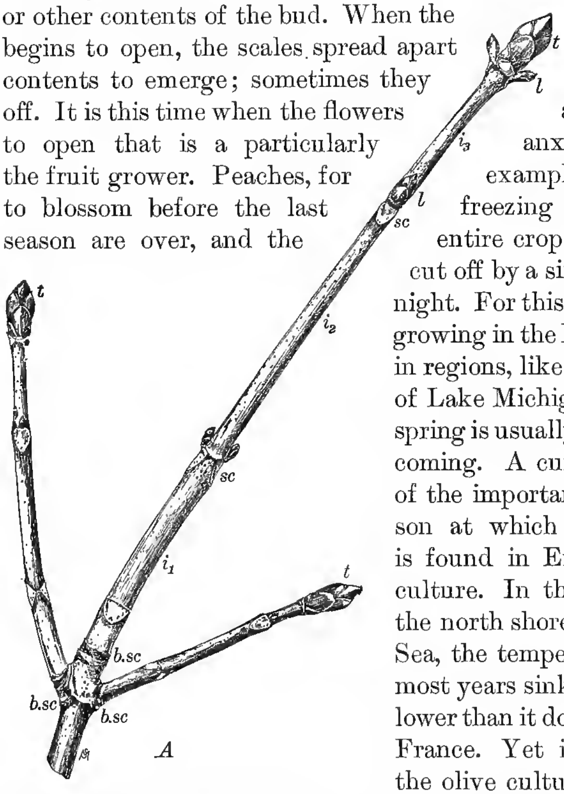

FIG. 85. Rapidly grown twigs of horse-chestnut in winter condition

b.sc, bud-scale scars; i_1, i_2, i_3, internodes; *l*, lateral buds; *t*, terminal buds; *sc*, leaf scars. The portion i_1–i_3 and the large terminal bud grew during the preceding spring and summer. The opposite lateral twigs are of the same age as the portion i_1–i_3. One third natural size

90. The record borne by the twig. In most cases the twig bears upon its surface and in its rings of wood a fairly complete record of the most important events of its life. Some of the principal markings on the surface of a twig which enable us to make out its history are: (*a*) bud-scale scars (from leaf buds); (*b*) fruit scars; (*c*) leaf scars. Other markings are found which tell less of the life history of the twig than those just enumerated, but which should also be considered, namely, (*d*) lenticels.

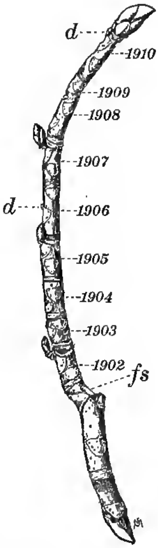

FIG. 86. A slowly grown twig of horse-chestnut in winter condition

d, dormant buds; *fs*, flower-cluster scar. The internodes are numbered in succession (beginning at the bottom) with the respective years during which they were formed. One third natural size

The *bud-scale scars*, as the name implies, are the markings (Figs. 82 and 85, *b.sc*) left by the falling of the scales when the bud opened. Plants like geraniums, with naked buds, do not show such scars. As the twig or branch in most cases is prolonged by the growth, spring after spring, of its terminal bud, each ring of scars marks the beginning of a new season's growth. In many trees it is easy to determine the age of twigs or branches by counting the number of such rings (Fig. 86). The distance between the rings of scars depends upon the rapidity of growth of the shoot in length, varying all the way from a fraction of an inch to ten or more feet per year.

If a twig were cut across smoothly, just above and just below a ring of bud-scale scars, would the number of rings of wood in the two sections be the same? Why, or why not?

91. The record; fruit scars. Fruit scars of the same species are often quite unequal in size, the smaller ones marking the positions of unsuccessful fruits, and the larger ones of fruits which grew to maturity. Sometimes in mixed buds the young flowers may be destroyed by frost as the bud opens, and in that case no fruit scar will be left at the end of the season, the bud developing much like an ordinary leaf bud.

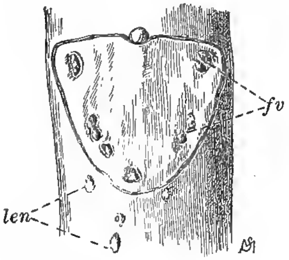

FIG. 87. Leaf scar of horse-chestnut

fv, scars marking position of fibro-vascular bundles; *len*, lenticels. Twice natural size

The only way in which one can become thoroughly familiar with the course of development of shoots, flowers, and fruits from buds is to mark some buds like that shown at *A* in Fig. 76. This may be done by tying a bit of twine loosely above each bud; its history is then to be followed for at least a year and recorded by means of frequent drawings.

92. The record; leaf scars. A *leaf scar* is the place which was occupied by the base of the leafstalk while it remained attached to the shoot. Some of the things which can be learned from the study of leaf scars are the number, position, and arrangement of leaves on the shoot for several years back, the relative sizes of the leaves, and the mode of bud-bearing of the species studied, — i.e. whether there were accessory buds, or the buds were all axillary (Figs. 75 and 85). On careful examination of any large leaf scar, as that of ailanthus, horse-chestnut (Fig. 87), coffee bean, it is seen to be dotted with a considerable number of minute projections, *fv*. These mark the course of the fibro-vascular bundles from the leaf into the stem. In leaves of dicotyledons there are usually about as many such dots on the scar as there were principal veins in the leaf. Why?

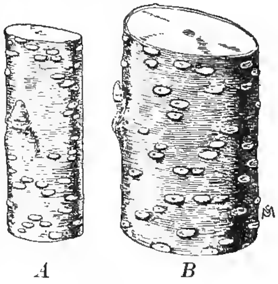

FIG. 88. Lenticels, wild black cherry

A, soon after the destruction of the stomata, to which the lenticels succeed; *B*, at end of first season's growth. One and one-half times natural size

93. Lenticels. On the general surface of the bark of many kinds of twigs and young branches — for example, of birch, cherry, elder, and sumach — there are found many dots, or markings with a rough surface, known as *lenticels.* These are nearly circular on the younger twigs, but on branches of moderate size they become lengthened at right angles to the length of the branch. In many kinds of birch and most cherries the lenticels finally become narrowly oblong or lens-shaped (Fig. 89). This is due to the fact that as the branch increases in diameter the lenticel is drawn out by the transverse expansion of the bark.

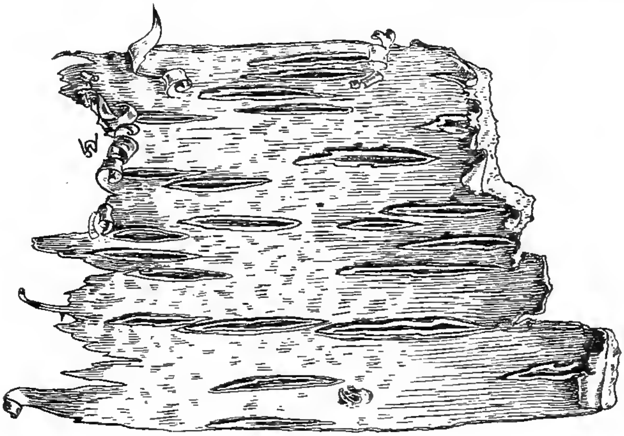

FIG. 89. Lenticels, wild black cherry

From a tree fifteen or twenty years old. One and one-half times natural size

Lenticels originate as stomata (Sect. 14) in the epidermis of the young shoot. On growing older the interior of the lenticel becomes filled with a spongy mass of thin-walled cells. Air is admitted into the interior of the stem and gases can pass out through the lenticels far more freely than through other parts of the bark.

CHAPTER VII

FLOWERS

94. What is a flower? A little has been said in Chapter II about the structure and work of the flower, but it will be necessary in the present chapter to take up these matters somewhat more in detail. First may come the question as to what a flower really is; that is to say, to what other organs of a plant the parts of a flower correspond. Put in more technical language, this question would be, *What is the morphology of the flower?*

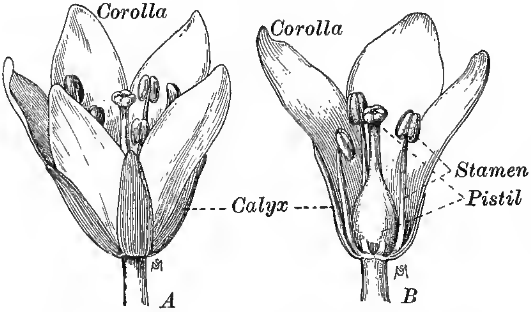

Fig. 90. The floral organs of alpine azalea (*Loiseleuria*)

A good example of a flower in which the floral organs do not all spring separately from a knob-like receptacle. Here the calyx is very slightly and the corolla decidedly bell-shaped. The stamens are distinct from each other, but the pistil is single and represents several united carpels. *A*, an exterior view; *B*, a lengthwise section of the flower. After H. Müller

A flower is a specialized and highly modified branch or shoot for reproduction of the plant. If this is true, then the sepals or divisions of the calyx, petals or divisions of the corolla, stamens, and pistils (Fig. 90) must represent leaves. It would take too much space to present here the evidence of the branch-like nature of the flower. Much of this evidence rests upon the study of the lower plants, and especially on the investigation of the steps by which the higher kinds of plants have in the course of ages been developed from these.

95. The arrangement of the organs of the flower. Many of the most familiar flowers have the four sets of organs shown in Figs. 90 and 92. Sometimes there are intermediate forms, transitional between the parts of one set and those of another, — a fact easily understood if all the floral organs represent leaves. The organs are generally arranged in *cycles* or *whorls*, — that is, in circular fashion around the axis, which is known as the *receptacle*.[1] Often (but not always) the parts of each set stand opposite the spaces between the parts of the adjoining sets; e.g. the petals opposite the spaces between sepals, stamens opposite the spaces between petals, and so on.

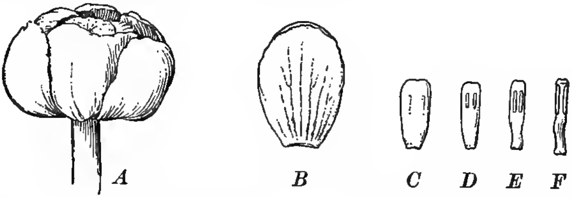

FIG. 91. Transitions between petals and stamens in the yellow pond lily

A, external view of flower; *B*, a sepal; *C*, a petal; *D*, *E*, transitional forms; *F*, a stamen

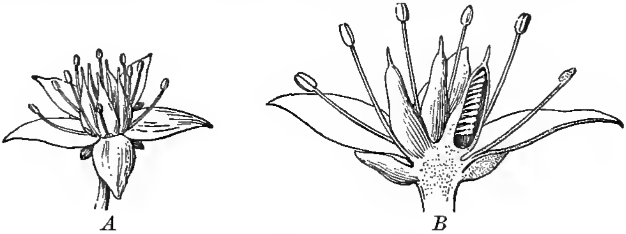

FIG. 92. Flower of stonecrop

A typical example of the kind of flower in which the members of all four sets of floral organs (sepals, petals, stamens, and carpels) spring separately from a knob-like receptacle. *A*, entire flower; *B*, vertical section. Both magnified. After Decaisne

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[1] In the lowest seed plants, the gymnosperms (pines, spruces, cedars, and so on), the parts of the flower are arranged in a spiral fashion. So, too, are some of the floral organs in the arrowhead (*Sagittaria*), the pond lily, and the buttercup.

Frequently the arrangement of the floral organs differs from that just described by reason of the absence of one or more sets of organs or from the multiplication of the whorls. In the buckwheat, for example (Fig. 93), only one whorl surrounds the stamens and pistil. In such cases it is usual to assume that the missing flower leaves are the petals, and the flower is said to be *apetalous* (without petals). Sometimes neither sepals nor petals are found (Fig. 94). On the other hand, many flowers have both calyx and corolla, with the number of petals equal to that of the sepals, but with indefinitely numerous stamens, as in buttercups.

FIG. 93. Apetalous flower of buckwheat (*Fagopyrum esculentum*)

A, flower; *B*, section of flower. Both somewhat magnified. After Marchand

96. Unisexual flowers. Among many families of plants the flowers do not contain both stamens and pistils. One kind of flower has stamens only, and is called a *staminate flower*, while the other kind has pistils only, and is called a *pistillate flower* (Figs. 94 and 96). Such flowers are said to be *unisexual* or *diclinous*.

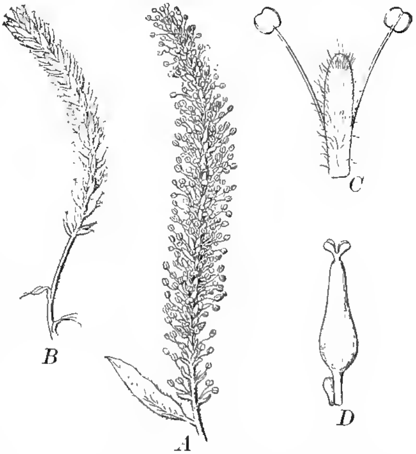

FIG. 94. Diœcious flowers of white willow (*Salix alba*)

A, staminate catkin, natural size; *B*, pistillate catkin, natural size; *C*, a staminate flower, magnified; *D*, a pistillate flower, magnified. After Cosson and De Saint-Pierre

Sometimes, as in corn and cucumbers, one plant bears both staminate and pistillate flowers. Such plants are said to be *monœcious* (meaning "of one household"). Many plants, such as willows and poplars, bear the staminate and the pistillate flowers on different individuals. Such plants are said to be *diœcious* (meaning "of two households").

Fig. 95. Catkins of willow

Pistillate catkins at the left; staminate at the right. Slightly reduced

It is often a matter of much practical importance to recognize the partially or completely diœcious character of cultivated plants, or, at any rate, the fact that many or all of the individuals of a species or variety produce no good pollen. This is well known to be true of strawberries, and so staminate varieties must be planted among those which produce little or no pollen.

97. Symmetry of the flower. The calyx and corolla of most flowers of the higher seed plants show some kind of *symmetry* or orderly arrangement of the parts; that is, the divisions of the calyx or corolla either radiate from a central axis, like the spokes of a wheel from the hub (Fig. 97, *B*), or they are arranged with corresponding halves on either side of a central axis (Fig. 98, *B*). Flowers on the former plan are said to have radial symmetry or to be *actinomorphic* (ray-shaped), and those on the latter plan are said to have bilateral symmetry or to be *zygomorphic* (yoke-shaped). It is considered that the zygomorphic type of flower is in a general way more specialized and of a higher type than the actinomorphic one.[1]

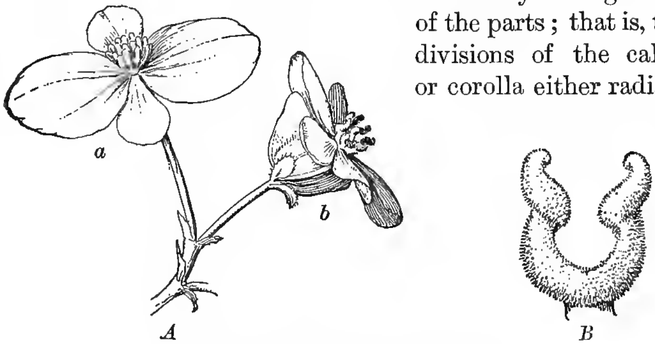

Fig. 96. Begonia flowers, monœcious

A: *a*, staminate flower; *b*, pistillate flower. *B*, twisted stigmas, enlarged

98. The receptacle.[2] The parts of the flower are borne by the more or less enlarged extremity of the flower stalk, which is

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[1] For illustrations consult any good modern flora, e.g. Gray's Manual of Botany, seventh edition.

[2] To the Teacher. Unless the class is to do a good deal of work in determination of species of seed plants by means of a flora, most of Sects. 98–105 should be omitted.

known as the receptacle shown in Fig. 92, *B*. This varies much in shape in different kinds of flowers, being sometimes nearly flat-topped, as in the lotus (*Nelumbo*); usually convex, as in the buttercup, raspberry, and strawberry; sometimes very concave or even flask-shaped, as in the sweet-scented shrub and the rose.

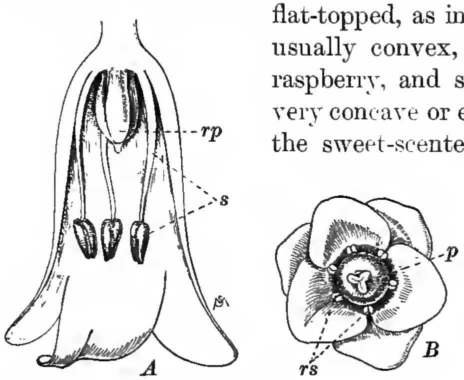

FIG. 97. Flowers of common asparagus

A, staminate flower, with perfect stamens (*s*) and rudimentary pistil (*rp*); *B*, pistillate flower, with fully developed pistil (*p*) and rudimentary stamens (*rs*). Such a flower is practically unisexual, but would seem to have become so by descent, with modification, from bisexual ancestors. After H. Müller

99. The perianth. The calyx and corolla taken together are known as the *perianth.* It is convenient to have a name which includes them both, as in many flowers, such as those of the Lily family, it is difficult or impossible to detect any marked distinctions between sepals and petals. In most flowers the sepals are green or greenish and the petals of some other color, ranging from violet to red. There are, however, plenty of exceptions to this rule. What are common instances of such exceptions?

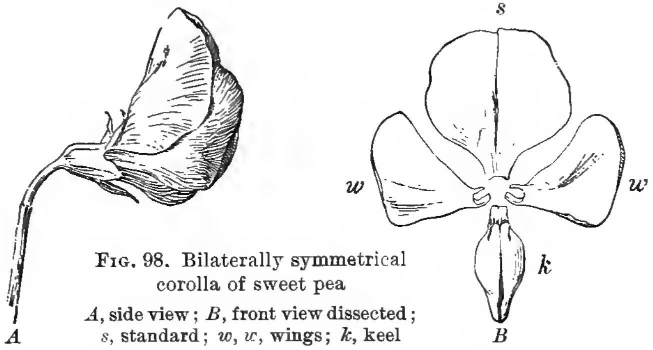

FIG. 98. Bilaterally symmetrical corolla of sweet pea

A, side view; *B*, front view dissected; *s*, standard; *w*, *w*, wings; *k*, keel

The flowers of monocotyledons and of dicotyledons very commonly have separate sepals and separate petals (Fig. 92). The sepals and petals are then said to be *distinct*. In the more specialized and higher families, both of monocotyledons and of dicotyledons, the receptacle often bears a tubular or cup-like outgrowth, and the perianth is borne upon this. In such cases the sepals, the petals, or both, appear as if grown together into a tube, upon the free border of which are seen teeth, or lobes, which indicate the number of divisions of which the perianth is composed (Fig. 97).[1]

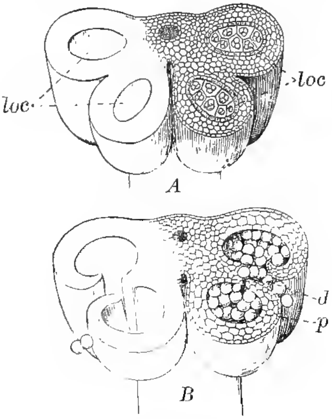

FIG. 99. Diagrams to show structure of an anther

A, younger stage, with four chambers or *locules* (*loc*) containing pollen mother cells dividing to form pollen grains; *B*, an older stage in which the pollen grains (*p*) are fully formed and each pair of locules is uniting to form a pollen sac, which will split open and discharge along the line of dehiscence (*d*). After Baillon and Luerssen

Sympetalous corollas occur of many extraordinary forms, enabling them to aid in seed production. The only such corolla shown in this book is the *Cypripedium* of the Orchis family (Figs. 281 and 282).

100. Forms of the stamen; union of stamens. A common form of stamen is that shown in Fig. 100, *A*, consisting of an enlarged portion called the *anther*, borne by a slender stalk called the *filament*. When the filament is lacking, the stamen is said to be *sessile*. Sometimes the filaments appear to be united, thus joining the stamens into one, two, or more

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[1] When the sepals are distinct the flower is said to be *chorisepalous* (separate sepals); when the petals are distinct, *choripetalous*. When the sepals or petals appear only as teeth or lobes on the margin of a tubular or cup-like outgrowth of the receptacle, the calyx is said to be *synsepalous* and the corolla *sympetalous* (*syn* signifies "together"). The terms *gamosepalous* and *gamopetalous* are also used (*gamos* signifies "marriage" or "union").

groups (Figs. 111 and 121). In such cases the stamens are said to be *monadelphous*, *diadelphous*, *triadelphous*, *polyadelphous* (in one, two, three, many brotherhoods). The function of the stamen is to produce *pollen*, a powdery or pasty substance composed of separate grains (Figs. 105 and 106), which is formed within four cavities in the anther (Fig. 99). The two cavities on each side generally join to form a single larger *pollen sac* as the anther matures. Pollen is discharged from the mature anther in various ways, as shown in Fig. 100. The special significance of some of these modes of discharge is explained in Chapter VIII.

101. The carpel. The simplest form of the organ which bears *ovules* or rudimentary seeds is called a *carpel* (from a Greek word meaning "fruit"). The most elementary kind of carpel is found in the lowest seed plants, and often consists, as in the pines and other cone-bearing trees, of a single scale, with a naked ovule borne at its base (Fig. 252). In the higher seed plants the carpel contains an ovule-bearing cavity (Figs. 14 and 101), in which the ovules are completely inclosed while they are maturing.

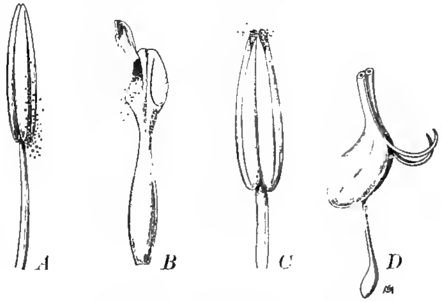

FIG. 100. Various types of anther

A, iris, discharging pollen by a longitudinal slit; *B*, barberry, discharging pollen by uplifted valves; *C*, nightshade; *D*, bilberry, discharging pollen through holes or pores at the top of the anther. *A*, *B*, *C*, after Baillon; *D*, after Kerner

102. The pistil. The entire carpellary portion of the flower of the higher seed plants is called a *pistil* (Latin for *pestle*).[1] In flowers which have but one carpel, *pistil* and *carpel* mean

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[1] It would be better to call it, as some botanists do, *gynœceum*, but the word *pistil* is so much in use in descriptive botany that it seems likely to be retained for a good while.

the same thing, but in flowers with two or more carpels, each carpel is one of the units of which the pistil consists. A one-carpeled pistil is *simple* (Fig. 14), a several-carpeled pistil is *compound* (Figs. 102, *A*, and 104, *A*). The parts usually found in a pistil (Fig. 101) are the *ovary*, or enlarged ovule-bearing portion, and the *style* or stalk, on which is borne the *stigma*, which is usually expanded, knob-like, or ridged, and with a rough moist surface. When there is no style the stigma is said to be *sessile*, and the stigma is borne on the ovary.

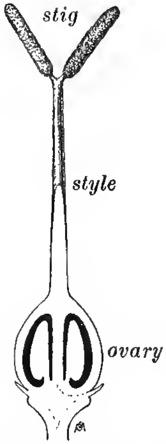

Fig. 101. A pistil, with the ovary cut through lengthwise

stig, the stigma

A compound pistil may consist of many separate carpels, as in the stonecrop (Fig. 92), strawberry, and buttercup. Frequently the carpels are more or less completely united (Figs. 102, *A*, and 295). The ovary of a compound pistil may be formed of the united ovaries of the carpels, or a considerable part of the ovary may consist of a cup-like or tubular growth beneath the carpels.

103. Locules of the ovary; placentas. Compound ovaries sometimes have but one ovule-bearing cavity, but more generally they consist of several separate chambers, known as *locules* (Latin, *loculi*, "little compartments"). They are then said to be *unilocular*, *bilocular*, *trilocular*, and so on.

Ovules are not borne by all parts of the interior of the ovary, but are usually produced only along certain regions. The ridge, column, or

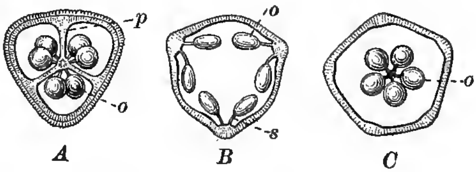

Fig. 102. Three modes of bearing ovules

A, ovary three-loculed, with the ovules borne on the axis (*central placenta*) formed by the united partitions; *B*, ovary one-loculed, ovules borne on the ovary wall along three *placentas*; *C*, ovary one-loculed, ovules borne on a *free central placenta*. After Behrens other ovule-bearing portion of the ovary is called a *placenta.* Some common types are shown in Fig. 102.

104. Superior, half-inferior, and inferior ovaries. The position of the ovary with reference to the other whorls of the flower is a matter of great importance in the classification of plants and is described by the use of appropriate names. When the pistil is borne nearer the extremity of the receptacle than any of the other whorls the ovary is said to be *superior* (Fig. 93). When, however, the end of the floral axis is expanded in a more or less cup-shaped manner, so that the stamens (and the divisions of the perianth) seem to spring from around the ovary, the latter is said to be *half-inferior.* When the concave floral axis,

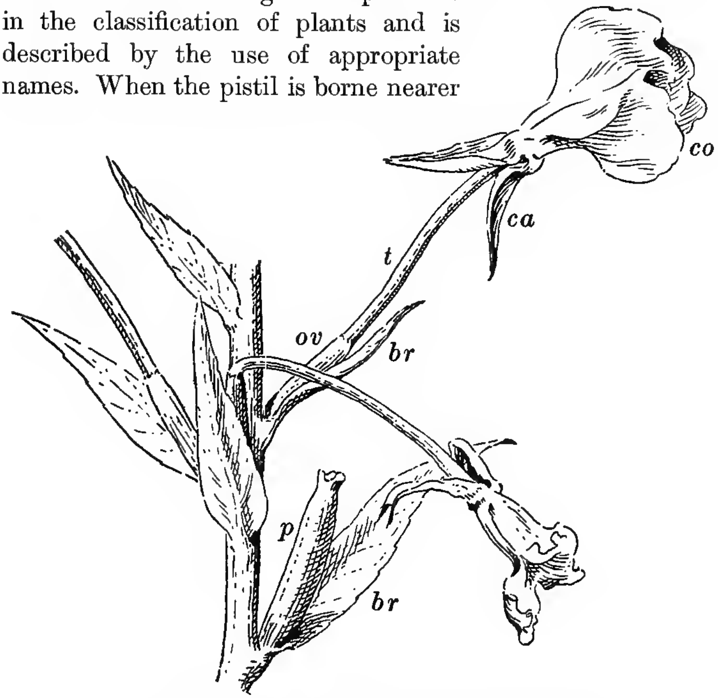

FIG. 103. Part of a flower cluster of evening primrose

br, bracts; *ca*, calyx; *co*, corolla; *ov*, ovary; *p*, pod; *t*, tube of perianth, appearing as if it sprung from the tip of the ovary. Slightly reduced on the margin of which the stamens are borne, appears to be grown fast to the ovary, the latter is said to be *inferior*[1] (Fig. 103).

105. Floral diagrams. Lengthwise sections through the flower greatly help the student to understand its structure. But still more is to be learned from a suitable cross section. Diagrams like those in Fig. 104 are constantly used in flower descriptions to show the relations of the floral organs. Such a diagram is not simply a sketch of the cut surfaces made by dividing the flower crosswise near its center; it is rather a representation of what would be shown if all the whorls of the flower were brought into the best position for making a characteristic section, which would pass through the middle portions of sepals and petals and through the anthers of the stamens and the ovaries of the carpels. Note that the sepals are distinguished from the petals by being represented with midribs. If any part of the flower is lacking (as in the case of antherless stamens, represented only by filaments), the position of the missing or incomplete organ may be indicated by a dot.

Fig. 104. Floral diagrams

A, Lily family; *B*, Heath family; *C*, Madder family; *D*, Composite family. The dot above the diagram indicates the position of the stem or axis which bears the flowers. The sepals are distinguished from the petals by being represented with midribs. In *B* the alternate stamens are printed lighter, since some flowers of this family have five and some ten stamens. After Sachs

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[1] Often flowers with superior, half-inferior, and inferior ovaries are said to be respectively *hypogynous*, *perigynous*, and *epigynous*.

CHAPTER VIII

POLLINATION AND FERTILIZATION

106. Pollination. By the term *pollination* the conveyance of pollen to the pistil is meant. Some of the various means by which this result is secured are discussed later on in the present chapter. In whatever way the pollen is carried from the stamens to the pistil (usually by the wind, by animals, or by contact of the anthers with the stigma), its lodging place in the higher seed plants is on the stigma. This generally has a rough, often moist and sticky surface.

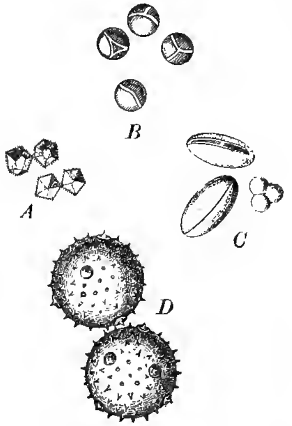

FIG. 105. Types of pollen grains

A, dandelion; *B*, hemp; *C*, gentian; *D*, squash. All greatly magnified. After Kerner

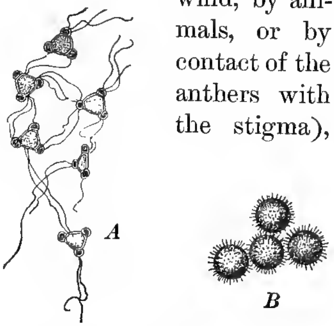

FIG. 106. Types of pollen grains

A, evening primrose, the grains united by sticky threads; *B*, marsh mallow. Greatly magnified. After Kerner

107. The pollen grain and its germination.[1] Pollen grains are of many forms, a few of which are shown in Figs. 105 and 106.

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[1] The logical order of treatment would be to say all that is to be said about pollination before dealing with its result, fertilization. It is, however, more convenient to discuss the minute structure of pollen and the pistil soon after Chapter VII is completed, and then to give details of some of the modes by which pollination is secured.

Each mature grain contains a *generative nucleus* and a *tube nucleus* (*g* and *t*, Fig. 107, *A*). After the pollen grain lodges on the stigma the inner coat of the grain becomes slightly distended by osmosis, produced by contact with the moist stigmatic surface. The distention of the inner coat causes it to protrude through the outer coat and it at length develops into the wall of a *pollen tube* (Fig. 107). This tube has the nucleus (*t*) at its tip and a *generative cell* (*g*) somewhere within the tube. Finally the generative cell divides into two *male nuclei*, these develop into *male cells* (Fig. 107, *B*), and the tube nucleus disappears.

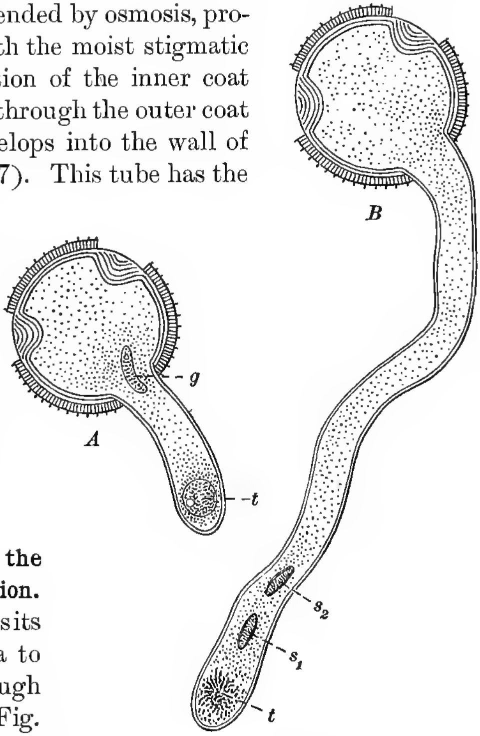

FIG. 107. Germination of the pollen grain of a dicotyledon

A, an early stage in the germination; *B*, later stage, with the tube rather fully developed; *g*, generative cell; *t*, tube nucleus; s_1, s_2, male cells formed from the generative cell. It is apparent that when the growth of the tube is far advanced the tube nucleus (*t*) almost disappears. Much magnified. After Bonnier and Sablon

108. Course of the pollen tube: fertilization. The pollen tube makes its way from the stigma to the ovary either through a canal or passage (Fig. 108), or by directly traversing the cellular tissue of the style, upon which it acts so as to eat its way along by means of ferments (Sect. 36) secreted by the tube. The tube may require a day or more to reach the ovule. Food materials from the style are dissolved by the enzymes and used in promoting the growth of the pollen tube.[1] When the tip of the tube reaches the ovary it usually penetrates to the interior of an ovule by means of the little opening (*micropyle*) at one end of the ovule (Fig. 109).[2] One of the male cells now unites with the egg nucleus of the ovule. The other male cell in many cases unites with the central nucleus of the embryo sac to form the *endosperm nucleus*

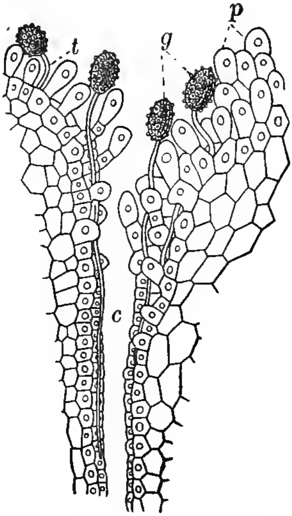

FIG. 108. Pollen grains producing tubes, on stigma of a lily. Much magnified

g, pollen grains; *t*, pollen tubes; *p*, papillæ of stigma; *c*, canal or passage running toward ovary

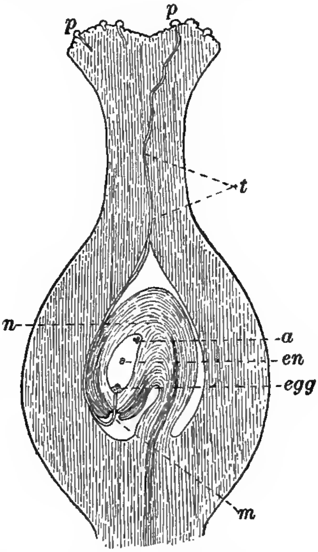

FIG. 109. Diagram to illustrate course of the pollen tube during fertilization

p, pollen grains; *t*, pollen tube; *n*, *nucellus*, or body of the ovule; *a*, *antipodal cells* of embryo sac; *en*, endosperm nucleus of embryo sac; *egg*, the egg apparatus, consisting of the egg cell and two coöperating cells; *m*, the *micropyle*, or small opening through which, in most ordinary flowering plants, the pollen tube makes its way to the egg at the tip of the embryo sac

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[1] See Green, Vegetable Physiology, chap. xxvi. P. Blakiston's Son & Co., Philadelphia.

[2] In some plants the tube makes its way directly through the tissue of the ovule.

(Fig. 265). The result of fertilization is to cause the egg of the ovule to develop into an embryo. One of the first steps of embryo formation is shown in Fig. 267. The fertilization of the egg within the ovule may result from the proper placing of a single pollen grain, but the result is more certain if there are several grains.

109. Advantages of reproduction by seed. As has already been shown (Sects. 33 and 75–80), reproduction may readily be accomplished by buds produced on roots, stems, or leaves, — *vegetative reproduction.* This method is much quicker than that by the agency of seed, as is well shown in the case of the potato. It would seem that *sexual reproduction*, reproduction by means of seed, a more complicated process, would hardly have originated unless on the whole it were of advantage to plants.[1] It is evidently desirable for the continuation of the various kinds of plants to have such a comparatively portable, heat-, cold-, and drought-resisting structure as the seed to disseminate plants over large areas and to maintain plant life under unfavorable conditions. But some botanists have been led to think also that sexual reproduction is of distinct advantage to plants by giving them greater vigor than is secured by long-continued vegetative reproduction, as in the case of potatoes grown for years by planting the tubers. It is also of advantage to the plant to reproduce by means of seed, because this secures variations in the offspring which may result in greater fitness to meet the conditions of its existence (Chapter XXIII).

110. Ecology. Plant *ecology* (from two Greek words meaning "house" and "discourse") is the subdivision of botany which discusses the relations of the plant to its surroundings. Defining the subject more in detail, it may be said that ecological botany treats of the effects upon plants of the various forces and forms of energy, — such as gravity, heat, light, electricity, currents of air and water, — as well as of the effects of chemical elements and compounds. It also comprises the study of

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[1] For a brief account of the beginnings of sex in plants see Chapter XIII.

the social relations between plants and other injurious or helpful plants and animals.[1]

The ecology of flowers is largely concerned with the ways in which pollination is brought about.[2] This subject is of sufficient importance to have accumulated an extensive literature, the principal treatise upon it being Knuth's "Blüthenbiologie," embracing nearly three thousand pages. There is also an excellent English translation of this remarkable book.[3]

111. Pollination and floral characteristics. Some of the most obvious divisions of flowers into everyday groups, such as are made by children and other unscientific people, are those into scented and scentless, showy and inconspicuous kinds. Another less obvious but important distinction is based on the presence or absence of the sweet liquid (commonly called honey, but more properly known as nectar) so familiar at the tips of columbine spurs and in clover and honeysuckle blossoms. Such characteristics as those just mentioned have much to do with the way in which flowers have their pollen transferred from anthers to stigma.

Fig. 110. Pistil of timothy with feathery stigmas

sti, stigmas. Magnified about twenty times

Flowers with feathery stigmas (Fig. 110) and dry, dust-like pollen are usually pollinated by the wind.

Flowers with stigmas which, before they wither, curve so as to bring the anthers into contact with the stigma (Fig. 111) are usually self-pollinated.

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[1] A great deal of what was said about the behavior of roots, stems, and leaves in Chapters III–VI is to be classed as plant ecology, though it was not given a separate name in those chapters.

[2] See Kerner-Oliver, Natural History of Plants, Vol. II. Henry Holt and Company, New York.

[3] Knuth-Davis, Handbook of Flower Pollination. Clarendon Press, Oxford.

Flowers of any other color than green, or which are fragrant, have nectar, or show marked deviations from radial symmetry (Figs. 98 and 281), are generally more or less wholly dependent upon animals (commonly insects of some kind) for pollination.[1]

112. Wind-pollinated flowers. The number of plants which depend upon the transference of pollen by the wind is very great, embracing as it does large families, such as that of the cone-bearing trees (Pine family), the grasses, and the sedges.

It is easy to see that pollen-carrying by the wind must be a very wasteful process, since only now and then a pollen grain is likely to alight on a stigma of the species of plant which produced it. Accordingly, flowers which have their pollen carried by the wind yield it in enormous quantities. It is estimated that a medium-sized plant of Indian corn produces about 50,000,000 pollen grains; a pine tree must produce an unimaginably great number. The stigmas of wind-pollinated flowers which catch the dust-like flying pollen are brush-like, as in the hazels; feathery, as in most grasses (Fig. 110); or prolonged and thread-like, as in Indian corn (Fig. 336). Wind-pollinated flowers frequently appear before the leaves of the plant which bears them. What advantage is there in this?

113. Self-pollinated flowers. As a rule, inconspicuous flowers with moist, sticky pollen are wholly self-pollinated or can pollinate their own stigmas when pollen from another flower is not supplied to them. Familiar examples of such flowers are pigweeds,[2] knotgrass,[3] the common chickweed,[4] the round-leaved mallow[5] (Fig. 111), the low cudweed,[6] and the common groundsel.[7] It is not infrequently the case that flowers, when they first mature, have the anthers and the stigma far enough apart to make it impossible for pollen to lodge upon

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[1] See Bergen and Davis, Laboratory and Field Manual of Botany, Sect. 149. Ginn and Company, Boston.

[2] *Chenopodium*, various species.

[3] *Polygonum aviculare.*

[4] *Stellaria media.*

[5] *Malva rotundifolia.*

[6] *Gnaphalium uliginosum.*

[7] *Senecio vulgaris.*

the stigma as long as the flower remains undisturbed; but at a later period in the development of the organs, anthers and stigmas may grow into contact with each other and self-pollination be secured (Fig. 111).

It is a remarkable fact that when a stigma is pollinated with pollen from the same flower or from another flower of the same plant, and also with pollen from another individual of the same kind, generally only the latter pollen takes effect in fertilizing the egg. In other words, *foreign pollen is prepotent over pollen from the same individual.*[1]

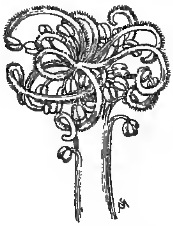

FIG. 111. Stamens and pistils of round-leaved mallow

The flower has been open for a considerable time, and the stigmas have curved so as to come into contact with the stamens and insure self-pollination. After H. Müller

114. Self-pollination and cross-pollination. The process of self-pollination is usually rather simple, as may have been inferred from Sect. 108. Not infrequently the beginner in botany may be led to wonder whether it would not be advantageous to the plant world if all flowers were bisexual and pollinated their own pistils. The matter is not, however, quite as simple as it appears to be. The earliest seed plants were doubtless remotely related to our evergreen cone-bearing trees of to-day (such as pines, spruces, and cedars), and these cone-bearers have unisexual flowers (Figs. 251 and 262) and are wind-pollinated. Bisexual flowers came later. It is likely that, later still, plants with unisexual flowers have come into existence by descent, with gradual modifications, from ancestors which bore bisexual flowers. One proof of this is drawn from the fact that there are many cases of flowers which are practically unisexual but show rudimentary pistils in the staminate flowers and rudimentary stamens in the pistillate ones, as in the common asparagus (Fig. 97). Occasionally the asparagus has perfect stamens and pistils in the same flower.

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[1] See Darwin, Cross and Self Fertilisation in the Vegetable Kingdom, chap. x. D. Appleton and Company, New York.

By *cross-pollination* is meant the process of transferring foreign pollen to the stigma. The effect in fertilization is the same whether the pollen is carried by the wind or otherwise.

115. Advantages of cross-pollination. As already stated (Sect. 113), foreign pollen is usually more effective than the pollen from the same individual. Charles Darwin, the great English naturalist, showed by experiments continued through eleven years that in many cases the plant derives great advantages from cross-pollination.[1] He found that in plants the flowers of which are not especially suited to self-pollination if left to themselves, but which he pollinated thoroughly by hand, the plants grown from the seeds of cross-pollinated flowers usually much exceeded in height, weight, and fertility those from self-pollinated flowers. It was found, for instance, that when the yellow monkey flower (*Mimulus luteus*) was self-pollinated to the ninth generation the plants thus produced were $\frac{52}{100}$ the height of plants which came from those self-pollinated to the eighth generation and then cross-pollinated with a plant of another stock. In fertility the two kinds (self-pollinated to the ninth generation and cross-pollinated at the end of the eighth generation) were in the ratio $\frac{3}{100}$.

Cabbages were raised by Darwin from seeds of a third self-pollinated generation and also from those of the second self-pollinated generation crossed with a plant from a distant garden. The self-pollinated cabbages were only $\frac{22}{100}$ the weight of the cross-pollinated ones. These two examples may serve as extreme instances of the benefits of cross-pollination. In many cases less advantage is gained by it, and there is a considerable group of plants which seem to be indifferent to the source from which the pollen comes, that from the same flower answering as well as that from another individual of the same species. The practical value of a knowledge of the effects of different kinds of pollination is often very great (Chapter XXIII).

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[1] See Darwin, The Effects of Cross and Self Fertilisation in the Vegetable Kingdom, chaps. i and vii–ix. D. Appleton and Company, New York. For facts about flowers which do not need cross-pollination see Sects. 121 and 125.

116. Insects as carriers of pollen. Most flowers which require or are benefited by cross-pollination and which are not wind-pollinated depend upon insects as pollen carriers. It is not an overstatement to say that, in general, flowers seem to have acquired their colors (other than green) and their odors as means of attracting the attention of insects which may serve to cross-pollinate them. Insects vary greatly in their efficiency as pollinators, the small ones with smooth surfaces on the head, legs, and abdomen, such as ants and many beetles, carrying little pollen, while bees, moths, and butterflies often carry considerable quantities. Many bees in particular are provided with a special collecting apparatus for pollen (Figs. 112 and 113). Although the portion which they carry to the hive or nest for food is of no use for pollination, much of that which is smeared over the general surface of the body serves to pollinate the stigmas of flowers which they afterwards visit. A good practical illustration of the importance of insect visits is afforded by the case of cucumbers grown in winter under glass. It is found necessary to keep hives of bees in the cucumber houses in order to insure pollination and consequent crops of cucumbers.

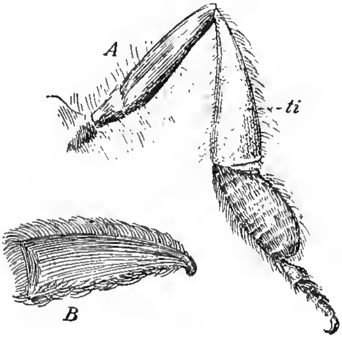

Fig. 112. Pollen-carrying apparatus of leg of honeybee

A, right hind leg of a honeybee (seen from behind and within); *B*, the tibia (*ti*), seen from the outside, showing the collecting basket formed of stiff hairs. After H. Müller

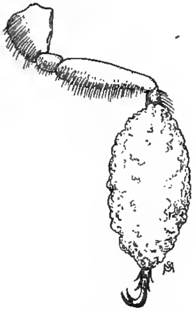

Fig. 113. Right hind leg of a bee (*Macropis*)

The tibia is covered with pollen of the common loosestrife. Magnified. After H. Müller

Some idea of the number of insect visits may be gathered from the fact that in a single locality dandelion flowers have been seen to be frequented by 100 kinds of insects.[1] The statistics of visitors to the flowers of yarrow, Canada thistle, and the willows are fully as remarkable.

117. Attractions offered by insect-pollinated flowers. Insects are led to visit flowers for the sake of procuring food. This is usually either pollen — as in the flowers of many species of meadow rue, *Clematis*, *Anemone*, poppy, rose, *Spiræa*, and St.-John's-wort — or both pollen and nectar, as in most kinds of conspicuous flowers.

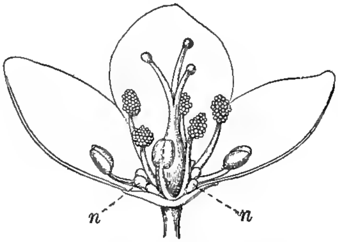

Fig. 114. Flower of buckwheat

Lengthwise section, showing nectar glands *n*. Five anthers are discharging pollen; the other three here shown are not quite mature. After H. Müller

Nectar is usually secreted by *nectar glands*, small organs which are often to be found near the base of the flower, as in buckwheat (Fig. 114). Sometimes the nectar remains on the surfaces of the glands, sometimes it trickles down into the bottom of the flower, and sometimes — as in the columbine and the honeysuckle — it is stored in pouches called *nectaries*, situated at the bases of separate petals or at the bottom of the sympetalous corolla.

Honey is nectar which has been swallowed by the bee and, by partial digestion in its crop, has undergone slight chemical changes.

118. Odors of flowers as attractions to insects. It is evident from familiar facts that many insects have an acute sense of smell. The way in which flies are attracted by decaying meat or fish, and bees and wasps by a cider press at work, or by fruit-preserving operations, is a matter of common observation. A single cluster of carrion-scented flowers has been known to attract carrion flies and dung beetles from a distance of hundreds of yards. Some flowers — such as those of the

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[1] See Knuth-Davis, Handbook of Flower Pollination, Vol. II. Clarendon Press, Oxford.

Virginia creeper (*Psedera*), the Dutchman's-pipe, the blueberries, and many others — are so inconspicuous that apparently their numerous insect visitors must be attracted by an odor which is almost or quite imperceptible to us.

It seems certain that the odors of flowers have been developed with reference to the sense of smell in animals (usually insects), and that these odors serve as a most efficient means of insuring insect visits.

It is a most interesting fact that many flowers give off their scent mainly at the time of day when the insects which pollinate them are most active. Thus some catchflies, the petunias, some kinds of tobacco, and several honeysuckles have little odor by day, but are very fragrant at night when the moths which pollinate them are on the wing. On the other hand, many plants of the Pea family, which are pollinated by day-flying bees and butterflies, give off their scent mostly by day, and especially in strong sunshine.

119. Colors of flowers as attractions to insects. There has been much discussion among botanists as to how far insects are led to visit flowers by displays of color. It appears to be fairly certain that no insects can make out the forms and sizes of objects at a distance of more than six feet, and that many are unable to see clearly even two feet.[1] In spite of this, however, it seems probable that the colors of flowers are an important means of attraction for many flower-frequenting insects.[2]

The commonest method of color display is that in which the color (other than green) is mainly found in the corolla, as in the flowers of the poppy, rose, sweet pea, and morning-glory. Sometimes the calyx also is bright-colored, or, as in the *Hepatica*, the *Anemone*, and the *Clematis*, the corolla is wanting and the showy calyx looks like a corolla. Not infrequently the

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[1] See Packard, Text-Book of Entomology. The Macmillan Company, New York.

[2] See Kerner-Oliver, Natural History of Plants, Vol. II. Henry Holt and Company, New York. Also Knuth-Davis, Handbook of Flower Pollination, Vol. I; and Andreae, Inwiefern werden Insekten durch Farbe und Duft der Blumen angezogen, *Beiheft*, *Bot. Centralblatt*, *15*, 1903, pp. 427–470.

display is all made by an enlarged and conspicuous set of specialized leaves (bracts) which surround the flower, as in the flowering dogwood and many euphorbias (Fig. 292), or even by highly colored ordinary leaves, as in the poinsettia.

120. Degrees of specialization for insect visitors. Flowers with a spreading perianth and radial symmetry — like those of the stonecrop (Fig. 92) and the live-forever, the buckwheat (Fig. 114) and the caraway (Fig. 295), buttercups, poppies, roses, and hundreds of other familiar kinds — are open to all comers, and are frequented by many sorts of insects, from flies to bees.

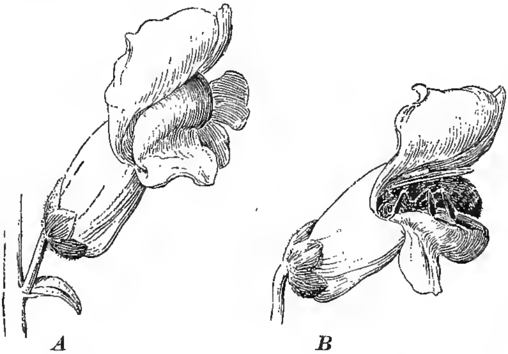

FIG. 115. Flowers of snapdragon

A, with lips of corolla tightly closed; *B*, with the lips forced open by a visiting bee

Flowers with bilateral symmetry — like violets, wild balsam (Fig. 119), most flowers of the Pea family (Fig. 98), mints, and many others — are usually not suited to indiscriminate visitors, but only to those insects which can get at the nectar, the pollen, or both. In violets, for example, the pollen is abundant, but is concealed within the throat of the corolla, and the nectar is deep down in the spur of the corolla. Both pollen and nectar are easily reached by the tongues of bees, but not by small insects. In the snapdragon the mouth of the corolla is firmly closed, so that small insects cannot enter it. Larger ones, such as bees, can, however, readily overcome the elasticity of the hinge at the junction of the lips and enter the flower (Fig. 115).

There are some flowers which appear to be dependent on pollination by a single kind of insect only, and therefore are unable to set any seeds if that species of insect is not at hand to carry their pollen. One famous example of this dependence of the flower on a particular insect is that of the common fig, which may bear large and juicy fruits without insect visits, but cannot produce seed that will grow without being pollinated by a small species of wasp. Another instance is that of the yuccas (Sect. 121).

121. Pollination in yucca. The yuccas are mainly plants of desert or semi-desert regions, especially characteristic of the southwestern United States and Mexico. One species, the Adam's-needle, or Spanish dagger, is a native of the Atlantic and Gulf coast, and commonly cultivated. The flowers of yuccas are white or nearly so, mostly with large spreading corollas, and borne in great clusters, of one of which Fig. 116 represents only a small portion. The stamens are somewhat shorter than the carpels, with abundant sticky pollen, and the pistil consists of three carpels which are joined to form a tube, which is stigmatic on its inner surface. Pollination is impossible without insect aid, and this is furnished by a small moth (*Pronuba*). Unlike most cases of insect-pollination, *that performed by the yucca moth is self-pollination.*

The flowers of yucca are fully open and in condition for pollination during only a short period. Throughout the day the female moth remains at rest within the flower, almost hidden by the stamens (Fig. 116). At dusk she begins active work, first crawling to the anthers, on the surfaces of which the pollen generally remains in a lump after its expulsion from the pollen sacs. She collects pollen into a mass, held as shown in Fig. 117, which is sometimes three times the size of her head. She then crawls over or within the flower, with occasional sudden starts, until finally she takes a position astride of one stamen and with her head toward the stigma, as shown in the top flower of Fig. 116. Lowering the abdomen between the stamens, she now thrusts the sharp tip of the egg-depositing apparatus (*ovipositor*) into the soft ovary wall and inserts an egg into an ovule. After depositing an egg,

Fig. 116. Flowers of yucca visited by the moth *Pronuba*

The work of the moth is suggested by its position in the several flowers. In the first flower (the lowest), the moth is gathering pollen; in the second, she is pollinating the stigma; in the third, she is in the position of rest during the day; in the fourth, in the position of rest when disturbed; in the fifth, ovipositing the moth runs to the top of the pistil, as shown in Fig. 116, uncoils the organs which hold the pollen mass, and with her tongue thrusts the pollen vigorously into the stigmatic opening for several seconds. As the stigma is usually pollinated after every deposition of an egg, in cases where ten or a dozen eggs are introduced into a single pistil it is pollinated as many times. After the hatching of the eggs, each little grub that is produced from them eats up the ovule in which it was deposited, leaving, however, many other ovules to mature into seeds. It then bores its way out through the capsule, drops to the earth, and makes a cocoon of silk a few inches underground. It probably does not assume the form of the adult (winged) insect until near the next blooming time of the yuccas.

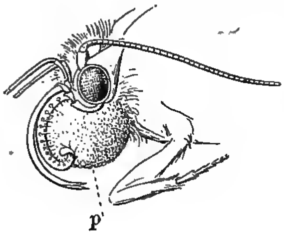

FIG. 117. Head of *Pronuba* moth. Magnified

p, mass of pollen held in position by spinous appendages of the moth's head

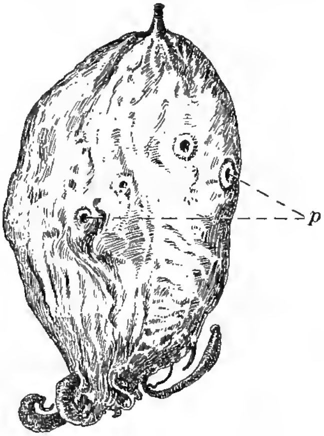

FIG. 118. Pod of a tree yucca

p, perforations caused by escape of larva of yucca moth. Somewhat reduced. After *Thirteenth Annual Report of Missouri Botanical Garden*

The relations of the yucca moth to the plant afford a most remarkable example of coöperation between a plant and one of the lower animals. Without pollination by the moth, yuccas produce no seeds, while, on the other hand, without yucca capsules and their contents the larvæ hatched from the eggs of the moth would starve.[1]

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[1] See *Proceedings of the American Association for the Advancement of Science*, 1880, Vol. XXIX, paper entitled "Further Notes on the Pollination

122. Bird-pollinated and snail-pollinated flowers. Although by far the greater part of the pollination done by animals is due to insects, birds also perform this office for many flowers. Those which are most efficient in this work are the sunbirds of Asia, Africa, and other hot countries, and our own humming birds. Most bird-pollinated flowers are large and showy, many of them scarlet or deep orange in color. Among the most familiar of our wild flowers much visited by humming birds are the wild balsam or jewelweed (Fig. 119), the trumpet creeper, and the cardinal flower; among cultivated ones are the scarlet salvia, the gladiolus, and the trumpet honeysuckle.[1]

FIG. 119. Wild balsam (*Impatiens biflora*)
The spurred flowers are much visited by humming birds

Snails are not so abundant in most parts of our own country as to be important agents in pollinating flowers, but in some parts of Europe they swarm in almost countless numbers on the foliage and the flowers of many species of plants, and are known to pollinate some flowers, particularly those of the Arum family, related to our jack-in-the-pulpit and dragon-root (Fig. 277).

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of Yucca, and on Pronuba and Prodoxus," by C. V. Riley; also the same reprinted as a pamphlet by the Missouri Botanical Garden, 1883. See also the *Thirteenth Annual Report of the Missouri Botanical Garden*, 1902, paper entitled "The Yucceæ," by William Trelease.

[1] Other flowers are the buckeye, horse-chestnut, canna, century plant, cotton, evening primrose, milkweed (*Asclepias*), oleander, painted cup, petunia, tobacco.

123. Prevention of self-pollination, dichogamy. Of course diœcious flowers like those of the willow cannot be self-pollinated. Monœcious ones like those of Indian corn (Figs. 335 and 336) are likely to be pollinated with pollen from another plant. As regards bisexual flowers, it is evident that there are many opportunities for self-pollination. But in all cases in which cross-pollination produces more seed or stronger plants, or both, it is clear that anything in the structure or mode of development of the flower which tends to secure cross-pollination is highly advantageous. One of the most effectual means of preventing self-pollination in bisexual flowers is the maturing of the stamens at a different time from the pistils, known as *dichogamy.* In some flowers, as in the figwort and some plantains (Fig. 120), the pistils mature first. In such cases the pollen from older flowers (in the staminate condition) is transferred to the stigmas of recently opened flowers (in the pistillate condition). Pollination of the plantain shown in Fig. 120 is due to the wind.

FIG. 120. Dichogamous flowers of plantain (*Plantago lanceolata*)

A, earlier stage, pistil mature, stamens not yet appearing outside the corolla; *B*, later stage, pistil withered, stamens mature. Six times natural size

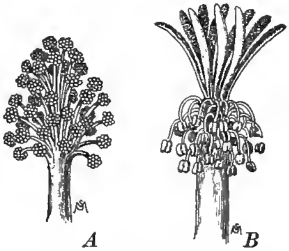

FIG. 121. Dichogamy in the high mallow

In *A* the stamens are mature but the stigmas are pressed together into a club-shaped mass (hidden by the numerous stamens). In *B* the anthers are withered and the stamens droop, while the stigmas have separated and are ready for pollination. After H. Müller

Usually, as in some mallows (Fig. 121) and in *Clerodendron* (Fig. 122), the stamens mature first. An insect visitor to a flower in the staminate condition becomes somewhat covered with pollen. Then flying to a flower in the pistillate condition, he is sure to leave pollen on the stigmas and thus insure cross-pollination.

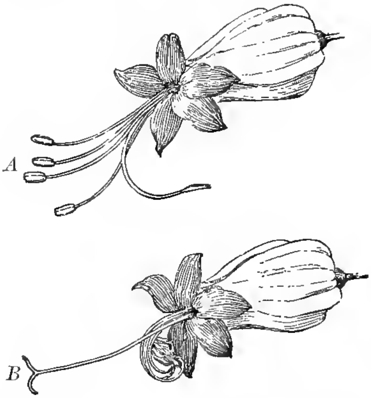

Fig. 122. Dichogamous flower of *Clerodendron* in two stages

In *A* (the earlier stage) the stamens are mature, while the pistil is still undeveloped and bent to one side; in *B* (the later stage) the stamens have withered and the stigmas have separated, ready for the reception of pollen

It is common to find the stamens of a flower maturing a few at a time, as in "nasturtium," buckwheat (Fig. 114), and many other flowers. This gives more opportunities for insects to carry away the pollen than would be possible if it all matured at once.

124. Prevention of self-pollination: dimorphism. A means of preventing self-pollination, even more effective than is dichogamy, is found in the structure of flowers in which some have a long pistil and short stamens, others a short pistil and long stamens. This condition occurs in the flowers of bluets (Fig. 123), the partridge berry, the primrose, and some other common flowers. It is easy to see that the head of an insect smeared with pollen by contact with the anthers of Fig. 123, *A*, would just come into contact with the stigma of *B*, and that the insect's abdomen covered with pollen in *B* would just touch the stigma of *A*. All the flowers on an individual plant are of one kind (either long-styled or short-styled), and the pollen is of two sorts, — each kind sterile on the stigma of any flower of similar form to that from which it came.

125. When self-pollination is advantageous: cleistogamous flowers. Some flowers are usually self-pollinated unless cross-pollinated by accident or by human agency. Wheat is a notable instance of the kind, and apparently self-pollination can go on in this grain for a long period without injury to the fertility or the robustness of the offspring.[1] Experiments in raising selected varieties of tobacco seem to show that in this plant self-fertilization, for several generations at any rate, produces better results than cross-fertilization.[2]

Whenever cross-pollination by the wind or by the agency of animals is impossible, it is evident that self-pollination would be advantageous, since it is infinitely better than no pollination at all. Examples of the impossibility of cross-pollination are the cases of plants which grow isolated or in localities in which the special pollinating animal is not found, as American yuccas in European botanic gardens. Many highly successful weeds owe part of their predominance to the fact that they seed well after self-pollination.

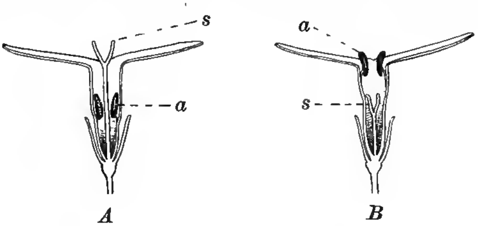

Fig. 123. Lengthwise section of dimorphous flower of bluets

A, long-styled form; *B*, short-styled form; *a*, anthers; *s*, stigmas. About three times natural size

Since occasional cross-fertilization appears to be sufficient to keep up the strength and fertility of many kinds of plants, it would seem to be an advantageous plan for these to unite the certainty which characterizes self-pollination with the renewal of strength which comes from cross-pollination. Violets and many other less familiar plants unite the two methods

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[1] See "Wheat: Varieties, Breeding, Cultivation," *Bulletin 62*, University of Minn. Agr. Exp. Sta., 1899.

[2] See "Tobacco Breeding," *Bulletin 96*, Bureau of Plant Industry, U. S. Dept. Agr., 1907.

by producing ordinary showy flowers and also inconspicuous closed or *cleistogamous* flowers. The latter are, in violets, borne on flower stalks close to the ground (Fig. 124), and

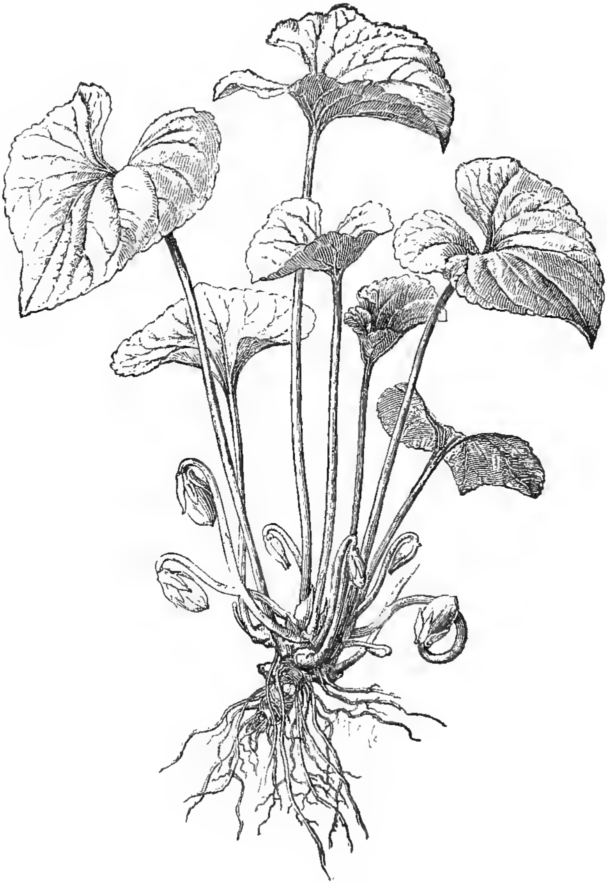

FIG. 124. A violet, with cleistogamous flowers

The objects which look like flower buds are cleistogamous flowers in various stages of development. The pods are the fruit of similar flowers and contain great numbers of seeds. The plant is represented as it appears in late July or early August, after the ordinary flowers have disappeared usually before maturing become partially buried in the earth. The cleistogamous flowers produce many more seeds than the showy ones, but the latter insure occasional cross-pollination.[1]

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[1] On the general subject of pollination of flowers and illustrations of special cases see:

Knuth-Davis, Handbook of Flower Pollination. Clarendon Press, Oxford.

Darwin, The Effects of Cross and Self Fertilisation in the Vegetable Kingdom. D. Appleton and Company, New York.

Darwin, Different Forms of Flowers on Plants of the Same Species. D. Appleton and Company, New York.

Darwin, The Various Contrivances by which Orchids are fertilized by Insects. D. Appleton and Company, New York.

Kerner-Oliver, Natural History of Plants, Vol. II. Henry Holt and Company, New York.

Gray, Structural Botany. American Book Company, New York.

Weed, Ten New England Blossoms. Houghton Mifflin Company, Boston.

CHAPTER IX

SEEDS AND SEEDLINGS; SEED DISTRIBUTION

126. Gross structure of seeds. The definition of the term *seed* has already been given (Sect. 22). The structure of seeds varies so greatly in details that in this place it will be possible to describe only a very few typical forms.[1] The most important parts of ordinary seeds are:

(1) The *embryo*, or miniature plant.

(2) The plant food stored elsewhere than in the embryo, usually known as *endosperm*.[2]

(3) The seed coat or coats.

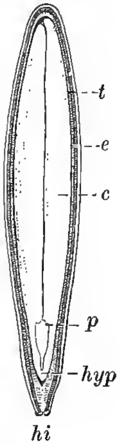

FIG. 125. Lengthwise section of squash seed

hi, hilum, or scar, marking place of attachment to the ovary; *hyp*, hypocotyl; *p*, plumule; *c*, cotyledon; *e* (innermost layer next to cotyledon), endosperm; *t*, testa. Two and one-half times natural size

All of these parts are well shown in Figs. 125 and 126. The embryo differs greatly in seeds of the various groups into which ordinary seed plants are assembled on account of their relationship to each other. Many embryos show a fairly well-defined set of organs, — the *hypocotyl*, or little stem; the *cotyledons*, or seed leaves; and the *plumule*, or seed bud.

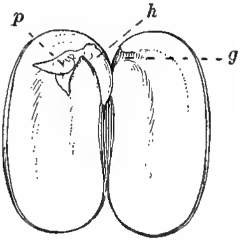

FIG. 126. A common bean split open, after soaking in water

h, hypocotyl, lying on one of the cotyledons; *g*, groove in the other cotyledon where the hypocotyl lay; *p*, plumule

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[1] See also Gray, Structural Botany, chap. viii. American Book Company, New York.

[2] When this reserve food is formed outside of the embryo sac it is called *perisperm*.

127. Classification according to number of cotyledons. The seeds of one great division of seed plants, the *monocotyledons*, — comprising grasses, sedges, palms, lilies, and many other groups, — have one cotyledon (Fig. 127). The reserve food is, as is shown in that figure, mainly stored outside the embryo.

The seeds of the other and still larger division, the *dicotyledons*, have two cotyledons (Figs. 125 and 126). The plant food in the seeds of dicotyledons is often stored in the embryo itself (Fig. 126), as in the chestnut, hazel, beech, oak, bean, and sunflower; or often, like that of the monocotyledonous onion (Fig. 127, *A*), outside of the embryo, as in buckwheat, four-o'clock, castor bean, honey locust, and morning-glory.

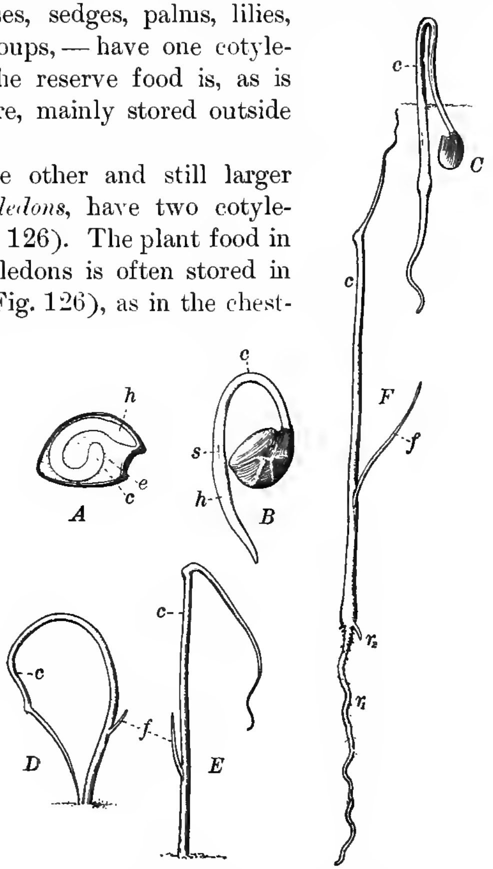

FIG. 127. Seed and seedlings of onion

A, seed; *B–F*, successive stages in development of the seedling; c, cotyledon; *e*, endosperm; *f*, first true leaf; *h*, hypocotyl; *s*, slit from which *f* emerges; r_1, primary root; r_2, secondary root. *A*, considerably magnified

128. Forms of reserve material. The study of the forms of the food stored in seeds is in many ways most important. For a time, usually, the seedling plant depends for its growth largely on the reserves in the seed from which it springs. And the most concentrated vegetable food used by man and other animals generally consists either of seeds themselves, as in the case of the grains, nuts, beans, and peas, or of manufactured products, such as oatmeal, corn meal, flour, cornstarch, cottonseed oil, derived from seeds.

The principal plant foods found in the seed are proteins of many kinds; carbohydrates in the form of starch, sugar, or cellulose; and fats or oils. The characteristics of these various substances can be learned only by means of careful laboratory work, though some of them are tolerably familiar to most people. Not infrequently the different kinds of reserve material are localized in special parts of the seed. In the grain of wheat and of corn the proteins are especially abundant in the translucent flinty outer part of the endosperm, while the starch lies mainly in the interior white portion (Fig. 333). The oil of the corn grain is stored mainly in the embryo, so that kinds which have large embryos contain a high percentage of oil and those with small embryos have a low percentage (Fig. 334).

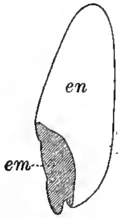

FIG. 128. Diagram of lengthwise section of a grain of wheat

en, endosperm; *em*, embryo. Somewhat magnified

Every seed must contain some protein material, since this is indispensable to the building of protoplasm, and no growth can take place without it. But it does not seem to make much difference whether the non-nitrogenous food in the seed consists mainly of starch as in rice, of oil as in Brazil nuts, or of cellulose as in coffee and date seeds. Along with much starch, many of the grains, particularly millet, contain a good deal of gum, sugar, and fat. The fact that sugar is not usually abundant in seeds may be due to the readiness with which it dissolves in water, which might lead to some of it becoming lost in the soil during germination.

129. The seed coat. The seed coat protects the embryo (and the endosperm, when present) from mechanical injuries. In order to allow germination to begin, either the general surface of the coat must, as in most seeds, be porous enough to absorb moisture, or, in such hard-shelled seeds as the coconut, hickory nuts, walnuts, and butternuts, there must be a thin or soft-walled place through which water can enter. Usually the little opening in the ovule, known as the *micropyle* (Fig. 109, *m*), remains in the seed and serves to admit moisture.

The coats of many seeds have wings or outgrowths of hairs which aid in their dispersal, as already mentioned. Other modifications in the coats of seeds apparently, in some cases, serve as aids in their dispersal, and others as means of preventing the seed from being eaten by animals.

130. Conditions for germination. A sound, live seed will germinate or sprout when suitable conditions are present. The requisites for germination are:

(1) The proper temperature.

(2) Enough moisture.

(3) Air or oxygen.[1]

The temperature most favorable for germination varies with the kind of seed; for any given kind there seems to be a lowest limit, a most favorable (*optimum*) temperature, and a highest limit. The approximate temperatures for a few species are given on the next page (in Fahrenheit degrees).[2]

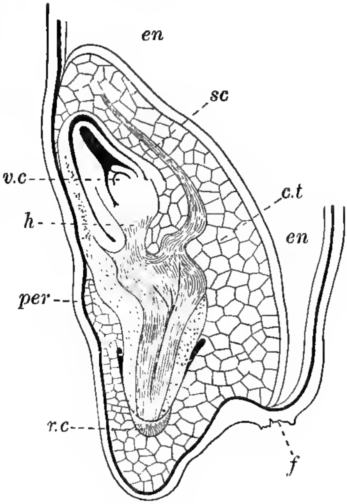

FIG. 129. Lengthwise section (somewhat diagrammatic) through the embryo end of a grain of wheat

en, endosperm; *sc*, scutellum, or absorbing portion of cotyledon; *c.t*, cellular tissue (containing much oil) in which the cotyledon is embedded; *v.c*, vegetative cone or growing point; *h*, hypocotyl; *r.c*, rootcap; *per*, periderm, or coating of grain; *f*, scar to which the funiculus or seed stalk was attached. After Warming. Magnified about 26 diameters

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[1] Some seeds begin to germinate without air, but soon die unless it is supplied to them.

[2] See Detmer, Keimungsprocess der Samen, chap. iii. G. Fischer, Jena.

GERMINATION TEMPERATURES

	LOWEST	HIGHEST	MOST FAVORABLE
Barley	32°–41°	100.4°	84°
Wheat	32°–41°	107.6°	84°
Scarlet runner	49°	115°	91.4°
Indian corn	49°	115°	91.4°
Squash	57°	115°	91.4°
Muskmelon and cucumber	60°	117°	93°

Most farmers have learned by experience that the temperature requirements of all kinds of seeds are not the same. All know, for example, that if corn is planted before the ground is warm enough, it will decay and have to be replanted, but that peas can be sown very soon after the frost is out of the ground.

There is moisture enough in a few kinds of seeds, like those of the willow and the poplar, to allow them to begin to germinate as soon as they are ripe. But most seeds need to be supplied with moisture from without. Too little moisture causes them to germinate very slowly, as is often noticed during spring droughts, while immersing them in water causes many kinds to rot because the air supply is not sufficient.

Lack of air as a hindrance to germination is particularly likely to occur when seeds are planted too deep in clay soils. In warm, open soils there is usually air enough, and the danger encountered is that of drying up, from shallow planting.

131. Preparation of seeds for germination. A few kinds of seeds, as above mentioned, may sprout as soon as they are ripe. Most sorts, however, need a period of rest and comparative dryness before they will grow. The importance of drying seeds is well shown in the case of corn. Kiln-dried corn has, in one instance, been shown to yield 16 bushels per acre more than air-dried seed of the same variety.

After the rest period the time required for germination varies greatly.[1] Grains, grasses, and many seeds of herbs of the Pea family germinate in 2 to 8 days, most seeds of plants of the Parsley family in about 14 days. Seeds of trees and shrubs usually require much more time; for example, those of the hornbeam and ash are said not to grow until the second spring after they are planted.

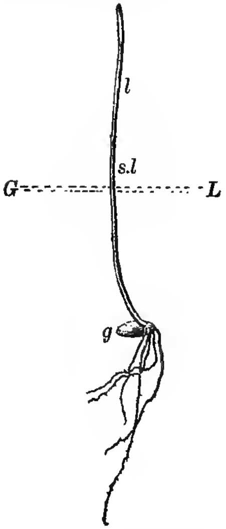

FIG. 130. Wheat seedling

g, the grain; *GL*, ground line; *s.l*, sheathing leaf; *l*, first true leaf. One half natural size

FIG. 131. Corn seedling

g, the grain; *GL*, ground line; *r*, first root, from the tip of the embryo; *r'*, later roots; *s.l*, sheathing leaf. One half natural size

132. Types of seedlings. Seedlings[2] may be divided into two groups, *monocotyledonous seedlings* and *dicotyledonous seedlings.* Those of the dicotyledonous group may be further sub-divided into plants with *underground cotyledons*, as the pea and the oak,

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[1] See Crocker, "Rôle of Seed Coats in Delayed Germination," *Botanical Gazette 42*, October, 1906.

[2] Not considering those of coniferous shrubs and trees (Fig. 256).

and those with *aboveground cotyledons*, as the maple, bean, squash, and morning-glory.

The monocotyledonous seedling may or may not raise its single cotyledon out of the ground after germination. The onion does so (Fig. 127) but the grains do not (Figs. 130, 131). In all the larger grains (as in corn) the fitness of the plumule for piercing hard clods or bits of sod is very noticeable, and serves the plant well in breaking out of the ground against opposition.

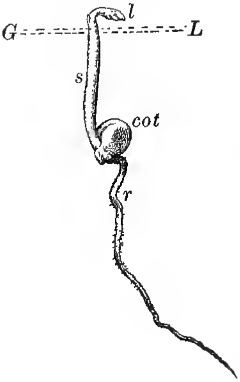

FIG. 132. Pea seedling

cot, the unopened cotyledons; *GL*, ground line; *r*, root; *s*, stem; *l*, rudimentary leaves. One half natural size

Dicotyledonous seedlings with underground cotyledons, like the pea (Fig. 132), are better able to force their way out of the ground if planted deep than are most of those with aboveground cotyledons, like the bean (Fig. 133). Therefore even large seeds of the latter type, like those of the bean, melon, cucumber, and squash, should not be planted deep. Very minute seeds, like those of portulaca, poppy, and most plants of the Pink family, should be planted on the surface of well-raked fine earth and then barely covered by sifting over them a little of the finest loam, or by dragging a trowel or other suitable implement lightly back and forth over the bed.

133. Function of the cotyledons. In many seeds of monocotyledons, as the grains, the cotyledon does not emerge from the seed nor rise above the surface of the ground. It forms an absorbing organ known as the *scutellum* (Fig. 129, *sc*), which serves to take up liquefied plant food from the endosperm and transfer it to the growing embryo. In the seed of the date palm it acts much in the same way. Other monocotyledonous plants, like the onion, bring the cotyledon out of the ground (often with the seed coat attached) and then proceed to develop ordinary foliage leaves (Fig. 127).

In dicotyledonous seeds of the type of the pea, the horse-chestnut, and the buckeye, the cotyledons remain inclosed in the seed coat and underground (Fig. 132), where they become emptied of their contents. They are so loaded with reserve material that they could not serve any useful purpose if they were to emerge into the air and light.

In the bean, they are raised into the air, turn green, develop stomata, and probably for a short time do some photosynthetic work, but soon wither and fall off.

In the squash, pumpkin, and most dicotyledonous plants of the farm and garden, the cotyledons become for a considerable time active green leaves, but they are shorter-lived than the subsequent leaves of the plant, are opposite or nearly so (while the later leaves may be opposite or alternate), are usually smaller than other leaves, and their shape always differs from that of the permanent leaves of the plant. Even in those cases where the cotyledon for a time becomes wholly

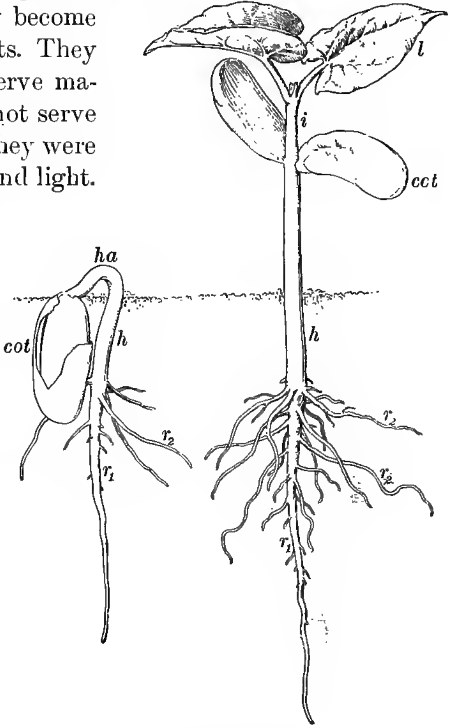

Fig. 133. Two stages in the growth of the bean seedling

In the younger stage the arch of the hypocotyl is but little above the surface; in the older stage the cotyledons have separated, the first internode has elongated considerably, and the first pair of foliage leaves has expanded. *Cot*, cotyledon; *h*, hypocotyl; *ha*, hypocotyl arch: *i*, internode; *l*, leaf; r_1, taproot which proceeded from the tip of the hypocotyl; r_2, branches of r_1. Natural size leaf-like in its appearance, as in buckwheat and the castor bean, its activity differs from that of the permanent leaves. The rate of transpiration for equal areas of such cotyledons, when compared with that of the later leaves, has been found to be from one and a half to two times as great.

It is easy to see that in a general way the readiness with which some cotyledons assume the character of temporary foliage leaves depends on their comparative freedom from deposits of plant food. For this reason some of the most leaf-like cotyledons, like those of the buckwheat and the morning-glory, are found in seeds with abundant endosperm.

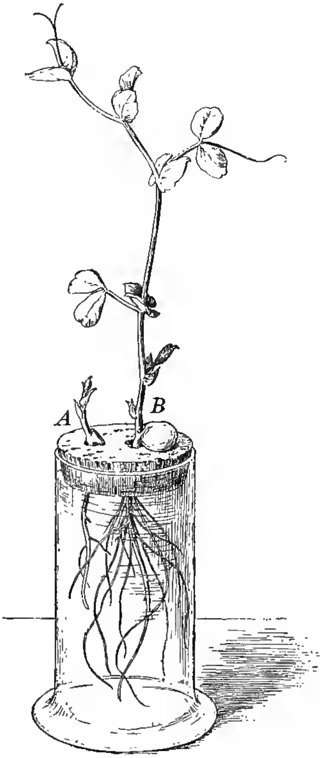

FIG. 134. Pea seedlings growing in water

A, deprived of both cotyledons; *B*, with cotyledons uninjured

134. Action of enzymes on reserve material of seeds. One of the most surprising things about the early growth of seedlings is the rapid way in which many kinds begin to grow even in sawdust or on moist blotting paper. Evidently the plant food at the start must all come from the seed, and the removal of most of the reserve food of the seed greatly retards the growth of the seedling (Fig. 134). It is not at once clear how the proteins and the starch of some seeds and the oil or cellulose of others are so quickly withdrawn from them and transferred to the growing plantlet. Most of the reserve substances found in seeds are soluble with difficulty or quite insoluble in water or the watery sap of plants. But the insoluble substances before being transferred into the seedling are transformed into soluble ones. This is due to the action of certain substances known as *enzymes* or *soluble ferments*. An enzyme as found in seeds is a substance secreted by the plant for the purpose of digesting or rendering soluble such plant foods as require digestive action before they can be absorbed by the tissues of the young seedling. Much has yet to be learned about the nature, occurrence, and action of the enzymes. In most seeds enzymes occur inside the cells along with the reserve materials, and so at suitable temperatures, in presence of moisture, the digestion of the cell contents can take place everywhere throughout the seed. The scutellum of the grains (Fig. 129, *sc*) secretes, from its outer layer, which is in contact with the endosperm, two kinds of enzymes, and rapidly digests the surrounding endosperm.

At very low temperatures, enzymes cannot carry on their work. Each kind has a special temperature at which it is most active; for many kinds this ranges between 86° and 113° Fahrenheit (30° to 45° Centigrade). Evidently the lowest temperature at which the enzyme of a given seed can act must limit the temperature at which germination can go on[1]; and the temperature at which the growth of the very young seedling is most rapid must be not far from the temperature at which the enzyme of its seed is most effective.

Of the many kinds of enzymes known, two of the classes most important in plant physiology are those known as *diastases*, which change starch into sugar, and those known as *trypsins*, which render insoluble proteins soluble. The most familiar case of action of enzymes on a large scale is the malting of barley, in which the starch of the grain is converted into a sugar by diastase. It is said that diastase can change 10,000 times its own bulk of starch into sugar.[2]

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[1] See the table of germination temperatures, Sect. 130.

[2] On digestion and enzymes consult J. R. Green, Vegetable Physiology, chap. xvi. P. Blakiston's Son and Co., Philadelphia.

SEED DISTRIBUTION

135. Usefulness of the seed. People in general, no matter how familiar they may be with seeds, do not stop to consider what the seed means in the perpetuation of any species of plant. Some seed plants, it is true, manage to perpetuate themselves for an indefinite time by vegetative methods, as by root buds, by various kinds of stem propagation, or even

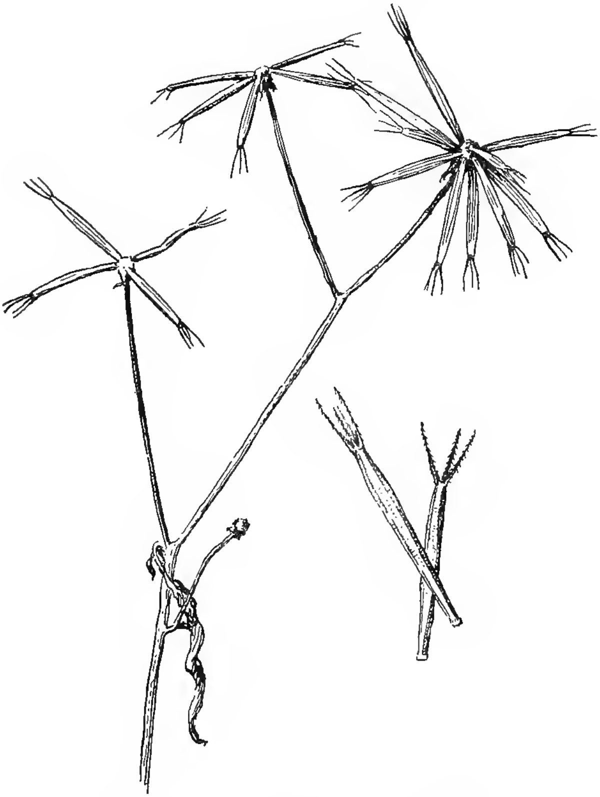

FIG. 135. Fruits of Spanish needles (*Bidens*)
Natural size and twice natural size

by their leaves. But even perennials generally depend upon the growth of seeds to continue the species. A forest of white pines, for example, when all its trees have died of old age or been killed by plant or insect enemies, by destructive winds or forest fires, can only be renewed by the growth of young pines from the seed. And in the case of annual plants all the individuals in existence at any one time will have died in a year, or little more, from that date, to be replaced by a new crop sprung from seeds.

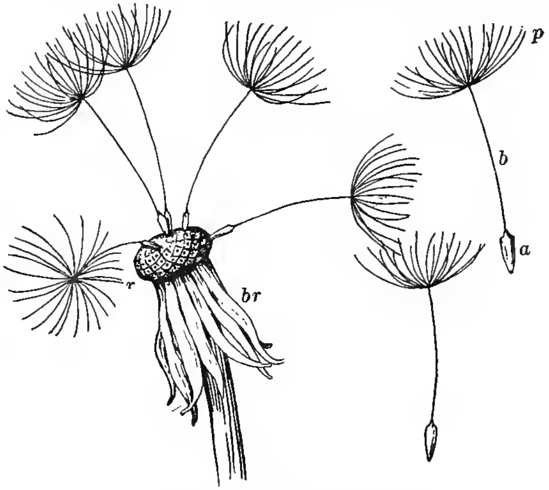

Fig. 136. Dandelion fruits

a, akene; *b*, beak of pappus; *br*, bracts; *p*, pappus (representing the limb of the calyx); *r*, common receptacle for all the fruits. Twice natural size

It is important to notice how well suited most seeds are to withstand conditions that would kill ordinary plants. Seeds are not injured by the lowest natural temperatures, and they resist considerably higher temperatures than those found in most climates. Lack of moisture does not usually harm them. And while some kinds of seeds remain capable of sprouting only for a few days, most kinds will remain good for a year and many for several years. *The seed is a matured ovule* *containing a new plant.* Defined from its function, it is a highly portable and not easily injured package, in which the rudiments of a plant, like its parent, may be carried about and hold life over from season to season.

136. Need of seed distribution. The successive crops of farm and garden annuals are secured by careful seed planting in prepared soil. The seeds of wild plants are also sown, on a still more extensive scale, by natural agencies. In any country the relative numbers of most kinds of wild seed plants usually remain from year to year without great changes except those which are brought about by human interference. This fact is evidence enough that seeds in unimaginable numbers must be scattered about in such a way as to make good the losses in the plant population of the world due to all destructive causes. The means of seed distribution will be taken up in Sects. 140 and 141.

137. The struggle for existence. Only a small proportion of all the seeds annually produced can have a chance to grow. The resulting contest among plants for a foothold and for the means of subsistence forms one portion of what the great English naturalist, Charles Darwin, called *the struggle for existence.* It is shown by careful calculation that about 5,300,000 acres of land could be sown with the wheat grown at the end of fifteen years from a single parent kernel, if every grain were to grow and live. But the wheat plant does not produce a very large number of seeds. The so-called Russian thistle (*Salsola Kali*, var. *tenuifolia*), a most troublesome weed, bears from 20,000 to 200,000 seeds. Taking the moderate estimate of 25,000 seeds to a plant, their offspring (if all the seeds grew) would number 625,000,000 individuals, and the next generation would number 15,625,000,000,000. Supposing each plant to have a diameter of about three feet and to occupy an area of seven square feet, the student can readily calculate how many square miles of territory the number of plants last named would cover, if actually in contact with each other throughout their circumferences.

The fact that any species, such as the ordinary ragweed (*Ambrosia artemisiæfolia*), common throughout most of the United States, does not promptly overrun all those portions of the earth's surface suited to its growth is due to:

(1) Lack of sufficiently thorough and rapid means of seed distribution.

(2) Multiplication of insect and plant enemies of the species (often not important).

(3) Overcrowding or competition between individuals of the same species (other ragweeds) or of other species.

138. How competition kills. The result of competition among plants is sometimes to make the overcrowded individuals dwarfish and unfruitful, or at other times to kill them outright. The means by which the successful individuals weaken or kill their neighbors are mainly:

(1) Overshadowing, resulting in deficient photosynthesis in the shaded plants from lack of light.

(2) Robbing the defeated plants of water.

(3) Robbing them of soluble salts (nitrates, phosphates, and so on, from the soil).

The deprivation of sufficient water and salts interferes with the nutrition of the overcrowded plants and may soon completely stop their growth.

The extent and reality of the competition here merely outlined can only be understood by aid of careful field work. Weedy ground may be found which contains as many as a thousand seedlings to the square foot, and if a small area of such ground is isolated and watched, the struggle for existence may be followed to its end, with only one or two of the thousand surviving.[1] It must be remembered that multitudes of seeds get no start in life as seedlings, and so do not even enter into competition, either from failure to lodge in a place

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[1] See also Charles Darwin, Origin of Species, chap. iii (D. Appleton and Company. New York), L. H. Bailey, Survival of the Unlike, pp. 258–261 (The Macmillan Company, New York), and Bergen and Davis, Principles of Botany, pp. 448–450 (Ginn and Company, Boston).

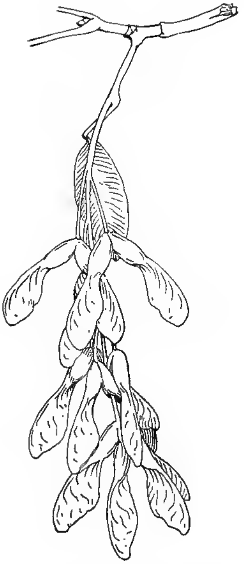

FIG. 137. Winged fruits of maple

One half natural size

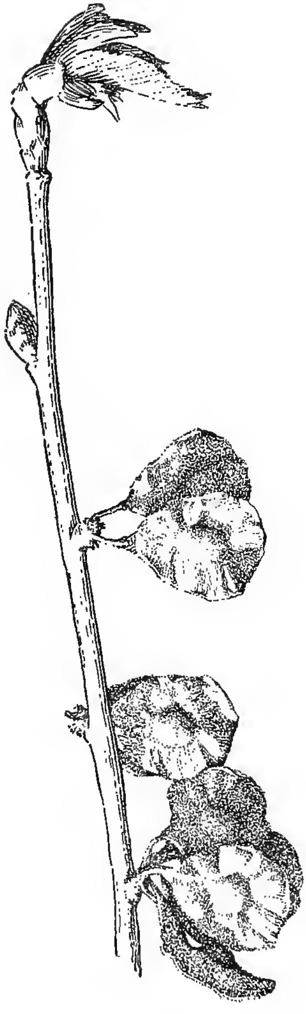

FIG. 139. Winged fruits of red elm

Natural size

FIG. 138. Winged fruits of *Ailanthus*

One half natural size

in which they may germinate, or because they are promptly destroyed by birds or other animals, or by molds or other organisms which cause them to decay.

139. Fruits. The term *fruit* in its most limited botanical sense means the ripened ovary with its seeds and other contents. In a grape there is nothing more than this. In a currant or gooseberry, however, the thickened and fleshy calyx surrounds the fruit proper and forms a part of what is usually called the fruit by botanists. In many dry fruits, such as those of Spanish needles (*Bidens*, Fig. 135) and of the dandelion (Fig. 136), the limb of the calyx forms some sort of hook, spine, plume, or other appendage, and the whole is usually spoken of as the fruit. Not infrequently the receptacle is

FIG. 140. Bract-winged fruits of linden

f, fruits of linden, with a wing-like bract (*b*) by means of which they are blown about by the wind. One half natural size enlarged and united to the ripened ovary, and is counted part of the fruit, or many ovaries may be joined by the receptacle into a single mass, as in the strawberry.

FIG. 141. Fruits of ironweed in heads, and some separate fruits

The latter one and one-half times natural size

140. Mechanisms which aid in the distribution of seeds. Seeds and fruits are in many instances so constructed that they are very likely to be carried about by wind, water, or animals. The winged seeds of the catalpa and the tufted ones of the willow are readily carried long distances by the wind. So, too, are the winged fruits of the maple, the *Ailanthus*, and the elm (Figs. 137–139), and the tufted ones of the thistle and the ironweed (Fig. 141). The seed capsules of the poppy, the morning-glory (Fig. 142), the evening primrose (Fig. 144),

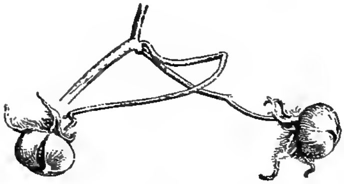

FIG. 142. Seed pods of morning-glory beginning to open, so as to allow the seeds to rattle out, a few at a time

One half natural size

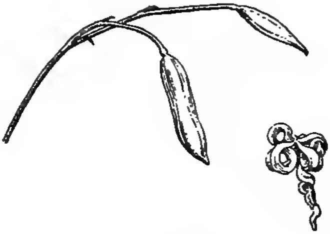

FIG. 143. Two capsules of the wild balsam and a third detached, split open, and curled up as it appears after throwing the seeds about

Two thirds natural size

FIG. 144. Pods of evening primrose open at the top and allowing the seeds to escape gradually

Three fourths natural size

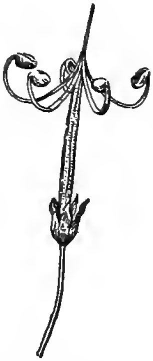

FIG. 145. Fruit of crane's-bill, the carpels splitting away from a central column and thus throwing the seeds about

Reduced

the larkspur, and many other plants, open at or near the top, and for weeks allow the seeds to be scattered by the wind whenever the stalks of the capsules are swayed back and forth by it. Such stalks are still more strongly swayed by a passing animal, and then throw many seeds directly at the animal, into whose fur they fall and are carried till they shake out.

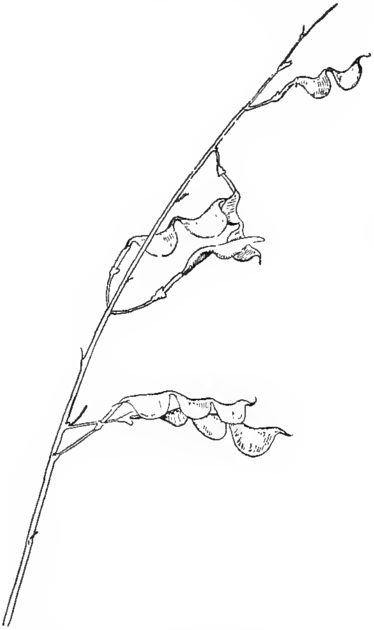

Fig. 146. Burs of sticktights (*Desmodium*)
One half natural size

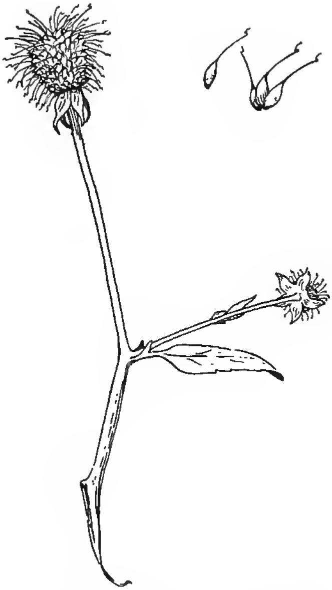

Fig. 147. Head of fruits of avens and some of the separate, bur-like fruits, with hook-like remains of the style

The latter one and one-half times natural size

Some fruits or clusters of them, as white pine cones, or whole plants, known as tumbleweeds (Fig. 356), are rolled along the ground by the wind, carrying with them multitudes of seeds. Among the commonest are old witch grass (*Panicum*), tumbleweed (*Amaranthus*), and the "Russian thistle" (*Salsola*).

Water plants very commonly produce seeds or fruits which will float, and these are often carried for miles by the water, to lodge and grow long after their voyage began. It is supposed that many uninhabited islands of the South Seas have in this way been planted with coco palms.

Various devices throw seeds about (Figs. 143 and 145), especially when disturbed by an animal, into whose fur the seeds may fall. Burs in great numbers are carried about by animals, sometimes clinging for months to the hair, fur, or feathers (Figs. 146 and 147).

FIG. 148. Fruit of the wild black cherry, a valuable timber tree

The seeds, which are hard and indigestible, are disseminated mainly by birds. One half natural size

141. Dispersal of edible seeds. Edible seeds and fruits — such as nuts, the grains, berries, and stone fruits like plums and cherries — are often carried long distances by animals. They are frequently swallowed, and later voided undigested and in a condition to grow. In this way wild cherries (Fig. 148) and wild apples are planted about pastures and in open woods. So, too, raspberry, currant, and gooseberry bushes, asparagus, and bittersweet may be found growing in the forks of trees high above the ground. Squirrels, blue jays, and some other animals carry away nuts and bury them, often leaving them to grow the following spring (Fig. 325).[1]

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[1] On the general subject of seed dispersal see Kerner-Oliver, Natural History of Plants, pp. 833–877 (Henry Holt and Company, New York); also Beal, Seed Dispersal (Ginn and Company, Boston).

CHAPTER X

THE GREAT GROUPS OF PLANTS

142. The basis of classification. In the preceding chapters little has been said about classifying plants into groups. Practically all the plants discussed so far belong to one group, and since flowers and seeds are characteristic structures in these plants, the group is usually spoken of as the *Flowering* or *Seed Plants.* Throughout the entire plant kingdom one or more kinds of structures are generally used as the basis for arranging plants into groups. What a plant may do with these different structures, or where the plant lives, may have some influence upon the classification of the plant, but ordinarily these things all give way to considerations of structure in determining the group to which a plant belongs.

It is true that such expressions as "desert plants," or "parasitic plants," are used to group together plants that live in certain kinds of regions, or that live by means of certain processes, and such bases of classification are most interesting and profitable; but it has been found much more convenient and more satisfactory to arrange the great groups upon the basis of structure and form. Beginners in botany are often more interested in what plants are doing than in what their structures are, but we must know what the structures are in order to understand what is being done. Also a better degree of uniformity in classification is obtained by using plant structures as its basis.

143. The meaning of *genus* and *species*. In most wooded regions one or more kinds of oaks may be found. The following kinds are common, and are known to many people who have not studied botany: white oak, bur oak, red oak, black oak, blackjack oak, live oak, and several other kinds. While

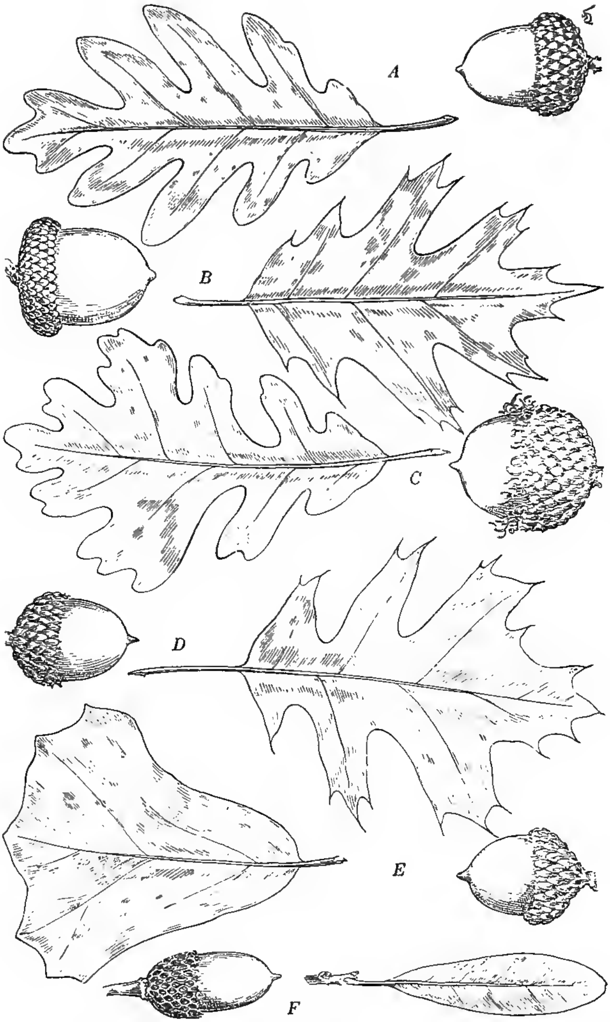

FIG. 149. A group of leaves and acorns illustrating some of the differences between six species of oak (*Quercus*)

A, the white oak (*Q. alba*); *B*, the red oak (*Q. rubra*); *C*, the bur oak (*Q. macrocarpa*); *D*, the black oak (*Q. velutina*); *E*, the blackjack oak (*Q. marylandica*); *F*, the live oak (*Q. virginiana*). The acorns are about three fourths natural size and the leaves less than one half natural size. Modified from R. B. Hough all these are oaks, and bear to one another many resemblances in form of tree, form of leaf, and in the proportion of parts, there are sufficient differences in form to distinguish them one from another. The botanist uses a *genus* name, which is *Quercus*, to include all the oaks, and to this genus name he adds a *species* (specific) name by which to indicate the particular kind of oak of which he is speaking. In names of many plants the specific name suggests a prominent characteristic of the particular kind of plant to which the name refers; as in *Quercus alba*, alba, meaning "white," refers to the whitish bark of the tree; and in *Quercus nigra*, nigra refers to the blackish bark. A list of six of the oaks, together with the leaf outlines and drawings of the acorns (Fig. 149), should help to make more clear the meaning of genus and species. This meaning needs to be understood, since we usually speak of plants by their common names or by their generic names, and often it is necessary also to use the specific names.

144. The leading groups of plants. Quite similar plants are grouped together into one *species*, and species that closely resemble one another are grouped together into one *genus*. In the same way similar genera (plural of *genus*) are grouped together into one *family*, and families of close resemblances are grouped into an *order*. Orders are grouped into *sub-classes* or directly into *classes*, and the classes into *great groups*, of which there are four. These four great groups together constitute the *plant kingdom*. Other intermediate groups are sometimes used.

Of the four great groups of plants, the one which includes the flowering, or seed plants, is the *spermatophytes*, a name which means "seed plants." The spermatophytes are divided into the *angiosperms*, or plants with inclosed seeds, and the *gymnosperms*, or plants with exposed seeds. The group next below the spermatophytes is the *pteridophytes*, or fern plants, the group which includes the true ferns and certain other plants which are rather rare. Next below the pteridophytes is the *bryophytes*, or moss plants, consisting of the *mosses* and *liverworts*. The lowest group is the *thallophytes*, the lowly or prostrate plants, which group includes the *fission plants*, the *fungi* and the *algæ*. It is the last-named group, the thallophytes, which we shall first consider.

145. Some aspects under which plants are studied. The study of the great groups, their subdivisions, and the proper classification of plants, is known as *taxonomy*, or *systematic botany*. The study of plant structures, their similarities, differences, and relationships is known as *morphology*. Special study of the cell is *cytology*. Plant activities or work and their relations to the immediate surroundings of the plant are included in *physiology*, while the relationships of plants to one another and to the environment in general is *ecology*. One phase of ecology deals with the distribution of plants over the earth and is known as *ecological plant geography*. The study of plant diseases is known as *phytopathology*, or *plant pathology*. A study of the bacteria constitutes *bacteriology*. A consideration of the useful or harmful aspects of plants is included under the general term *economic botany*, and under this head there are such subdivisions as *agricultural* and *horticultural botany*. These are but the leading aspects under which plants may be studied.

It is evident that these divisions have no sharply marked lines between them, and that they are not all made upon the same basis. For example, we might study the bacteria as shown in their structure, which would be morphology; or as shown in their relation to disease, which would be pathology; or in their relation to farm and garden crops, which would be economic botany.

146. Names of plants and groups not most important. It is impossible to study plants in any extended way without having definite names for them and their parts, as well as for the different kinds of work that they do. We need names of the different people whom we know in order that we may speak of them in a definite way. If we had not these names we should constantly have to use long descriptions that would be inconvenient and confusing. How plants live and the relations that they bear to other living things are the really important things, and though names are quite necessary, we must keep clearly in mind that they are merely tools, by means of which, in our thinking and speaking, we may easily handle plants. There are two great pieces of work that plants do, as has been made evident in the preceding chapters: plants must have ways of securing and using the needed food materials, — they must attend to the needs of nutrition; and they must attend to the establishment of succeeding generations of their kind, — the work of reproduction. All that plants do may in some way be related to one or both of these two great pieces of work. Protection through the winter seasons and drought, and responses to the conditions of life in water or in tropical regions are in some way related to nutrition and reproduction.

While, therefore, we shall study, in some of the following chapters, a few representatives of the great groups of plants, we shall always have to keep in mind that what we really want to find out is what plants are, how and where the different groups live, how their habits of living are related to the life of other living things, and how they reproduce themselves.

CHAPTER XI

THE BACTERIA (SCHIZOMYCETES)

147. Introductory. In the preceding chapter it was stated that the thallophytes constitute one of the four great divisions of the plant kingdom. They are plants of very simple structure, and do not have roots, stems, and leaves. Some of them are extremely simple, one-celled plants, and others are very large and quite conspicuous. In methods of producing their offspring thallophytes are also comparatively simple. Of all the thallophytes the bacteria are simplest in structure, and we shall consider them first in the series of plant groups.[1]

What the bacteria are and how they live are questions of very great hygienic as well as botanical importance. Bacteria have sometimes been represented as wholly dangerous to men, a conception very far from true. They have been called germs, microbes, bacilli, and microörganisms, often without any definite notions as to the real meaning of these names. Even the fact that they are plants is not generally recognized by the public, though for many years scientists have known it. What the bacteria are, how they live, and how their life affects the life of other living things are some of the questions to be discussed in this chapter.

148. Form. There is variation in the form of bacteria, as there is among higher plants. Three groups, classed according to form, are generally recognized, — the spherical (*coccus*), rod (*bacillus*, Fig. 150), and spiral (*spirillum*) groups. There are sphere forms of wide difference in sphericity, rod forms with

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[1] Cultural experiments offer a better means of laboratory study of the bacteria than does microscopic work. Demonstration microscopes will be found helpful, however, in giving an idea of the size and form of a few of the common types of bacteria.

great variations in length and diameter, and spiral forms having from a fraction of one spiral to many spirals. Furthermore, spherical forms may become piled upon one another so that colonies result, and rods may be joined (Sect. 152) in such a way as to construct filaments. Within these groups many species of bacteria are known. One high authority, Migula, considers that there are 1272 distinct species of bacteria, most of which belong to the bacillus type.

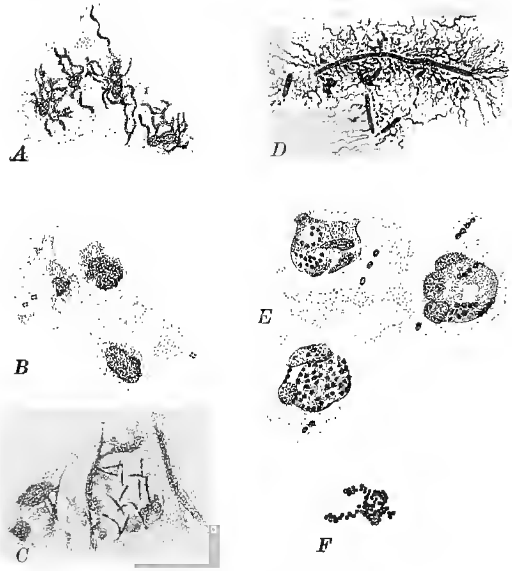

Fig. 150. A group of bacteria

A, *Bacillus typhosus*, from a six-hour-old culture upon nutrient agar. In such cultures the main body of the bacillus is short and the cilia are relatively prominent; magnified 1000 diameters. *B*, *Micrococcus tetragenus*, three groups each of four individuals, each showing the characteristic arrangement; the larger bodies are portions of the pus in which the bacteria occur. *C*, *Bacillus tuberculosis;* the very slender bacilli are shown among particles of sputum. *D*, *Proteus vulgaris*, a widely distributed saprophytic bacillus. *E*, *Pneumococcus*, some individuals of which have been inclosed and partially digested by the large white blood corpuscles (phagocytes). *F*, *Staphylococcus aureus*, a small spherical bacterium usually arranged in chains; magnified 1000 diameters. Modified from Jordan's "General Bacteriology"

149. Size. The variations in size are even greater than those in form. The average bacillus type of bacterium is about $\frac{1}{25000}$ inch ($\frac{1}{1000}$ mm.) in diameter and $\frac{1}{10000}$ inch ($\frac{1}{400}$ mm.) in length. The spherical bacteria have an average diameter slightly less than that of the average bacillus forms, while most spiral forms are larger. There are known forms that are very much smaller than these averages. It is indeed thought by some bacteriologists that the failure to discover the bacteria that produce certain diseases is due to our inability, even by means of the most powerful microscopes, to see these organisms. It is suggestive in this connection to state that the organism which produces yellow fever (perhaps an animal organism and not a bacterium at all) is small enough to pass through the pores of a compact porcelain filter.[1]

If the average bacteria are $\frac{1}{25000}$ inch in diameter and $\frac{1}{10000}$ inch in length, and if such bacteria were placed upon one another end to end compactly until a pile one inch long, one inch high, and one inch wide was constructed, the cubic-inch mass would contain 6,250,000,000,000 individual bacteria. This is approximately 65,000 times the number of human beings in the United States. Or, assuming that a man's finger nail is $\frac{1}{50}$ inch ($\frac{1}{2}$ mm.) in thickness, by placing one upon another, end to end, to make a single stack of average bacteria as high as the finger nail is thick would require no less than 1250 bacteria.

150. Structure. These are extremely simple plants, and are believed by some to be structurally the simplest known living things. The wall of the cell is often made up of a slime-like sheath. In some bacteria this wall is a distinctly gelatinous capsule. It is not of cellulose material, as it is in the higher plants. Internally the cell structure is quite simple, consisting of structures that are thought to be cytoplasm and granules of nucleus-like material.

Many bacteria have been observed to have long hair-like flagella extending from or through the cell wall (Fig. 150).

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[1] Reed and Carroll, American Medicine, 1902, p. 301.

Sometimes these are present in sufficient numbers to cause the entire cell to have a woolly appearance. In other cases but one or a few of these flagella are present. These are organs of locomotion.

151. Motility. Many kinds of bacteria can move from place to place by means of the hair-like flagella. The rate of their movement, which varies greatly, may be strikingly rapid. "The typhoid bacillus may travel a distance of 4 mm. (about $\frac{1}{6}$ inch), or about 2000 times its own length, in one hour; the cholera spirillum may attain for short distances a speed of 18 cm. (about 7 inches) per hour,"[1] a speed that is 45 times as great as that of the typhoid bacillus. There are other spirillum forms that move with great rapidity. These distances may seem short, but if put in terms of the actual length and bulk of the organism, they become more significant. If a man should travel as many times his own length as the typhoid bacillus or as the cholera spirillum (assuming that the cholera spirillum is of length similar to the typhoid bacillus, though it really does attain a much larger size), how far would he travel in one hour?

152. Reproduction. The usual method of reproduction is by fission, in which the bacterial cell divides into two new cells, each of which is a new individual. The newly formed cells usually separate soon after being formed. Sometimes, however, they continue to divide for a number of generations without becoming separated, thus producing a chain or filament of plants. In a very short time the new plants become full-grown and ready again to divide. In the case of some kinds of bacteria newly formed individuals divide within twenty minutes to a half hour after they themselves are produced. Thus two or three generations may be formed within an hour's time. The possibilities of this rate of reproduction are enormous. If all conditions were to remain entirely favorable for reproduction, a bacterium which divides but once an hour would in two days produce offspring

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[1] Jordan, E. O., General Bacteriology, 1908, pp. 59–60.

numbering 281,500,000,000, and "in three days the progeny of a single cell would balance 148,356 hundredweight."[1] Of course it is well known that ordinarily this rate of reproduction cannot be realized, because growth conditions do not remain favorable. The food supply is soon exhausted, and the excretions from the bacteria themselves render conditions unfavorable. But in situations where bacteria can grow they really do reproduce themselves and increase their number with astonishing rapidity. The possibilities of production and growth of large numbers are evident when we keep in mind that for a considerable time many millions of bacteria could live in a cubic inch of milk or beef broth.

In another kind of reproduction that is found in but a few of the bacteria the interior of the bacterial cell becomes rounded and inclosed by a relatively heavy wall. This heavy-walled body may remain inactive for a long period, and upon the return of favorable conditions may again produce the kind of cell which formed it. Such specially made reproductive cells are called *spores*. They often serve to preserve bacteria through periods of unfavorable conditions, — as drought, lack of proper air, absence of suitable food, and unfavorable temperature. Some kinds can withstand freezing or boiling temperatures. It is much more difficult to destroy bacteria that produce spores than those which have only the usual growing structures. There are very few spore-forming bacteria among those that produce diseases of men. This is fortunate for men, since the problem of combating disease would be much more complex if all our disease-producing bacteria should possess these resistant spores.

An illustration of bacterial spore action is seen in the disease known as anthrax. Sometimes sheep, cattle, rats, mice, and other animals, as well as men, are killed within a very short time — a few hours to a few days — by this disease. Before adopting the method of treatment devised by Louis Pasteur, France, in single years, has lost as much as $20,000,000

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[1] Jordan, E. O., General Bacteriology, 1908, p. 61.

worth of cattle and sheep. The spores form only when the bacteria are exposed to the air. When an animal dies of anthrax, if its body decays while exposed to the air, millions of anthrax spores are formed. These spores can lie in the field for very long periods, probably several seasons, and withstand the variations in temperature, moisture, and light. Under ordinary conditions these will not germinate until they are introduced into the body of an animal, when they again begin their growth.

153. Nutrition. Bacteria absorb their food material directly through the walls of their cells. Living, as they do, within or upon their food supply, direct contact with it is secured. Most kinds of bacteria live upon organic foods. The sources of this food are as numerous as are the kinds of organic substances in the universe, — living and dead bodies of plants and animals, plant and animal products, materials in solution in water, materials in the air and the soil. Some bacteria[1] thrive without free oxygen and thus can live upon food material in places where other organisms cannot live. A few bacteria can construct food somewhat as the green plants do.

It must also be noted that bacteria, like other living things, produce and excrete substances that, if retained, would be injurious to them. If excreted and accumulated about the bacteria in great quantity, these substances would soon kill them. If a jar of beef broth is carefully sealed after any ordinary bacteria have been introduced into it, there will at first be a rapid increase in their number and the liquid will become clouded with the organisms and their products. But the excretions soon accumulate to such an extent that the bacteria can no longer grow. They become dormant or die and settle to the bottom of the jar or collect in a jelly-like mass at the surface.

154. Relation to decay. The bacteria and certain other dependent organisms (as molds, yeasts, many animals), while living upon the bodies or the products of plants and animals,

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[1] Known as *anaërobic* species.

use parts of them as food. The processes of securing this food result in partial or complete breaking down of the food substance. This is known as decay. While a body is undergoing decay, usually several kinds of bacteria and other organisms live in turn upon it. In complete decay all of the nutrient organism is used as food, passes into the air as gases, or is dissolved in water and carried into the earth or into streams. The materials that result from decay are not only directly the remnants of the original plant or animal body, but may also contain excretions from decay-producing organisms. Furthermore, many of these organisms of decay have themselves died and decayed.

Processes of decay are of great biological importance. It is necessary to have the dead bodies and the waste products of living bodies of plants and animals reduced to a form that makes their removal possible. The materials that are broken down are thus made usable for future growth of plants and animals. Without decay, all usable food material would eventually be rendered unavailable for further growth of plants and animals, so that life on the earth would cease. The earth's supply of food materials would be locked up in organized plant and animal bodies.

155. Relation to agriculture and gardening. It has long been known that the introduction of decayed and decaying organic matter into soils enables them to sustain a more luxuriant vegetation. Undecayed organic matter is not available for those plants which we usually desire to grow. Such material must await more complete disorganization before it can be useful. It is desirable to regulate decay so that the largest possible amount of its products may be retained in the soil. This is one of the problems of scientific agriculture. For example, if stable manure in large masses is allowed to "heat" under the rapid destructive action of the bacteria and other living things which flourish in it, much valuable ammonia is given off into the atmosphere and lost. Slower decay, especially if underground, wastes but little ammonia. The bacteria are of great importance to agriculture and gardening in other ways, but these are considered in the chapters Further Discussion of Dependent Plants and Further Discussion of Plant Industries.

156. Relation to other industries. It is impossible to do more in this connection than to suggest a few of the industries in which bacterial processes have an important part. The number and extent of the changes, physical, chemical, or both, that always occur when bacteria grow, suggest the immense industrial field that lies before the student of bacteriology; for bacteria may, under favorable circumstances, grow upon almost any organic substance. In this immense field there is as yet but a small amount of positive knowledge. There are, however, a few cases in which some of the facts are known. From general knowledge and from what has already been said, it is evident that all our fruits, vegetables, meats, etc., are at times in danger of destruction by bacteria or other organisms. How to prevent this destruction has been one of the important problems since civilization began. Surplus production of food is useless unless some of it may be kept for future needs. If men could not preserve foods, they could live only in regions where there is perpetual food production, or they must constantly migrate into regions where food might be had.

In *preservation of fruits* much progress has been made by improvements in methods of gathering them. Most fruits have a natural covering, which, if unbroken or unbruised, and kept clean, will for a long time prevent the entrance of organisms of decay. If two sets of ripe apples are gathered, one carelessly so that bruising and scratching of the surface occurs, the other with sufficient care to avoid these things, and both are placed upon a shelf in the schoolroom, an interesting demonstration will be made of the desirability of care and cleanliness.

Low temperature and drying were found to prevent decay long before it was known how decay is produced. Refrigeration has now become a leading method of preventing decay, since bacteria do not thrive at or below the freezing temperature.

Foods are thereby kept for years, and shipped all over the earth. Drying is proportionately less used than formerly, since this process causes most foods to lose some desirable qualities. Destructive organisms cannot thrive upon thoroughly dry food. Dried fruits, dried meats, and dried grains (a natural process of preservation) may be kept for years. Preservation in salt and sugar or their strong solutions serves the same purpose as drying, since salt and sugar have such avidity for water that destructive organisms have their protoplasmic water extracted and therefore cannot grow. Fish, beef, pork, and other meats may be preserved by thoroughly smoking with wood smoke. The creosote that is carried into the meat by this process helps to prevent the growth of destructive organisms. This method of preservation, though thoroughly wholesome, requires long exposure to the smoke. It is not so extensively used for beef and pork as formerly, though large quantities of fish are still preserved in this manner.

Sterilization and canning have recently offered very great opportunities for food preservation and shipment. By means of heat properly applied all bacteria and other organisms of decay may be killed. If such thoroughly sterilized food is hermetically sealed in vessels that have been similarly sterilized, it will not decay. It is difficult, but entirely possible, to sterilize thoroughly both food and sealing appliances so that absolutely no organism will grow.[1] Other methods of preservation by introduction of chemicals that prevent growth of bacteria are sometimes used. These chemical preventives are poisons. If eaten by men in very small quantities, injurious results are not immediately noticeable, but their use is attended by constant danger. Milk, meats, and confections that are so preserved should always be avoided.

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[1] Sometimes in canned goods, stale meats, and other foods, poisonous *ptomaines* are formed. They are probably secretions from bacteria, results of chemical change or decay of such foods as meats and fruits, or originate from the disorganization of bacteria. For means of prevention, see "Care of Food in the Home," *Farmers' Bulletin 375*, U. S. Dept. Agr., 1909.

The relation of bacteria to *milk and water supply* is a subject of great importance. A rather large number of harmless bacteria may often be found in reasonably pure milk and water; but careless handling of bottles and cans, or the use of tuberculous cows, may result in widespread disease, and has been known to cause epidemics of tonsilitis, scarlet fever, and typhoid fever. If milking is done through absorbent cotton or several layers of cheesecloth, used as a cover for the milk pail, most of the impurities are caught therein. Milk pails and shipping cans should always be sterilized before they are used. Milkmen who otherwise were fairly careful in their work have been known to rinse their pails and cans in polluted wells or streams. Bacteria of various diseases have thus been distributed. Either milk or water may be sterilized by boiling, and may be kept so if placed in sterile vessels. Both, however, are better if they can be secured and kept in a pure condition without it. An efficient method of preserving milk is by Pasteurization,[1] in which the vessels containing the milk are placed in water and brought to a temperature of 150° to 155° F., and then cooled and kept cool until used. This method kills most of the bacteria in milk and makes less change otherwise than does boiling.[2]

The formation of acetic acid (the acid of vinegar) is due to the growth of several kinds of bacteria. Part or all of the processes of curing tobacco, tanning of leather, preparation of plant fibers as flax and hemp, butter and cheese making, and many other important industries depend upon the growth processes of different kinds of bacteria.

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[1] "Directions for the Home Pasteurization of Milk," *Circular 152*, Bureau of Animal Industry, U. S. Dept. Agr., 1909.

[2] "Care of Milk on the Farm," *Farmers' Bulletin 63*, U. S. Dept. Agr., 1906.

"Bacteria in Milk," *Farmers' Bulletin 348*, U. S. Dept. Agr., 1909.

"Sources of Bacteria in Milk," *Bulletin 51*, Storrs Agr. Ex. Sta., Storrs, Conn., 1908.

"Milk and its Products as Carriers of Tuberculosis Infection," *Bulletin 143*, Bureau of Animal Industry, U. S. Dept. Agr., 1909.

157. Relation to diseases of plants and animals. Growth of bacteria within other plants and in animals often results in disease of the host organism. Types of plant diseases that are caused by bacteria are the crown galls produced upon roots of apples, peaches, and pears; also cucumber wilt, and soft rot of cabbage. Many diseases of animals are caused by bacteria, as hog cholera, tuberculosis of cattle, and anthrax or splenic fever. It was in connection with the study of animal diseases that the causal relation of bacteria was first conclusively proved. Bacteria were discovered almost two hundred years before it was proved that they cause diseases. Indeed, a good deal was known about the nature of these diseases before it was known that they *are* caused by bacteria. Means were finally devised for isolating and growing alone many kinds of bacteria, and then by the introduction of certain kinds into susceptible animals definite kinds of disease resulted.

Very brief reference to two kinds of bacterial disease will afford illustrations of some effects produced upon plants and animals by disease-producing bacteria. In the case of black rot of cabbage the bacteria enter the cabbage leaf through the leaf pores. Once within the leaf, they grow rapidly, and brown or black spots appear on the leaf as outward evidence of the inward ravages of the bacteria. These leaves may become shriveled. The disease may spread throughout the plant and result in destruction of the entire head of cabbage. The organisms of decay may follow the bacteria which produce the disease.

In the disease known as anthrax, already referred to in Sect. 152, when active anthrax bacteria or their spores are introduced into the alimentary tract of cattle or sheep, they find their way into blood vessels, where they grow with surprising rapidity. In most cases the death of the host animal occurs within a few hours to a few days from the time of infection. If the dead body decays in an exposed place, the anthrax bacteria or their spores may soon become a means of new infection and the death of other animals.

158. Relation to diseases of man. In the section on nutrition of the bacteria (Sect. 153) attention was directed to the fact that excretions are regularly produced by them. In case of disease-producing forms some of these excretions are injurious or poisonous, and are known as *toxins.* In susceptible plants or animals toxins may produce disease. Each kind of disease-producing bacteria forms its own peculiar toxin or toxins, which in time produce particular kinds of disease. Substances that neutralize toxins or their effects are known as *antitoxins.* The diseased organism tends to manufacture these "anti-bodies," or antitoxins, which, when formed in sufficient quantities, counteract the influence of the toxins. In some cases (smallpox, diphtheria), when one has had a disease and has produced sufficient antitoxin to enable him to overcome the attack, he is usually not again susceptible to this particular disease. He is *immune.* Some people are naturally immune to certain diseases. There are diseases (such as mumps, measles, scarlet fever, diphtheria, smallpox) against which most people may acquire immunity by once surviving an attack. This immunity is usually lifelong, though exceptions are known. In the case of other diseases (typhoid, influenza), one is soon susceptible to another attack.

Smallpox vaccination[1] consists in infecting human beings with bacteria that have been grown in such unfavorable ways that their ability to produce the disease is greatly reduced. Consequently the result of vaccination is to cause a very mild attack, which, however, is strong enough to produce immunity against fully virulent smallpox. This lasts for a period of years (usually given as seven years), though the protective effect gradually diminishes.

In the case of diphtheria it has been found possible to secure from horses and mules an antitoxin that will counteract diphtheria toxins in the human body. These animals are naturally immune to diphtheria, but by injecting into their bodies toxins produced in beef broth by diphtheria bacteria, this natural

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[1] The specific bacteria which produce smallpox have not been identified.

immunity is greatly increased. First into the animal's body there is injected a small amount of toxin. This process is repeated, with an increasing amount, at intervals of a week or a little less, for a period of two or three months. The animal finally withstands, with no ill consequences, an amount of toxin that would have proved fatal if used at first. At this time some of the blood is drawn off, allowed to clot, and the antitoxic serum is sterilized. After its relative strength is determined, it is sealed in small bottles and is ready for distribution. A human being who has diphtheria may then be given the proper amount of antitoxin. If it is properly given, and given early enough, the attack is defeated.[1]

Great benefits have come to the human race through the discovery of diphtheria antitoxin. It was generally introduced in 1894. A study of the following table, containing data for ten years before and ten years after the introduction of antitoxin, will give an idea of the value of this scientific discovery.

AVERAGE ANNUAL DEATH RATE FROM DIPHTHERIA PER 10,000 POPULATION[2]

	Before Use of Antitoxin (1885–1894)	Antitoxin Period (1895–1904)
Paris	6.41	1.49
Berlin	9.93	2.95
Vienna	8.14	2.95
London	4.85	3.88
New York	15.19	6.62
Boston	11.76	6.34
Baltimore	7.34	4.99
Chicago[3]	14.29	5.13

An estimate of the number of lives saved annually in New York and Chicago will further illustrate the benefits from the use of antitoxin.

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[1] Certain disastrous cases where impure antitoxin was used, resulting in infecting patients with other disease germs, are inexcusable. These cases, however, should not lead people to decline to use antitoxin.

[2] Jordan, E. O., General Bacteriology, 1908.

[3] Use of antitoxin begun in 1895–1896; drop from 12.01 (1895) to 7.62 (1896).

159. Watercourses as means of distribution of bacteria of disease. As may be expected, water courses are means of distribution of some kinds of bacteria. To what extent this is true for all kinds is not known, but in case of the typhoid bacteria there has been much conclusive investigation. The following illustration is one of a number that might be cited. The southern part of New Hampshire and the northern part of Massachusetts are drained by the Merrimac River. In the region thus drained are many industrial cities and towns. In 1890–1891 there occurred in this region a great epidemic of typhoid fever. The water of the Merrimac River and its tributaries was the means of carrying away the sewage for the entire region, and the cities of Lowell and Lawrence, which took their water supply from this river, took sewage-polluted water. The cities of Concord, Nashua, and Haverhill did not get their water from the Merrimac. The epidemic began in Lowell, and this was soon followed by a more severe epidemic in the city of Lawrence, situated downstream from Lowell. There is a small stream, Stony Brook, which flows through a suburb of Lowell and empties into the Merrimac three miles above the point at which the Lowell water supply was taken. The first cases of typhoid were along Stony Brook, and these cases polluted the water, thus in turn polluting the supply for the main part of Lowell. Furthermore, the Lowell sewers entered the Merrimac nine miles above the water intake for Lawrence, and thus polluted the water supply so that typhoid fever was well distributed throughout those parts of Lawrence where this water was used.

The other cities in this same valley had very little typhoid fever, while Lowell and Lawrence suffered many deaths, reaching in twelve months (1890) 187 per 10,000 population in Lawrence and 195.4 per 10,000 population in Lowell. There are many such cases showing the effect of typhoid-polluted water.

160. Tuberculosis: the great white plague. The disease commonly known as tuberculosis is so generally distributed and so destructive that it has been called "the great white plague." Its universal importance demands that a separate paragraph be given to a brief statement concerning it. It is the most destructive disease that affects the human race, and in the United States it causes about one ninth of all deaths. It costs the United States many hundreds of thousands of dollars annually, and, if a money estimate could be placed upon the many untoward circumstances that accompany and follow tuberculosis, the sum would be appalling.

The tubercle bacilli may infect almost every part of the human body. Though the lungs are the regions most frequently attacked, the bones and joints, the intestines, the throat, skin, and other organs often are the regions of growth of these bacilli.

The growth of tubercle bacilli in the body is usually very slow, and months or years may pass before conspicuous consequences follow infection. Furthermore, the germs may live upon a handkerchief, in the floor of a house, in a public building, in public transportation vehicles, in the dirt of the street, etc., for a very long time, and then grow when they are introduced into the human body. Some of the lower animals (cattle, hogs, poultry, etc.) are subject to tuberculosis, and while there seems to be some doubt whether it is of exactly the same kind as tuberculosis of human beings, the dangers are such that careful disposition should be made of all tuberculous animals.

The usual source of infection is through the organs of breathing, though the germs may be carried into the mouth and other organs by means of milk and other food. Since the dried or partially dried tubercle bacilli may be transported by the air, it is evident that the greatest precaution should be taken to keep the air from becoming contaminated with these germs. Furthermore, it is known that when tubercle bacilli are moist, the direct light of the sun has a destructive effect upon them, and that fresh air is likely to contain fewer tubercle bacilli than the "close" air of rooms in which many people have been. Plenty of fresh air, sunshine, and wholesome food are most important factors in preventing attacks of tuberculosis, and these, together with good general vitality of the body, are one's best guaranty against this disease. On the other hand, poor food, bad air, dark rooms, and low vitality render the body a favorable growing place for these disease germs when once they are introduced. These predisposing factors are of tremendous importance in relation to tuberculosis, and too much emphasis cannot be given them. The nature of the occupation and habits of men have much to do with predisposing and exposing them to tuberculosis. This was proved by an Englishman named Newsholme, in 1898, when by means of records he showed that for each 100 agriculturists who died from tuberculosis and other respiratory diseases, there were 453 potters and earthenware workers, 407 cutters, 373 plumbers, and 335 glassmakers who died from these same diseases. At a time when so much is known about how to prevent tuberculosis it seems a needless waste of human life to allow so many people to become affected by it.

161. Prevention of disease. Bacteria are distributed into almost every nook and corner of the earth, — in soil, air, water, dust, and upon and within the bodies of plants and animals. Disease-producing bacteria are common, though less abundantly distributed than forms which do not cause disease. A good deal is known regarding the methods of distribution and infection of the most dangerous disease-producing forms, though our knowledge is by no means complete. Polluted water and milk have often been the means of wholesale distribution of typhoid germs (Fig. 151). The house fly is one of the most dangerous agents of distribution of typhoid and probably of other disease bacteria. The atmosphere is an efficient means of carrying bacteria of tuberculosis. They must, however, be dry in order that they may be thus carried. Every possible effort should be made to remove the breeding places of flies (refuse from stables, exposed and decaying sewage, etc.) and to keep them out of public and private dwelling places; to insure a pure and well-kept supply of milk and water; to keep vegetables and other foods that are handled in public places free from dust and flies and promiscuous fingering; thoroughly to disinfect all known or suspected

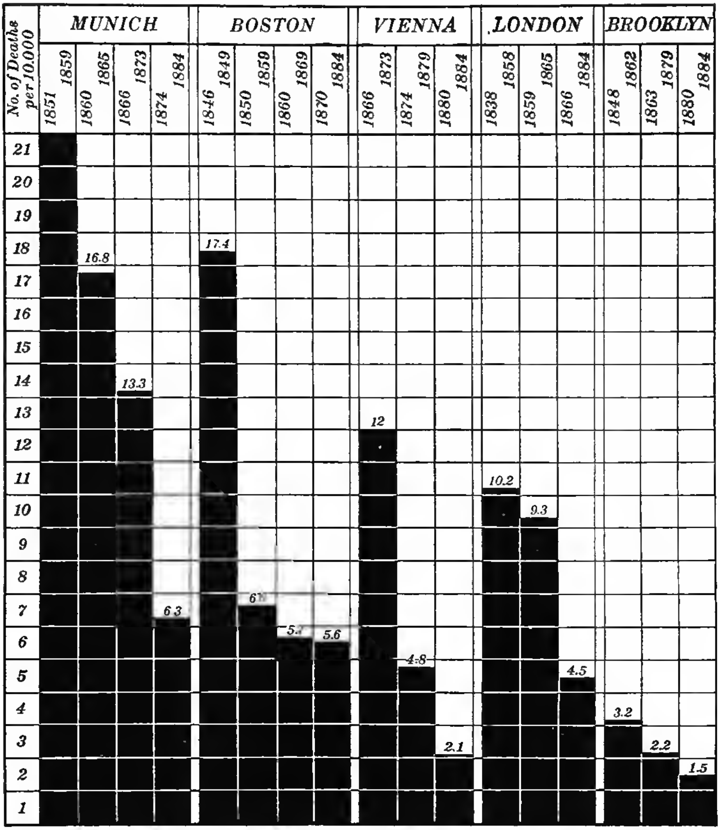

FIG. 151. A chart illustrating the number of deaths from typhoid fever before, during, and after the introduction of improved systems of sewage disposal and water supply

Five prominent cities of the world are selected. The figures indicate the number of deaths per each 10,000 inhabitants. Rearranged from a chart in Abbott's Hygiene of Transmissible Diseases disease-bearing materials of all kinds;[1] to have large quantities of fresh air; to have all the sunshine possible, for sunshine is destructive of many disease germs.[2]

It is of great importance also that a high standard of vigor be maintained as a means of preventing bacterial disease. Many people have had disease-producing bacteria introduced into their bodies without any serious consequences, indeed without even being conscious of danger. Their bodies were in such vigorous condition that the initial growth of bacteria was prevented. An instructive experiment relative to this point was performed by Pasteur. Ordinary domesticated fowls are not readily susceptible to anthrax. Pasteur found, however, that if he kept the fowls at lower temperatures than was normal for them, they were very susceptible to anthrax and that under such circumstances it proved deadly to them. This is a common principle in hygiene. When through excessive fatigue, loss of proper sleep or nourishment, or for any other reason, bodily vigor is greatly reduced, susceptibility to disease is increased.

Modern bacteriology has offered the human race the means of escape from many diseases. Ignorance, lack of care, and financial greed are often the only excuses that can be offered when certain diseases occur. If only those who are responsible for them might be attacked by these preventable diseases, the matter would not be so serious, for in that case disease and the resulting deaths would tend to eliminate those who do not act upon the knowledge of sanitation which we now

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[1] In Bacteria, Yeasts, and Molds in the Home, by H. W. Conn (Ginn and Company), there is an excellent popular discussion of the nature of bacteria and the effects of their growth.

[2] In Germany it is unlawful for filtered water to contain more than 100 bacteria per cubic centimeter, and it should always contain less. Boston has a legal standard which requires that market milk shall not contain more than 500,000 bacteria per cubic centimeter; and Rochester, New York, and Milwaukee, Wisconsin, have legal standards of 250,000 per cubic centimeter. Some kinds of certified milk may contain less than 10,000 bacteria per cubic centimeter. On the other hand, in impure milk the number may run from several hundreds of thousands to several millions.

possess. This, however, is a public matter, and innocent people must now suffer from the lack of precaution of others.[1]

162. Classification. The thallophytes are divided into the fission plants (schizophytes), the algæ, and the fungi. The fission plants are divided into the bacteria (schizomycetes) and the blue-green algæ (schizophyceæ or cyanophyceæ). Formerly the bacteria were included with the fungi, and the blue-green algæ with the algæ, but resemblances in structure and methods of reproduction are such that the two groups are now classed together as the schizophytes. The name means "splitting plants," or "fission plants," and refers to the formation of new individuals by the division of the old ones. Likewise the technical name of the bacteria, schizomycetes, means "splitting fungi," or "fission fungi," and that of the blue-green algæ, schizophyceæ, means "splitting algæ," or "fission algæ."

The classification of the bacteria and the blue-green algæ is as follows:

- Plant Kingdom
  - Thallophytes
    - Schizophytes
      - *Class I.* Schizomycetes (bacteria)
      - *Class II.* Schizophyceæ or Cyanophyceæ (blue-green algæ)

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[1] Why are some public drinking places so arranged that one must drink from running water? Why do some states have a law prohibiting railway trains from carrying public drinking cups? What is the nature of the water supply and care of the drinking water for your school?

CHAPTER XII

THE BLUE-GREEN ALGÆ (CYANOPHYCEÆ)

163. Introductory. The life habits, size, and structure of the blue-green algæ are such that we can obtain the best notion of the whole group by selecting for discussion a few representative plants. "Representative plants" cannot fully represent this or any other group, any more than three or four selected students would adequately represent an entire school. However, in an elementary textbook it is not advisable to present a large number of plants from each group.

164. Where found. The blue-green algæ are found in pools of stagnant water, along shores of streams, lakes, and oceans, in places where the water contains considerable organic matter. They may appear as coatings to sticks, stones, etc., as floating pieces of dirty, bluish-green material, or as small masses free-floating or attached and held together in jelly-like balls. Usually they may be readily distinguished from other algæ by the distinct bluish-green color.

165. *Glœocapsa:* structure and nutrition. In stagnant water such as is found in old pools, horse tracks in open fields, and sometimes in aquarium jars in the laboratory, the plant known as *Glœocapsa* may appear as bluish-green fragments floating or adhering to the sides or bottom of whatever may contain the water in which it is growing. These fragments are made up of a great many plants, each one so small that when alone it cannot be seen without magnification. The appearance of the masses of many plants may be thus determined, but that of a single plant can be determined only by the aid of a compound microscope.[1] A single plant when separated from the

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[1] In the first studies of the single-celled algæ it is often better to use a good specimen under a compound microscope as a demonstration than to

others (Fig. 152) is spherical in its general form. It has a well-defined wall, the *cell wall*, inside of which is the living substance of the plant, the *protoplasm*. Although in higher plants the protoplasm is clearly divided into different parts, — *cytoplasm*, *nucleus*, and *chloroplasts* (Sect. 8), — in *Glœocapsa* these different parts are not evident. The protoplasm of *Glœocapsa* is granular, and there is a blue-green stain distributed throughout it. It is only when these plants are massed together that the characteristic blue-green color is seen. In a single plant this coloring matter is present in such small quantities that when observed under a microscope the color is not easily detected.

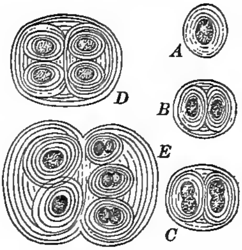

FIG. 152. *Glœocapsa*, one of the simplest of the blue-green algæ. Magnified 300 times

A–E, successive changes in the development of new individuals from a parent cell

The living protoplasm builds the wall that surrounds the inner part of the cell, but the wall itself is not alive. Some of the water in which *Glœocapsa* lives is absorbed by the wall, which causes the older outer parts to swell, thus producing layers of jelly-like material around the protoplasm and the inner cell wall. Also through the wall the food material is absorbed. Even with the small amount of chlorophyll and blue pigment present in one of these plants photosynthesis (Sect. 17) can be carried on. Since the plant lives in stagnant water, in which there is much decaying organic matter, it is not impossible that it may absorb and use directly as food some of these decaying organized foods. In times of drought these plants may become dry, although, being protected by means of the heavy gelatinous covering, they dry very slowly, and when favorable conditions again come they may continue to grow.

have the student attempt to find a good specimen without any notion as to what single-celled plants are. Individual studies will then be more intelligible and more successful.

166. *Glœocapsa:* reproduction. After a *Glœocapsa* plant has been growing for a time it may divide into two new plants. The wall divides, completing the separation of the protoplasm into two cells and thus two new plants are formed (Fig. 152). The separation of the protoplasm really begins before the walls push inward, but this protoplasmic division cannot readily be observed. The new plants, before they become free from the mass of jelly inclosing them, may again reproduce themselves, so that four, eight, or even a much larger number may be united in one colony. In such cases the plants are held together so very closely that they often do not assume the spherical form.

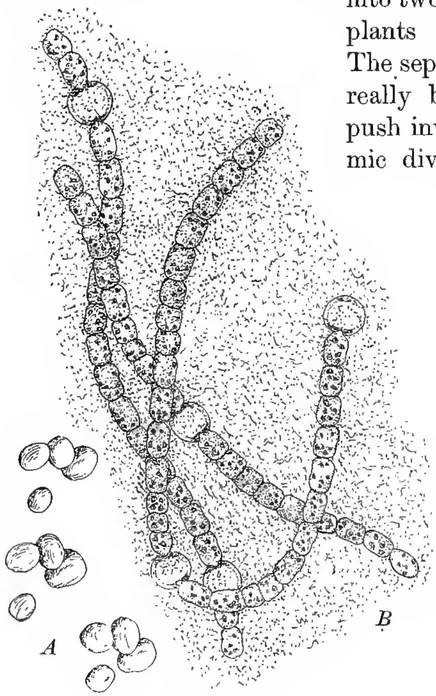

FIG. 153. *Nostoc*

At the left (*A*) are several of the *Nostoc* balls, which appear as glistening, rounded masses (natural size). At the right (*B*), inclosed in gelatinous material, are a few chains of *Nostoc* plants which have been taken from one of the balls and greatly magnified. In the chains several of the enlarged heterocysts may be seen

Each new *Glœocapsa* plant is essentially the kind that its parent was before the division occurred. In fact the parent plant by division becomes directly two new individuals. This method of reproduction by division or fission (splitting) is the simplest known in the plant kingdom, and is characteristic of the simplest animals as well as of the simplest plants.

167. *Nostoc:* structure and nutrition. In regions such as those mentioned as the living place of *Glœocapsa*, and also upon damp soil or floating upon standing water, there may be found the jelly-like balls of *Nostoc.* Instead of the rather ragged fragments of the *Glœocapsa* masses, *Nostoc* usually is found in irregularly rounded compact balls (Fig. 153, *A*), which have a dark bluish-green color. The ball is a colony of plants, but when it is taken in the fingers no evidence of the existence of single plants can be obtained.

Under magnification the ball is seen to be composed of granular jelly, through which are interwoven thousands of chains of cells, each of which is a *Nostoc* plant. Usually two kinds of cell are found in the chain, one or more larger ones called *heterocysts* (which simply means "different cells"), and ordinary cells (Fig. 153, *B*), each one resembling a *Glœocapsa* plant. These ordinary cells of *Nostoc* manifest an evident difference from those of *Glœocapsa;* the jelly-like mass about *Nostoc* plants is not in layers about each cell, as is true in *Glœocapsa.* The cells are loosely held together in chains by attachments of their walls, thus making a slightly more complex plant than *Glœocapsa.*

In nutrition, *Nostoc* may absorb directly through the cell walls the materials that are needed for photosynthesis, or it may, perhaps, absorb organized foods, since much food of this kind is in the water in which the plants live. Since the jelly mass is often quite large, obviously there must be absorbed through the outer part of the *Nostoc* ball the food needed not only for the outermost plants but also for those that are more deeply situated.

In times of drought the gelatinous nature of the *Nostoc* balls results in extremely slow drying, though if the drought be long-continued the whole ball may become so dry as to crumble between the fingers. Even when as dry as this, not all of the plants are killed, and a large number of them proceed to grow when furnished the needed moisture. This covering of jelly and the consequent slow drying seems to be of the greatest importance in the life of both *Nostoc* and *Glœocapsa.*

168. *Nostoc:* reproduction. If a single *Nostoc* cell is separated within the mass from the chain in which it has grown, it soon divides in essentially the same way as does the *Glœocapsa* plant; but in the case of *Nostoc*, the new cells thus formed are likely to remain together, and will redivide in the same direction as did the cell at first, and thus form a new chain. *Nostoc* is not, however, usually reproduced by one cell's becoming free and behaving as just described. Divisions of the cells do occur as stated, sometimes all or nearly all of the cells of a chain dividing at the same time. This, if continued, would soon produce a plant of great length, — a result which does sometimes occur. Usually, however, in one or more cells of the chain the protoplasm dies and the cell wall greatly enlarges, thus producing a heterocyst. This heterocyst apparently weakens the connection between the adjoining cells, and the chain separates at this point, the heterocyst usually adhering to one of the new chains (Fig. 153, *B*). The presence of two or more heterocysts may result in breaking the chain of cells into three or more new *Nostoc* chains at the same time. This kind of reproduction resembles that which was seen in *Glœocapsa*, in as much as the cells divide to reproduce the plant. It differs in the fact that new plant chains are formed by an additional reproductive structure, the heterocyst.

169. *Oscillatoria:* structure and nutrition. In the same kind of regions in which *Glœocapsa* and *Nostoc* are found, but more abundant and more widely distributed, is the plant *Oscillatoria*. *Oscillatoria* filaments grow together, sometimes forming mats of a dark green, dirty-looking growth. At times when a few plants are seen growing free from others, they present a beautiful clear green growth in which very little bluish coloring matter can be detected. The mats, though often slimy, are not covered by the masses of gelatinous substance that are seen in the two preceding forms.

Some of the *Oscillatoria* plants are so large that if placed in a dish of water they may be studied in a general way without magnification. They are thread-like plants, the length of each individual greatly exceeding its thickness. Some of them perform a peculiar swinging or oscillating movement, from which the generic name *Oscillatoria* is taken. They may, however, move forward as well as sidewise.

Under a compound microscope *Oscillatoria* is seen to consist of a great many cells held very closely together in a common tubular sheath (Fig. 154). If free from the sheath, one of the cells assumes the spherical form. But normally the cells are compressed so closely in the sheath that the separate walls appear as one common wall. A plant therefore consists of many of these cells held together in a common wall. It may grow in length by having the cells divide, which they regularly do.

As compared with *Glœocapsa* and *Nostoc*, *Oscillatoria* contains a great deal of chlorophyll, which may be much or little obscured by blue coloring matter. It lives in water, often at the outlets of sewers and drains, or upon damp surfaces, from which it absorbs the needed materials for the construction of foods. It grows vigorously, being able to thrive throughout a wide range of temperature and other climatic conditions.

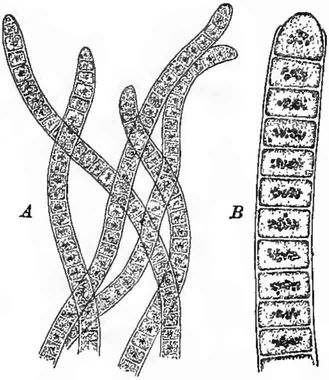

FIG. 154. *Oscillatoria*

A, tips of several plants; *B*, part of one plant enlarged to show cellular structure. Both magnified, *B* much more than *A*

170. *Oscillatoria*: reproduction. Division of cells in this plant does not necessarily mean reproduction of the individual, but may signify merely its growth. A single *Oscillatoria* cell may, if free, grow until it has reproduced a plant similar to the one from which it came. This is not, however, its usual method of reproduction. In a long specimen usually one or more cells die, thus weakening the sheath that holds the cells together. This allows the plants to break at these points, and each piece that is set free is a new plant and may continue to grow until it assumes the proportions of the old one. This is essentially the same kind of reproduction that is seen in *Nostoc*, except that here, instead of having a heterocyst, the dead cell does not become enlarged. *Oscillatoria* plants may also break at any point to produce new individuals.

171. General characteristics of the blue-green algæ. In addition to the types of blue-green algæ that have been discussed, many other kinds are abundant. They are found in the same kinds of regions as those that have been presented in the preceding paragraphs. Members of this group have the characteristic *blue-green color*, with this color pretty *evenly distributed* throughout the interior of the cells. The blue-green algæ are *extremely simple in structure*, being one-celled plants (as *Glœocapsa*), or plants made up of cells arranged in rows so as to form simple chains (as *Nostoc*), or filaments (as *Oscillatoria*). Some of the members of the group are more complex than *Oscillatoria*, as *Glœotrichia* and *Rivularia*, which are commonly found as small, glistening, jelly-like balls attached to sticks and to the stems of other plants. They are usually found in shallow fresh-water lakes, or sometimes free-floating. The entire group consists of plants that are relatively simple in form and structure. The cells are simple, and definitely organized chloroplasts are not present. Nuclei of the kind known in the other algæ and in the higher plants have not been demonstrated in this group, although fragments that resemble the nuclei of higher plants have been found.

Most of the members of the group have a jelly-like covering, and in many forms this holds the plants together in colonies. This covering seems to be of advantage to the plants during periods of drought by regulating the rate of drying.

The *water or moist habitat* and the simplicity of structure suggest the simple way of securing *food material*, namely by absorbing it directly through any part of the wall of the plant. By means of chlorophyll, members of this group may manufacture foods through the process known as photosynthesis.

New plants are established by the blue-green algæ in the simplest ways that are possible. *Reproduction* takes place by means of *fission* of the single-celled forms, or by the *breaking* into two or more parts of the chains or filaments of the less simple forms. Sometimes in certain species of *Nostoc* reproduction is said to occur by means of a special heavy-walled cell which, after lying quiet for a time, may grow into a new plant.

The growing plant is often spoken of as the vegetative plant, and when reproduction occurs as it does in the blue-green algæ, by division to produce new plants, the process is known as *vegetative reproduction.* Such reproduction is characteristic of the blue-green algæ.

The blue-green algæ have a very wide *distribution.* They are found in both fresh and salt waters, in warm and cool temperatures, and at high and low altitudes. They thrive in water, and also upon land, provided they have a supply of moisture. Many of them are most luxuriant near the mouths of sewers, in case light and temperature conditions are favorable. In regions where moisture is intermittent they thrive part of the year and are dormant the rest of the time. Often they grow in such numbers as to tinge the water with green, or whatever other color the plant may have. Fresh-water lakes are often distinctly green from the growth of *Rivularia*, *Glœotrichia*, and other forms. The Red Sea owes its hue to the abundant growth of a reddish-brown member of this group. The margins of some of the pools about geysers and lakes in the Yellowstone National Park, and shores of lakes and streams, are often so colored.

172. Classification of the Fission Plants (Schizophytes):

Thallophytes
  Schizophytes
    Class I. Schizomycetes (bacteria)
      Illustrated by numerous type forms and various methods of living
    Class II. Schizophyceæ, or Cyanophyceæ (the blue-green algæ)
      Leading genera used as illustrations, — *Glœocapsa, Nostoc, Oscillatoria*

CHAPTER XIII

THE GREEN ALGÆ (CHLOROPHYCEÆ) AND OTHER ALGÆ

173. General considerations. The green algæ are found in almost all inland waters, floating freely upon the surface, lying in heavy mats near or below the surface, forming masses upon the bottom, and often attached to various solid substances in the water. A few are marine in habit. They are widely and abundantly distributed and may be found by any observing student. Not infrequently they are spoken of as "pond scums," "water mosses," and "seaweeds."

Usually it is easy to distinguish green algæ from most other algæ by the fact that in members of this group the chlorophyll is not obscured by any other coloring matter. Various shades of green are presented in different plants, and indeed in the same kinds of plants at different growth periods, but the color is not readily confused with that of the other groups.

174. *Pleurococcus*: structure and habitat. This green alga grows in great abundance upon the partially shaded portions of trees, fences, rocks, and old buildings, and when moist it presents the appearance of a coating of green paint. Sometimes it is called "green slime." It adheres so closely to the object upon which it grows that few people recognize it as a plant. It is one of the most widely distributed of all plants.

When examined under suitable magnification it is seen that the green slime is composed of thousands of single-celled plants, each so small that as a separated individual it is not visible to the ordinary observer (Fig. 155). A careful measurement of a number of plants showed their average diameter to be about $\frac{1}{2000}$ of an inch (.014 mm.). In other words, if a row of these plants side by side should be arranged across the unsharpened end of an ordinary lead pencil, approximately 500 plants would be required to complete the row. How many would be required to occupy one cubic inch?

Each plant is somewhat spherical and has a well-defined cell wall. Within this wall is the protoplasm, which is colored green by the chlorophyll. The chlorophyll is usually confined to a special part of the protoplasm, this part being called the *chloroplast*, which means "a body which bears chlorophyll." Often it is not possible to distinguish the chloroplasts in *Pleurococcus*, the chlorophyll appearing to be evenly distributed throughout the plant. The *nucleus* is another special part of the protoplasm. It is a mass of protoplasm denser than the other portions, usually lies near the center of the cell, and is a structure of great importance in the activities of the plant.

When chloroplasts are evident it is possible also to see about them a thin, almost colorless, protoplasmic substance, the *cytoplasm.* A single *Pleurococcus* plant, therefore, consists of the cell wall and the protoplasm that is contained by this wall. The protoplasm may be divided into chloroplasts, cytoplasm, and nucleus. In some cases, also, there may be seen vacuoles, which are regions within the cell surrounded by cytoplasm but containing air or cell sap.

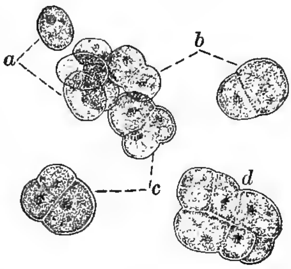

FIG. 155. Green slime (*Pleurococcus*)

a, single plants showing cell wall, granular cytoplasm, and nucleus; *b*, plants in process of reproduction by division or fission; *c* and *d*, further divisions sometimes resulting in formation of colonies of plants. Greatly enlarged

175. *Pleurococcus:* nutrition. The protoplasm of this plant contains chlorophyll, and if carbon dioxide and water are obtainable it can carry on photosynthesis. Carbon dioxide may be secured from the air. The bark, or other support upon which the plants grow, is often sufficiently moist to enable *Pleurococcus* to obtain water from it. Rains and heavy dew supply water more or less intermittently. Possibly water may be absorbed directly from a moist atmosphere. If dry bark with *Pleurococcus* on its surface is placed within a moist bell jar, the plants soon become bright green, thus indicating that they are at work.

Heat, cold, and the extreme drought either of summer or of winter are some of the great extremes which this plant must undergo in order to live. Exposed as it is, it nevertheless is able to pass through such periods and grow luxuriantly within a short time after the return of favorable conditions. If in zero weather *Pleurococcus* is brought into the laboratory and moistened, within a few hours it begins to grow.

176. *Pleurococcus:* reproduction. *Pleurococcus* cells divide, thus forming new plants directly, as has been seen to occur in *Glœocapsa.* This vegetative reproduction in favorable weather results in a rapid multiplication of the plants. Divisions follow one another in such a way that whole colonies, the descendants of one individual, are often found grouped together (Fig. 155).

Sometimes, in near relatives of *Pleurococcus* that live in the water, another kind of reproduction occurs. Within the cell wall the protoplasm divides so as to form several (eight, sixteen, or thirty-two) small bodies. Each of these has a nucleus and cytoplasm which are obscured by chlorophyll, an extremely thin cell wall, and two small hair-like extensions, the *cilia* (singular, *cilium*). After a time the old plant wall breaks, and these bodies, by means of the active cilia, begin to swim about in the water. Soon they become quiet, the cilia are lost or are withdrawn into the main body of the cell, and the cell begins to grow and develop into a new plant like the one that formed it. Thereafter it may reproduce itself vegetatively or by the process just described.

These cells that are specially made for the work of reproduction are called *spores.* In the study of other kinds of plants we shall find several kinds of spores; and while they may differ in the ways in which they are formed, they are alike in that all may reproduce the kinds of plants that form them.

Spores that have special structures by means of which they swim are called *zoöspores*, meaning "animal spores," or "moving spores." They were thus named when it was supposed that self-caused movement is a distinguishing feature of animals.

Plants which have swimming spores have means of more ready distribution than do those that reproduce entirely by means of fission.

177. *Spirogyra:* its habitat and structure. The algæ commonly spoken of as "pond scums" are found in standing water, often floating upon its surface. One of the most abundant of these is *Spirogyra*. Within the water, it appears as long threads of a clear green color, at times attached by one end to some support; when floating upon the surface of the water, it commonly appears in yellowish-green mats in which are many bubbles of gas or air. It is soft like silk, and may thus be distinguished from most other algæ likely to be found in similar places.

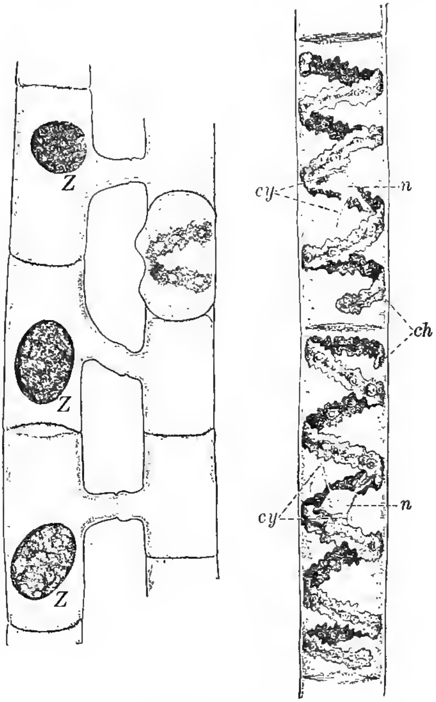

FIG. 156. *Spirogyra*

ch, the spirally arranged chloroplast; *n*, the nucleus which is supported by the bands of cytoplasm (*cy*); cytoplasm also appears just within the cell wall. The central cavity of the cell is usually occupied by one or more large vacuoles. At the right are two cells of one plant. At the left are parts of two plants whose cells have conjugated to form zygospores (*Z*). Greatly enlarged

When magnified, the cells that compose *Spirogyra* are seen to be very large as compared with those of any alga yet studied. They are joined end to end, thus forming the filamentous plant. Each cell has a cylindrical cell wall which contains one or more peculiar spirally arranged chloroplasts, each of which extends almost or quite the entire length of the cell (Fig. 156). Different species of *Spirogyra* may have different numbers of chloroplasts in each cell, and this is one of the ways of distinguishing the species from one another. If the chloroplast were uncoiled, it would be like a ribbon with the edges more or less indented. A layer of cytoplasm lies just within the wall, and the cytoplasmic threads run from all sides to the nucleus, which the cytoplasm surrounds. Much of the interior of the cell is occupied by one or more vacuoles. The cytoplasmic layer and the nucleus may be made more conspicuous by mounting the plants in an iodine solution, which pulls the cytoplasm away from the cell wall and also stains the nucleus and the threads which support it.

178. *Spirogyra:* nutrition. The supply of water for this plant is secured from the surrounding medium in which are dissolved the carbon dioxide and other inorganic materials from which foods are made. Indeed there is much water within the plant. By carefully drying, it may be demonstrated that sometimes as much as 98 per cent of *Spirogyra* is water. That photosynthesis is carried on is often made evident by the oxygen bubbles that arise from the active plants. It is possible to collect the oxygen that is produced by algæ approximately, as shown in Fig. 12. A test tube is placed over the small end of a glass funnel, both being under water in order to exclude all air from them. While under water the large end of the funnel is placed over a mass of algæ. The apparatus is then made secure and left in an upright position. As the plant continues its work, oxygen bubbles arise and accumulate in the closed end of the tube, thus forcing out a similar volume of water. The oxygen may be tested by the ordinary tests for this gas. Because of the size and the length of this plant, and the size of its chloroplast, it can expose more chlorophyll to the light and hence do more photosynthetic work than any plant yet studied in the present chapter.

When *Spirogyra* cells divide, the division wall is at right angles to the length of the plant. Such division results in an increase in the number of cells and usually in growth in length of the whole plant. Growth occurs so rapidly that within a few days after the plants are first seen in the spring they become so abundant that they may pollute the water in which they grow.

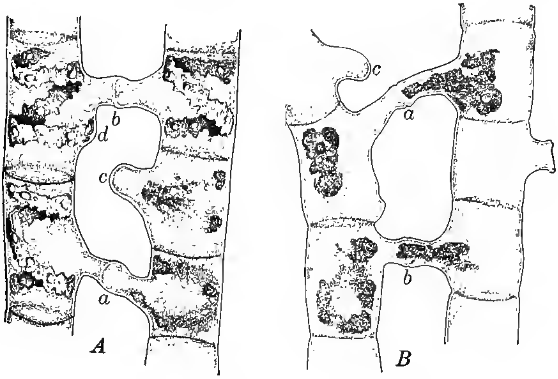

FIG. 157. *Spirogyra* in process of spore formation

A, conjugating cells; *a* and *b*, conjugating tubes; c, a tube from a cell which has begun to conjugate with one that is already paired; *d*, a second tube from a paired cell. Such secondary tubes rarely develop. *B*, *a* and *b*, tubes through which the protoplasm is passing to unite with that of the pairing cells; c, a tube similar to c in *A*. Greatly enlarged

179. *Spirogyra:* reproduction. Plants may become broken into two or more pieces, and each piece may grow into a separate plant, thus securing vegetative reproduction. At times, however, there occurs a kind of reproduction quite different from any that we have as yet studied in the algæ. The cells of two plants that lie near one another unite in pairs, this union being made by means of tubular outgrowths from the pairing cells (Fig. 157). These tubes meet between the old cell walls, their ends fuse and form a continuous passageway from one cell to the other. Then the protoplasm from one cell passes through the tube and unites with that from the other cell. About this mass of protoplasm, which has now become greatly condensed, there forms a very heavy cell wall (Fig. 156). This heavy-walled body is a spore and may grow into a new plant. It is formed by *union of cells* and not by *cell division*, as was true in the case of the zoöspores of plants related to *Pleurococcus*. Reproduction by cell union is *sexual*, and by cell division is *asexual*. The spore of *Spirogyra* is a sexual spore. Because it is formed by the union of *similar cells*, it is called a *zygospore*, which means a "yoked spore." Cells that unite to form sex spores are called *gametes;* hence a zygospore is a sexual spore that is formed by the union or *conjugation* of similar gametes.

Dozens of *Spirogyra* cells in two adjacent plants may conjugate to produce zygospores. Usually the different pairs in the united filaments will be found in about the same stage of spore formation, though occasionally there will be some variation. Sometimes the cells from one plant will unite with cells from more than one other plant. Also occasionally one cell may unite with the adjoining one in the same plant. Sometimes the contents of cells that have not united with other cells will assume the form and characteristic coverings of the zygospore, and such spores may grow into a new plant.

Zygospores are set free by the decay of the old cell walls. After a period of rest, as during drought or winter, they germinate and produce new *Spirogyra* plants. It is of obvious advantage to the plant to have a heavy-walled resting spore which will carry it through unfavorable periods.

180. *Cladophora:* habitat and structure. Various species of *Cladophora* are found attached to objects along shoals in streams, over dams, about waterfalls, sometimes in heavy floating mats along the margins of ponds, lakes, and even the oceans. It is a most widely distributed genus, and one of the few green algæ ever found in salt waters. *Cladophora* usually has one end attached to some kind of support, and is extensively branched (Fig. 158). When growing vigorously, new branches are constantly being formed at the upper ends of some of the segments. Each segment appears to be one cell, though really a good many nuclei with their accompanying masses of cytoplasm are contained within each wall. Such a structure is called a *cœnocyte*, and though this same condition is found in another plant that we shall study (*Vaucheria*, Sect. 183), it is not common in the plant kingdom. For our purpose we may think of each segment of *Cladophora* as like one cell. All of these branching segments may together compose a plant of great size as compared with the smaller dimensions of a *Nostoc*, an *Oscillatoria*, a *Pleurococcus*, or even a *Spirogyra*.

In each segment there are many small chloroplasts, crowded together so closely as to present an almost solid green color even when viewed under considerable magnification.

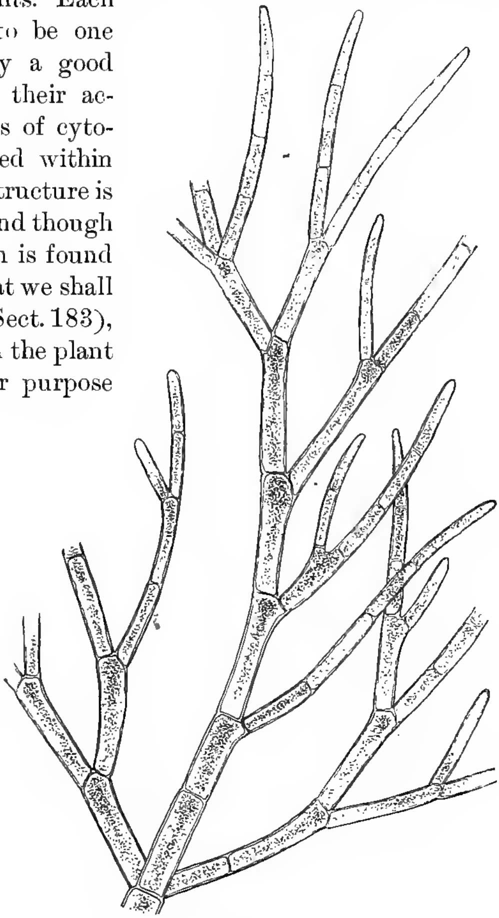

FIG. 158. Branching of *Cladophora*

After Collins

181. *Cladophora:* nutrition. *Cladophora* is well supplied with the food materials that it needs. It grows chiefly in moving water, which is better aërated than still water. This water also carries in solution more or less inorganic substances from the soil. The holdfast usually holds the plant securely in this favorable environment. Furthermore, its system

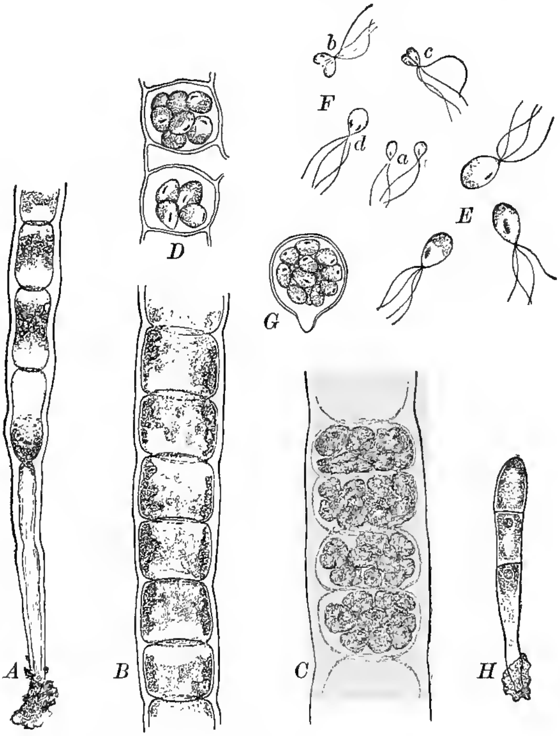

FIG. 159. One of the filamentous algæ (*Ulothrix*)

A, the base of a plant showing the attaching or holdfast cell and a few vegetative cells; *B*, a group of vegetative cells; *C*, cells in which gametes have formed; *D*, two cells in which zoöspores have formed, and one cell from which the zoöspores have escaped: *E*, swimming zoöspores; *F*, *a*, *b*, *c*, *d*, gametes uniting to form a zygospore; *G*, the zygospore, after a period of rest, grows and finally produces zoöspores; *H*, a zoöspore germinating to produce a new *Ulothrix* plant. All greatly enlarged. *E*, *F*, and *G* after Dodel-Port of branching enables it to expose much chlorophyll to the light. Its rapid and luxuriant growth is evidence that it is a successful plant.

182. *Cladophora:* reproduction. It is probable that *Cladophora* reproduces itself vegetatively by continued growth of broken parts. Like *Spirogyra*, it does not have any regular method of bringing about vegetative reproduction. At times, however, in some of the segments, the contents divide into large numbers of small zoöspores. These escape from the old wall, swim about for a time, and then become attached and grow into new *Cladophora* plants. This method of spore formation is much like that of the relatives of *Pleurococcus*, except that zoöspores of *Cladophora* are formed in much greater numbers, by a special cell rather than by the whole plant, and under conditions suited to abundant and wide distribution. In Fig. 159 is shown the method of reproduction of *Ulothrix*, an unbranched plant which in its reproduction is quite similar to *Cladophora*. Plants such as *Cladophora* and *Ulothrix* have still another method of reproducing themselves. At times the cells, instead of forming zoöspores, form bodies which are like the zoöspores in form and movement, but smaller. It seems that one of these alone cannot reproduce the plant, or, if it should germinate, it produces a plant that does not live. It is not a spore, since it cannot directly reproduce the plant which formed it. Two of these bodies may unite and form a cell which is capable of reproduction. These zoöspore-like bodies are gametes and unite to form a zygospore, which then produces a new plant. In *Cladophora* and other plants (*Ulothrix*, *Draparnaldia*, Fig. 160) that reproduce themselves as it does there are interesting suggestions as to the origin of sexual reproduction among plants, namely, the origin of gametes from small and apparently weakened zoöspores. By the union of these simple zoöspore-like gametes there is formed the simplest kind of sex spore, the zygospore. *Spirogyra* forms its zygospore in somewhat the same way as does *Cladophora*, but the process is more complex and no relation of gametes to zoöspores is shown.

183. *Vaucheria:* habitat and structure. *Vaucheria* is commonly called "green felt," a name which suggests the characteristic appearance presented by it as it grows upon the moist surface of the earth, in pots, on growing tables in the greenhouse, or upon damp shaded soil out of doors. It also grows in pools of water, where it may be distinguished from many other algæ by its coarseness. Certain species of *Cladophora* are coarser than *Vaucheria*, but their greater length and more extensive branching will ordinarily enable one to distinguish them. If the earth upon which *Vaucheria* is growing is examined, the plants will be found to penetrate slightly into the soil, their size enabling one to see parts of them without

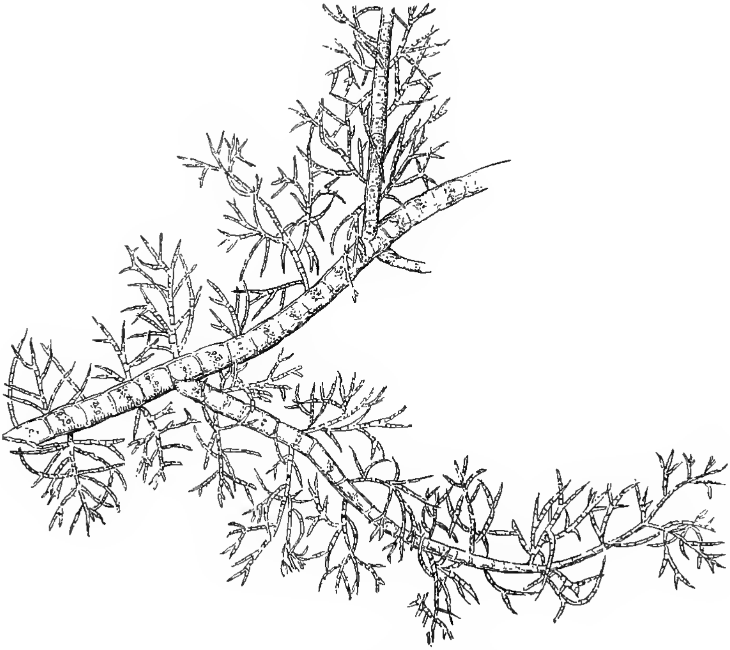

FIG. 160. A branch of the alga, *Draparnaldia*

After Conn

magnification. Plants that have been kept in a closed dish within the laboratory for a few days grow into a heavy moss-like mass and are good material for study.

Under low-power magnification the whole body may be traced through its intertwining with its neighbors. It branches considerably (Fig. 161), the branches arising irregularly and rebranching to a small extent. The newest branches are the greenest and most active, and as they grow forward older portions may die, thus separating the branches from one another and resulting in the formation of new individuals by vegetative reproduction. No cross walls appear in the vegetative part of the plant; hence the whole plant is a cœnocyte (Sect. 180).

184. *Vaucheria:* nutrition. Water may be absorbed from the earth upon which *Vaucheria* grows. In case of those species that live in the water the food supply is secured as in other floating algæ. The abundant chlorophyll suggests considerable ability to manufacture nutrient substances, but this plant is not so well suited to secure abundant exposure to light as is *Cladophora.* It is to be noted that, living on the land as these plants often do, they do not have the protection against extremes of light and temperature that water algæ enjoy; also that in nature *Vaucheria* plants are found in shaded and otherwise protected places. If direct sunlight falls upon these plants for very long, they are not able to live.

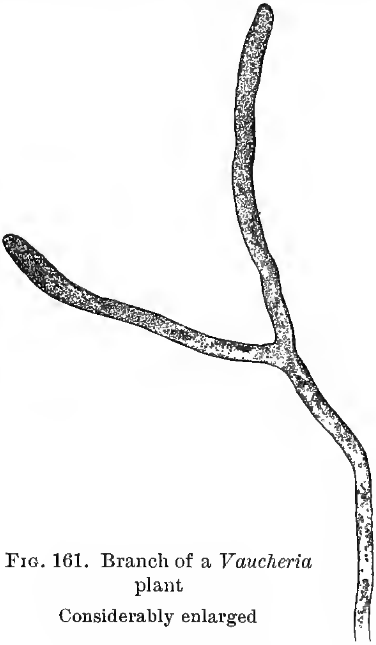

FIG. 161. Branch of a *Vaucheria* plant

Considerably enlarged

185. *Vaucheria:* reproduction. As suggested in Sect. 183, it sometimes occurs that branches are left as separated individuals by the death of the older portions of the plant. This results in vegetative reproduction. Asexual reproduction may be started by having the end of a branch cut off by a cross wall. The part that is thus cut off proceeds to form an immense zoöspore (Fig. 162, *A*, *B*). The wall which contains it breaks, and it slowly emerges, and, after a period of separate existence in the water, it germinates and forms a new plant (Fig. 162, *C*). This zoöspore is composed of many cells. It is therefore a compound zoöspore, and is cœnocytic. But the compound zoöspore produces only one new plant. Formation of zoöspores may be induced in the laboratory by keeping *Vaucheria* plants in a dish of shallow water.

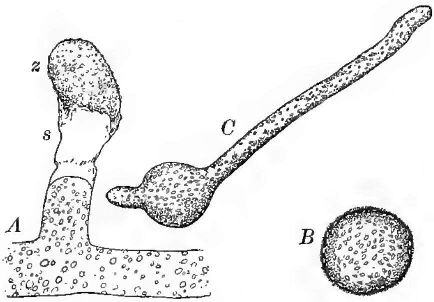

Fig. 162. The formation of zoöspores by *Vaucheria*

A, a piece of a plant at the tip of which a section has been cut off to produce the zoöspore (*z*); *B*, a zoöspore which has become free from the plant which formed it, and has assumed the rounded swimming form; *C*, a zoöspore germinating to form a new plant. Considerably magnified

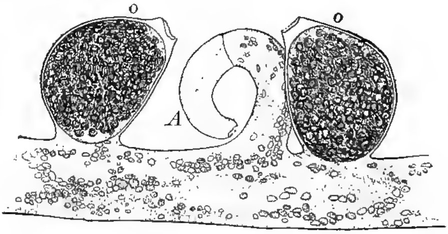

Fig. 163. The sexual reproductive structures of *Vaucheria* (*V. sessilis*)

o, oögonia; *A*, antheridia. Note the opening in the antheridium for exit of sperms, and in the oögonia for their entrance to the large eggs. Greatly enlarged

Another kind of reproduction may occur at the same time that zoöspores are being formed, though it usually occurs at other times. Upon the sides of the plant special short branches are formed. In one species of *Vaucheria* (*V. sessilis*) two kinds of branches arise near one another (Fig. 163). One of these is short and irregularly spherical, and has a beak at its free end. This branch forms one large cell within it. The other branch is longer, somewhat coiled, and has a terminal cell that is cut off by means of a cross wall, which is much farther from the main plant than in the other branch. In the terminal segment many small cells are formed. Through a small opening in the tip of this coiled branch these cells escape, some of them entering the beak of the other branch, and one of them uniting with the large cell. This union forms a spore which proceeds to develop a heavy protecting wall. After a period of rest this spore germinates and produces a new plant.[1]

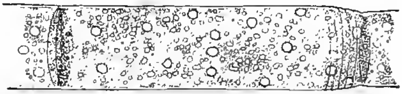

FIG. 164. A vegetative cell of a common species of *Œdogonium*

Greatly enlarged

If this spore had been formed by the union of similar gametes, we then should have called it a zygospore; but it is formed by the union of gametes that are very unlike, — one large gamete, the *egg* or *oösphere*, and the other a small gamete, the *sperm*, — and the resulting spore is called an *oöspore*, which means "egg spore." *When similar gametes unite to form a zygospore, the process is called conjugation, but when dissimilar gametes unite to form an oöspore, the process is called fertilization.* The special sex organ which produces the sperm is the *antheridium*, and that which produces the egg is the *oögonium*, which means the "egg case."

Vaucheria has three methods of reproduction, — vegetative, by asexual spores (zoöspores), and by sexual spores (oöspores).

One plant may use vegetative reproduction at one period of growth, asexual spore reproduction at another, and sex spore reproduction at another, but two methods are rarely used at once.

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[1] TO THE TEACHER. No attempt is made to present the difficult and technical questions relative to alternation of generations in the thallophytes.

186. Increase in complexity of sex organs and gametes. It is to be especially noted that in other algæ which we have studied reproductive bodies were formed from cells which at the outset were vegetative cells. In *Vaucheria* sex organs are made primarily for the work of reproduction, an interesting division of labor in the plant. In some green algæ, as *Œdogonium* (Figs. 164 and 165), vegetative cells are thus formed into oögonia and antheridia.

It is also important to note that in *Pleurococcus* the entire plant might divide vegetatively into two new plants; or, in relatives of *Pleurococcus*, the entire plant might become a spore case (sporangium), producing zoöspores. In *Cladophora*, zoöspores are formed, together with zoöspore-like gametes, the latter uniting

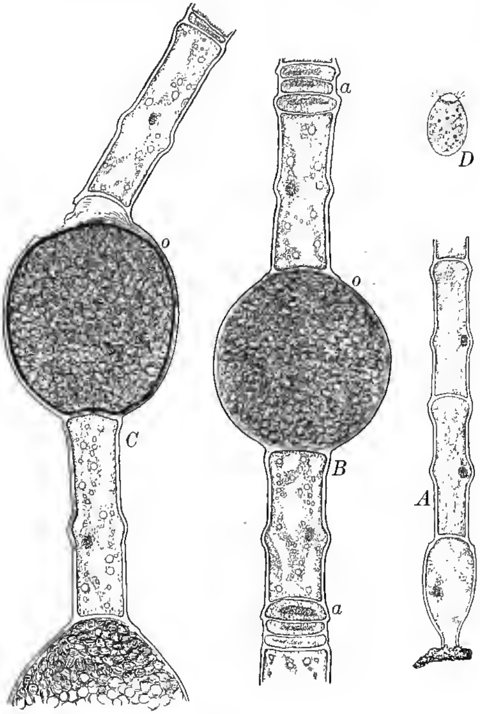

Fig. 165. Reproduction in *Œdogonium nodosum*

A, holdfast cell and two vegetative cells; *B*, part of a plant in which are an oögonium (*o*), containing egg, and two groups of antheridia (*a*), which have not yet formed sperms; *C*, part of a plant in which is an oögonium (*o*), which, by breaking away of one vegetative cell, has made a place for the sperm to enter, so that a fertilized egg or oöspore has been formed, as is shown by its heavy inner wall; *D*, a zoöspore of *Œdogonium*, —*D* redrawn from Pringsheim. All greatly enlarged to form zygospores, which constitutes the simplest kind of sexual reproduction. In *Spirogyra*, zygospores are formed by the union of similar gametes, the conjugation being brought about by siphon-like tubes which unite the cells from which the gametes come. In *Vaucheria* the gametes are differentiated into an egg and a sperm, which, by fertilization, produce an oöspore. These differentiated gametes are found in specialized sex organs made primarily for reproductive work.

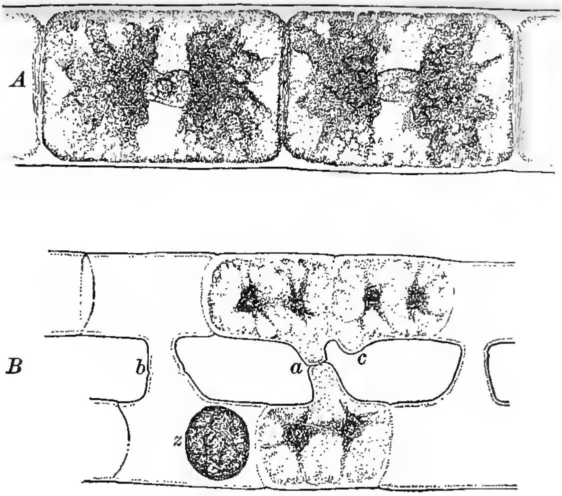

FIG. 166. *Zygnema*

A, two vegetative cells showing the central nucleus which lies between the parts of the dumb-bell-like chloroplast. *B*, conjugation to form zygospores; *a*, *b*, *c*, conjugating tubes; *z*, zygospore fully formed. Both greatly enlarged, but *A* more than *B*

187. Other green algæ.[1] The green algæ are more abundant than all others in inland waters, and it is not possible or desirable to mention many of them in this connection. Some of the following may be collected, however, in regions in which those already discussed are found. *Sphærella*, a unicellular

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[1] It is more important that the student should have an impression of the kinds of plants found among the algæ than that he should remember names of different genera.

form somewhat like *Pleurococcus*, is frequently found in stagnant water. It sometimes grows so luxuriantly in barnyard and roadside pools as to give the water a bright green appearance, and its resting spores may impart a dark red color to the drying pools in which the plants have flourished. Of the near relatives of *Spirogyra* there are several kinds, some of which are *Zygnema* (Fig. 166), *Mesocarpus* (Fig. 167), and the desmids (Fig. 168). The desmids are peculiarly fantastic forms, one-celled, but often found in colonies. They usually appear in stagnant waters. As in *Spirogyra*, these plants reproduce themselves by formation of zygospores. *Conferva*, which resembles *Ulothrix* (see Fig. 159), is fairly abundant in ponds and along margins of lakes. *Draparnaldia* is a branching form (Fig. 160) which resembles *Cladophora* and *Vaucheria*; *Ulva*, or sea lettuce, is a peculiar large salt-water form; while *Coleochæte* (Fig. 169) is a disk-like or plate-like form. *Chara*, or stonewort (Fig. 170), is a complex alga that is found in great abundance upon the bottom of shallow lakes and streams throughout the continent. It has a heavy coating

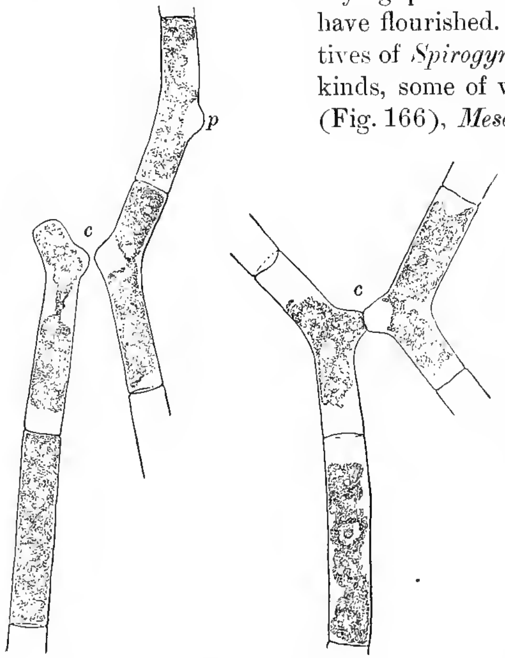

FIG. 167. *Mesocarpus*

c, conjugating cells which have bent toward one another and are producing conjugating tubes; *p*, a start toward conjugation with a third plant. Greatly enlarged of calcareous material, which, as the plant dies, falls to the bottom of the pond or stream. *Chara* grows in such luxuriance that its deposits eventually form deep layers of this calcareous material, or marl as it is called. Marl has been found of great value in the manufacture of cement, and not a few of the lakes in which *Chara* grows are being dredged to secure the marl deposits for this important manufacture.

188. Algæ and water supply. Many of our large cities have found it advisable to construct reservoirs for water. These are open pools, lakes, tanks, etc., and they are intended to hold water enough so that in times of scarcity there will be at hand a sufficient supply. Such reservoirs have proved so admirable as growing places for algæ that these plants have often become a nuisance. Their presence in water for domestic use is not attractive, and, besides, they may stop up the water pipes; but far more serious than these objections is the actual pollution of the water because of their presence. When they die they become the food for decay-producing organisms (Sect. 154), and often positively injurious substances may thus be generated. It has been found that by towing about in such reservoirs a quantity of copper sulphate, inclosed in coarse sacking, minute quantities of the salt become dissolved and the algæ are thus killed. The solution is not strong enough to render the water unwholesome for use.

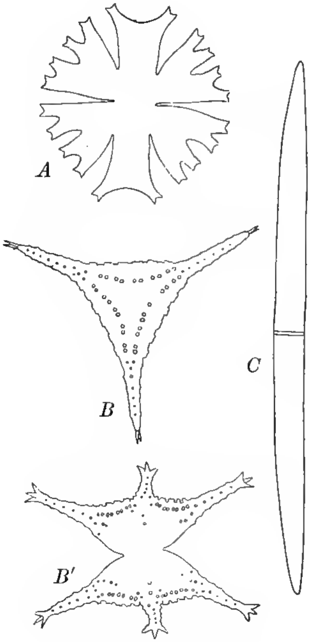

FIG. 168. Desmids

A, Micrasterias; B, B′, Staurastrum (two views); *C, Closterium.* After West

This treatment has been an important factor in improving the water within reservoirs used as sources of water supply for many American cities.[1]

189. The brown algæ: general characteristics. The blue-green and the green algæ are predominantly fresh-water groups, and are considered the chief representatives of algæ. The remaining groups, though almost exclusively salt-water plants, have such striking characteristics that brief mention of them must be made, and pupils who live near the seacoast will be interested in extending this study. The brown algæ, or brown seaweeds (*Phæophyceæ*), are found along the shores of all the oceans. They grow attached, by means of strong holdfasts, to rocks, piling, or any relatively fixed support that is available.

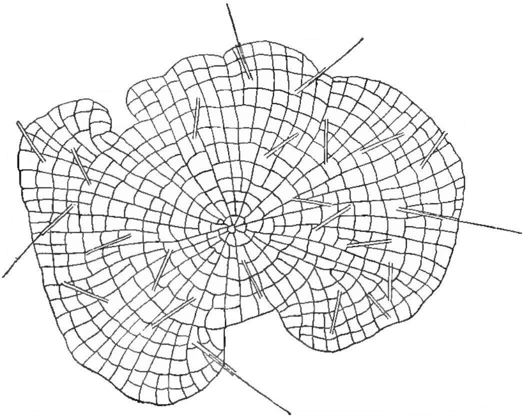

FIG. 169. *Coleochæte*, a flat-bodied green alga, which is a single layer of cells in thickness. It sometimes branches extensively

After West

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[1] See "A Method of destroying or preventing the Growth of Algæ and Certain Pathogenic Bacteria in Water Supplies," and "Copper as an Algicide and Disinfectant in Water Supplies," *Bulletins 64* (1904) and *76* (1905) respectively, Bureau of Plant Industry, U. S. Dept. Agr.

Whipple, "Microscopy of Drinking Water," chap. xii. John Wiley & Sons, New York, 1906.

From high-tide mark to a little below low-water mark *Fucus* and *Ascophyllum* (known as rockweeds) often form dense coatings upon rocks. At low tide these rockweeds hang loosely over the exposed rocks. Such masses exhibit the dark olive-green color that is characteristic of the group.

190. *Sargassum* and the Sargasso seas. Some of the brown algæ may become detached and be carried hundreds or even thousands of miles from their original growing places. This is true in the case of *Sargassum*, some species of which thrive along the shores of tropical oceans. In the North Atlantic Ocean, north of the Canary Islands, is a body of water known as the Sargasso Sea. Its entire area is more or less filled with floating *Sargassum* and other forms of plant and animal life. In other similarly quiet parts of the seas occur large regions filled with floating algæ. *Sargassum*, as is also true of some other brown algæ, is peculiarly fitted for floating by the presence of "air bladders," which are swollen regions of the leaf-like expansions (Fig. 171). In mid-ocean one may see small floating masses of these plants, which have been carried sometimes hundreds or even thousands of miles from their original homes.

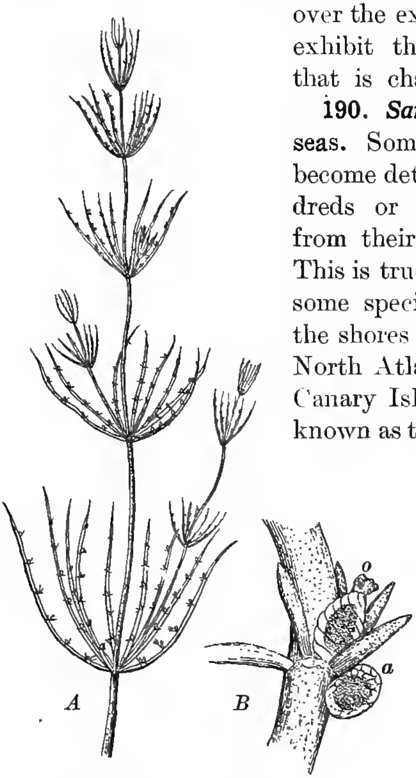

Fig. 170. The stonewort alga (*Chara*)

A, a slightly magnified piece of a plant showing the general appearance; *B*, a more highly magnified illustration showing the oögonium (*o*) and the antheridium (*a*), by means of which reproduction takes place

191. The kelps. The giant kelps belong to the brown algæ, and are represented by such forms as *Laminaria*, *Postelsia*, and *Macrocystis*. The cylindrical stem-like growth of the *Macrocystis* is said to reach a length of from 800 to 900 feet, while *Laminaria*, or "devil's-apron," grows into strap-like or widely spread, tough, leathery expansions. All of these forms have heavy root-like holdfasts, which furnish attachments so strong that the plant usually will break elsewhere before it will pull away from its support. The great length of these plants is not disposed vertically in the water, but the strong stem-like and leaf-like outgrowths trail out in a semi-upright position.

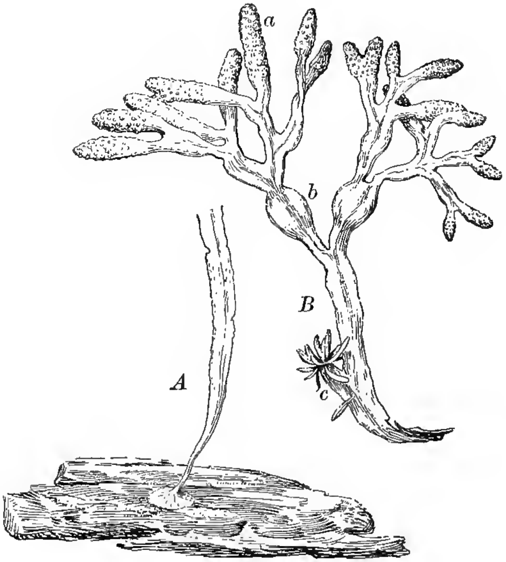

FIG. 171. Rockweed (*Fucus*)

A, the base of a young plant showing an early stage in formation of the holdfast, which attached the plant to a piece of wood. *B*, tip of a plant; *b*, air bladders; *a*, specialized regions in which reproductive organs are formed; *c*, new leaf-like growth where the plant had been broken. A little less than natural size

192. Reproduction. Vegetative reproduction in the brown algæ is secured by the breaking apart of branches from old plants. There is no known special method resulting in vegetative reproduction, as in *Pleurococcus*, *Nostoc*, etc.

Some members of the group (*Ectocarpus* and others) are reproduced by zoöspores and by the formation of zygospores that are the result of the union of similar motile gametes, as in such green algæ as *Ulothrix* and *Cladophora*. Others, of which *Fucus* is a representative, reproduce by means of oöspores that are formed by the union of sperms and eggs.[1]

193. Uses by man. At one time the world's supply of iodine was derived from the brown algæ; now it can usually be prepared more economically by chemical means. Soda was formerly secured from these plants, but chemical processes have driven out the laborious methods of securing that substance directly from plants. Gelatinous foods and a sugar known as mannite are secured from some species of brown algæ. In some coastal portions of this country the farmers collect and carry inland great quantities of brown algæ and spread them over the cultivated land as a fertilizer.

FIG. 172. A red alga (*Batrachospermum*), which is fairly common in fresh waters

Slightly magnified

194. The red algæ. The red algæ (*Rhodophyceæ*) chiefly inhabit deeper water than do the brown algæ. The class is almost wholly confined to salt water, and the few that do live in fresh water do not exhibit well the color characteristics of the class. One common fresh-water genus is *Batrachospermum* (Fig. 172).

The marine forms of this group present most striking shapes and colors. They are of different shades of red, varying from the most brilliant to those that are dark and somber, while some are a deep purple. Chlorophyll is present, but often is completely obscured by the other colors. Sometimes all the colors are obscured by deposits of calcareous material upon the plants.

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[1] If desired to study further the details of reproduction of the brown algæ, see Coulter, Barnes, and Cowles, College Botany, Vol. I; also Bergen and Davis, Principles of Botany.

There are no known unicellular red algæ. Usually the plants are quite complex and present expanded leaf-like structures

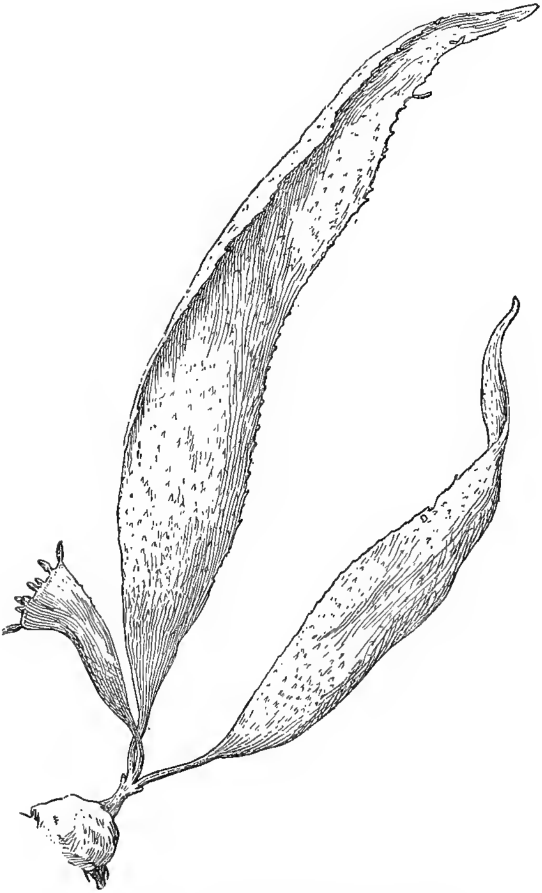

Fig. 173. A red alga (*Gigartina spinosa*)
Attached by means of its holdfast to a small stone

(Fig. 173) or are extensively branched (Fig. 174). They have basal holdfasts, which in general resemble those usually found in the brown algæ. Red algæ are, as a rule, smaller and more delicate than the brown forms.[1] There are often many branches, the smallest ones becoming quite thread-like, so that the entire plant looks to the beginning student like a sparsely branched stem with many finely divided leaves. In their asexual reproduction the red algæ may form spores in groups of four (Fig. 175).

FIG. 174. A red alga (*Dasya*)

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[1] The best way for the teacher to give a general notion of brown and red algæ is to secure card mounts or bottled material for class demonstrations of a few of the leading types in each group. These may be obtained from the Woods Hole Biological Laboratory, Woods Hole, Massachusetts, and from other reliable supply houses. Well-prepared card mounts preserve the natural colors, and may be kept indefinitely for laboratory use.

195. Uses of red algæ. Several genera of the red algæ are used as food. They may be dried and thus kept for long periods. The gelatinous material that is secured from them forms a delicacy much desired by some people. In the North Sea and elsewhere in the Atlantic Ocean occurs a red alga known as "Irish moss," which is collected in large quantities and employed in the preparation of jelly, to be used both directly as food and as the basis for the preparation of other foods. One of these gelatinous products of red algæ is agar-agar, which is extensively used as a growth medium in bacteriological work, and in similar work with some of the lower fungi.

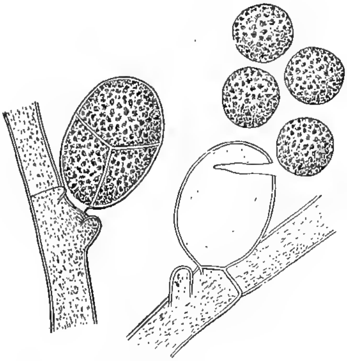

FIG. 175. The asexual reproduction of a red alga (*Callithamnion*)

At the left there is a branch upon which is a sporangium. Within its wall its division into four spores has taken place. At the right these four asexual spores have escaped from the sporangium. Much magnified. After Thuret

196. Classification of the algæ:

Thallophytes
  Algæ
    Class I. Chlorophyceæ (the green algæ)
      Leading genera used as illustrations,—*Pleurococcus, Spirogyra, Cladophora, Ulothrix, Draparnaldia, Vaucheria, Zygnema, Œdogonium, Chara*
    Class II. Phæophyceæ (the brown algæ)
      Leading genera used as illustrations,—*Fucus, Sargassum, Laminaria, Ectocarpus*
    Class III. Rhodophyceæ (the red algæ)
      Leading genera used as illustrations,—*Gigartina, Dasya, Callithamnion*

CHAPTER XIV

THE ALGÆ-FUNGI (PHYCOMYCETES)

197. General characteristics of the fungi. The algæ-fungi, as the name suggests, are fungi which resemble the algæ. It was noted in the discussion of the bacteria that the fungi are thallophytes which do not possess chlorophyll. Some of the fungi are so much like the algæ in general structure that if chlorophyll were added to them they might easily be classified together. There are other fungi which are very unlike the algæ.

Absence of chlorophyll suggests the absence of ability to manufacture foods from water and carbon dioxide (Sect. 17). In order to live, fungi must secure their carbohydrate food already prepared for them, and the first great question that arises relates to the ways in which non-chlorophyll-bearing plants secure their food.

198. The dependent habit of living. The dependent habit is characteristic of the fungi, though there are many dependent plants that do not belong to the fungi. Dependency may appear in any one of several forms. Such fungi as toadstools, mushrooms, and puffballs live upon decaying plant and animal material, — old leaves, logs, stumps, manure heaps, etc., — and when so living are called *saprophytes*. Sometimes dependent plants live upon living plants or animals, as in the case of tree-destroying fungi, wheat rust, and some of the bacteria of the human body. These, as we have seen, are called *parasites*, and the organism which furnishes the food material is the *host*. Two living organisms, plant or animal, may live together in such a way that each benefits from the presence of the other, and sometimes these are called *mutualists*, meaning "mutually helpful," and sometimes they are called *helotists*, meaning that one organism is held by the other in a condition of slavery. In case of some dependent plants it is not easy to determine the nature of their dependency.[1]

199. Bread mold (*Rhizopus nigricans*). If a piece of slightly moistened bread is placed in a glass jar or covered in a dish for a few days, an abundant supply of mold soon appears upon it. There may even be several kinds of molds developed upon the bread under such conditions within a very few days. The common bread mold, or black mold, is the one which usually appears. It grows about our homes in great abundance, soon appearing when bread, fruits, and other favorable nutrient substances are left exposed. When young the mold is white, only assuming its blackish appearance when spores are formed.

200. Bread mold: vegetative structures. A mass of growing bread mold is composed of many white threads greatly entangled one with another. This entanglement is due to the forward growth of the many free ends of these threads. Each thread is called a *hypha* (meaning "a single web"), and the whole network of *hyphæ* is the *mycelium*, or fungus mass. The mycelium is the interwoven network of which one hypha is a single thread.

Careful examination also shows that some of the hyphæ have grown down into the nutritive substratum (supporting substance), and if one could see through the bread after mold has grown on it for a few days, much of the mycelium would be seen within the bread. Branching downward from some of the superficial hyphæ are special root-like hyphæ (*rhizoids*) (Fig. 176), which descend and spread out within the nutrient material. At such places upright hyphæ also are formed. From these areas long runner-like branches (*stolons*) may extend over the surface a little way. From the stolons a new set of rhizoids and upright hyphæ may be formed. This method of vegetative extension gave rise to a much-used name, *Mucor stolonifer*, meaning "the stolon-bearing mold."

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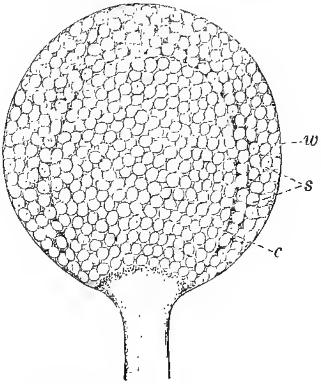
[1] Dependent plants are treated more fully in a separate chapter, but plant dependency necessarily receives attention throughout this discussion of the fungi.

Under magnification hyphæ of bread mold are seen to consist of heavy tubular cell walls in which the granular protoplasm is not separated by transverse walls, as it is in most of the algæ. If the nuclei could be seen, which is not possible in unstained material, many of them would be found within the tubular hyphal wall. This plant, therefore, is a cœnocyte, like the green alga *Vaucheria* (Sect. 183). If *Rhizopus* possessed chlorophyll, it would resemble the vegetative structure of *Vaucheria*.



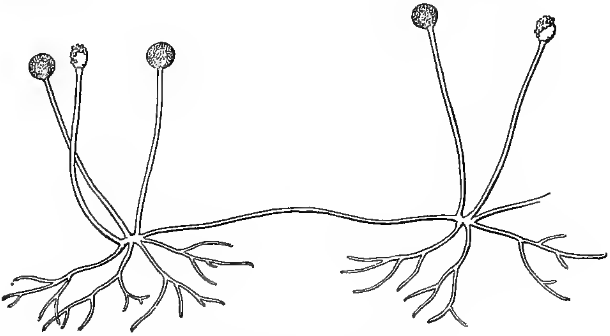


FIG. 176. Black mold

Below is a slightly magnified illustration of plants, one of which has given rise to the other by means of a runner, or stolon. Descending are the rhizoids and ascending are the aërial branches, upon the tips of which spores are borne within sporangia. Above and at the right a more highly magnified sporangium is shown. Its wall (*w*) incloses many spores (*s*), through which may be seen the columella (*c*), which is the swollen tip of the stalk upon which the sporangium is borne. This wall may be broken away, so as to leave some of the spores lying upon the columella, as is seen in two cases of the plants shown below

201. Bread mold: nutrition. Bread mold lives upon and within its nutrient substance and absorbs food material directly from it. Parts that are in contact with the substratum do the work of food absorption. Food is carried through the tubular cells to the parts of the mycelium that are above the food material.

202. Bread mold: effect upon the substratum. If a piece of bread upon which bread mold is growing vigorously be kept moist, the mold will not, usually, continue to grow until the bread is completely consumed. Either because of having secured all the food it can extract from the bread, because of having secreted substances that prevent its further growth, or because of being unable to hold its own with other organisms (molds and bacteria), the bread mold after a time ceases to grow. Other molds and bacteria may appear, one kind following another for weeks, until the decay of the bread is almost or quite complete. If kept tightly sealed, however, growth stops before all the food material is used. Molds often grow for a time in jars of fruit, forming upon the top of the fruit a coating which remains until the jar is opened. If this coating is removed and a fresh supply of air is admitted, a new growth soon appears.

203. Bread mold: asexual reproduction. In addition to vegetative reproduction by means of stolons, this mold also reproduces itself both asexually and sexually. There arise from the main body of the mycelium upright hyphæ, upon the ends of which sporangia are produced (Fig. 176). The upright stalks are called *sporangiophores* (meaning "sporangia bearers"). In the development of the sporangium, first a transverse wall cuts off a small tip of the upright stalk. This tip cell grows rapidly until it has become a large spherical body. Meanwhile the transverse wall has extended into the spherical sporangium, thus producing a little column (the *columella*) upon which the sporangium contents rest. The protoplasm of the sporangium divides into many small spores, which, when the sporangium wall breaks, are scattered widely into the air. The musty odor which is detected when we smell mold may be due to the presence of large numbers of these spores, or to gases that have been produced within the nutrient material.

If bread that has not been exposed to the air is cut in a room in which the air is quiet, and if one piece is covered directly in a glass dish, another similarly covered after five minutes' exposure to the air of the room, and another after five minutes' exposure on the outside window sill, an interesting test of the abundance of spores in the atmosphere will be afforded. One class of students, in performing this experiment, secured the development of mold upon all three pieces of bread, having in all five kinds of mold.

204. Bread mold: sexual reproduction. Bread mold rarely reproduces itself by sexual processes, but does so under some circumstances. The tips of hyphæ approach one another, and end cells are formed by means of transverse walls. These end cells gradually unite to produce a spore, and a heavy dark wall is formed about it. Since this spore is produced by the union of similar cells it is called a zygospore. It is a well-protected spore, and seems fitted for enduring great extremes in physical conditions. The germination of the zygospore of *Rhizopus nigricans* is an occurrence that is difficult to demonstrate in the laboratory, though it and closely related molds (*Mucor mucedo* and *Sporodinia*) form zygospores that have been seen to germinate and thus reproduce the mold plants. The similarity between the formation of zygospores in molds and in *Spirogyra* is worthy of note.

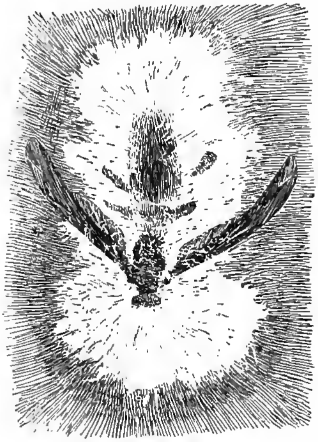


FIG. 177. Water mold growing on the body of a wasp

The fungus has grown upon the host until an extensive white fluffy mass has been formed

205. Water mold (*Saprolegnia*). Although there are several kinds of water molds, this is the most common one. It lives in the water, upon dead insects, fish, and other animals.

Sometimes living fish that are confined in close quarters become infested with this mold and die. In such cases the mold is first a parasite, but upon the death of its host it becomes a saprophyte. In late summer and early autumn, flies and other insects often become infected with water molds and related fungi (as *Entomophthora*). If these insects, when found lying on the floors and window sills, are placed in a dish of water, the mold sometimes grows rapidly, soon producing a "collar" of fluffy hyphæ about the thorax of the insect, and may cover the entire body (Fig. 177).

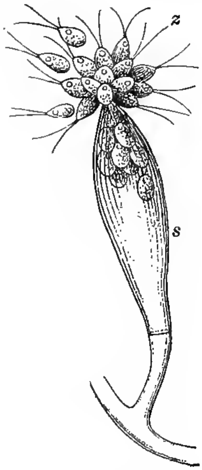


FIG. 178. A water mold bearing a sporangium (*s*), from which zoöspores (*z*) are escaping

After Schenck

206. Water mold: vegetative structures and nutrition. The mycelium of *Saprolegnia* branches and extends itself throughout the tissues of its supporting material. As in *Mucor* and *Vaucheria*, the plant is a cœnocyte. It absorbs its food material directly, and when the supply of food is abundant it may grow with striking rapidity. This plant is effective in bringing about decay of dead animal bodies in the water.

207. Water mold: asexual reproduction. At times the numerous hyphæ which extend from the nourishing material may form transverse walls, which separate large swollen tip segments from the bases of the hyphæ. Within each tip segment many zoöspores form (Fig. 178). These escape into the water in very large numbers and swim about quite actively. Upon coming in contact with favorable nutriment the cilia are withdrawn and the zoöspore germinates into a new hypha, which by growth may produce a new mycelium.

208. Water mold: sexual reproduction. From the tips of short hyphæ large spherical cells (oögonia) are formed, in each of which one to many eggs are produced. In some species groups of oögonia are formed upon a single hypha. Antheridial branches come in contact with the oögonia (Fig. 179). A tube grows from the antheridium and pierces the wall of the oögonium. Sperms from the antheridium escape and fertilize the eggs, thus forming oöspores which can reproduce the plant. In some cases when *Saprolegnia* eggs are not fertilized they develop heavy walls, and afterwards germinate as if they had been fertilized. Such development of eggs into oöspores without fertilization is known as *parthenogenesis*. It is a method of reproduction that is met with in some other plants and in some animals.

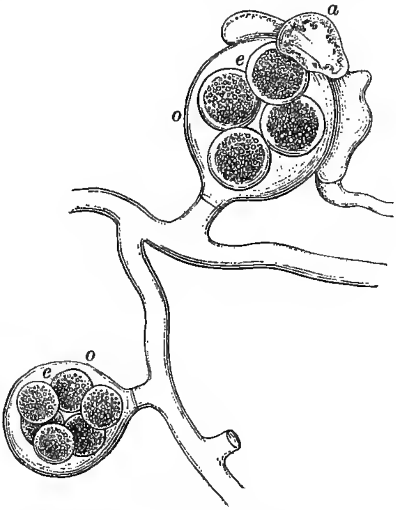


FIG. 179. Sexual reproduction of a water mold

Some of the hyphæ bear oögonia (*o*) and antheridia (*a*), and within the oögonia are the eggs (*e*). After Klebs

209. The grape downy mildew (*Plasmopara viticola*). There are numerous so-called downy mildews; the one here used as a type frequently appears upon the under surface of leaves of the grape. In the Central States, which region is supposed to be the original home of this parasite, it has been an injurious pest for many years. Its downy white growth upon the surface of the leaves (Fig. 180) is its most conspicuous distinguishing characteristic, but it also often grows upon green shoots and fruit. When conditions are thoroughly favorable (proper soil, moisture, and temperature) for the growth of grapevines, the parasite when present may do little damage. At other times it may all but destroy the crop and greatly reduce the vigor of the host plant.

210. Grape mildew: vegetative structures and nutrition. The downy patches that appear upon the leaves are merely the superficial parts of the parasite, since within the leaf the

FIG. 180. A leaf of the grape, upon which may be seen the white, fluffy patches of grape mildew

Photograph by H. H. Whetzel

mycelial hyphæ have grown for some time before the downy patches are produced. These cœnocytic hyphæ grow between the cells and send into the interior of the cells short branches (*haustoria*), which absorb food directly from the cell contents of the host (Fig. 181, *B*). When the mildew has thus grown within the leaf for a time, it sends through the stomata on the under surface numerous branches which constitute the superficial downy patches characteristic of the parasite.

211. Grape mildew: asexual reproduction. Some of the aërial hyphæ branch and upon tips of these branches produce spore-like bodies, the *conidia* (Fig. 181, *A*). These conidia fall from the conidiophores (conidia bearers), and when favorable moisture (dew, rain, etc.) is present they germinate. Instead of producing new hyphæ they usually act as sporangia and produce zoöspores (Fig. 181, *D* and *E*). The zoöspores may swim about for fifteen or twenty minutes, and then lose their cilia and begin to produce new hyphæ. If favorably located, the new hyphæ may find entrance to a leaf through its stomata and begin anew the growth therein.

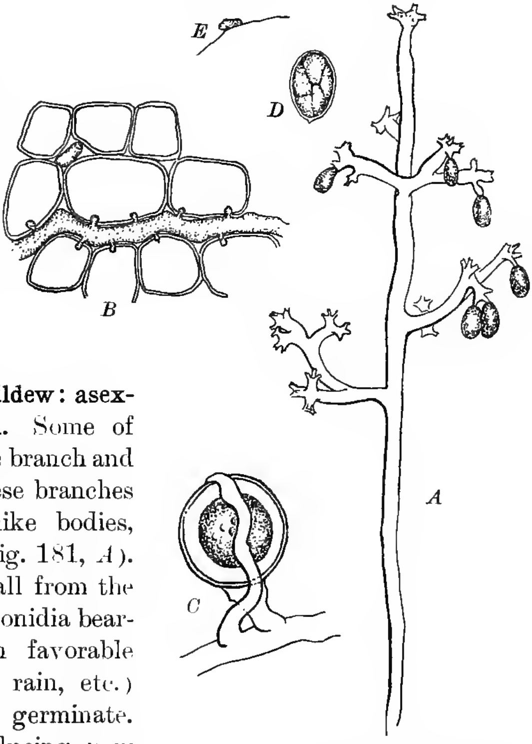


Fig. 181. Grape mildew (*Plasmophora*)

From the mycelium within the cells of the grape leaf haustoria (*B*) are formed. Upright hyphæ (*A*) bear conidia. These conidia divide, as at *D*, and form zoöspores (*E*). Within the leaf oöspores (*C*) are formed. After Duggar

212. Grape mildew: sexual reproduction. In the interior of the leaf short hyphal branches develop into oögonia and antheridia (Fig. 181, *C*). Each oögonium develops an egg, which, when fertilized by one of the many sperms from the antheridium, becomes an oöspore. This oöspore has a heavy wall and also is within the tissues of the leaf, so that apparently it is well fitted to endure severe winter conditions. Upon the decay of the leaf the oöspores are set free. They probably germinate to produce new plants, but "much work needs to be done in the way of determining to what extent the oöspores are necessary in the annual propagation of this species."[1]

213. Grape mildew: preventive measures. Usually it is possible to control the growth of this parasite so that serious damage is prevented. In 1881 the Frenchman Millardet began experimenting with the Bordeaux mixture[2] as a method of treating grape mildew. His experiments resulted in a chemical mixture which, when properly used as a spray, will obviate most of the ill effects of grape mildew. The same mixture has been found of great value in treating many other plant diseases, and almost all the state agricultural experiment stations issue special directions concerning local uses of this mixture.

214. Potato blight (*Phytophthora infestans*). This parasite is a near relative of grape mildew. Its vegetative characteristics closely resemble those just described. Its asexual reproduction by conidiospores and the consequent zoöspores gives it very ready and wide distribution. The parasite may infest leaf, stem, or tuber of the potato, and is one of the several fungous diseases that have proved very destructive of potato crops. It may be held in check by proper spraying (Fig. 349) with the Bordeaux mixture.[3]

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[1] Duggar, B. M., Fungous Diseases of Plants. Ginn and Company, Boston, 1909.

[2] The preparation as most commonly used consists of materials mixed in the following proportions: copper sulphate, 5 pounds; stone lime, 5 pounds; water, 50 gallons. Other proportions are often used.

[3] "Potato Spraying Experiments in 1906," *Bulletin 279*, N.Y. Agr. Exp. Sta.; "Certain Potato Diseases and their Remedies," *Bulletin 72*, Vt. Agr. Exp. Sta.

215. Other phycomycetes. Of the forms that have here been discussed, — *Rhizopus*, *Saprolegnia*, and *Plasmopara*, — each represents an important subdivision of the phycomycete class of fungi. There are many molds closely related to *Rhizopus*, and some of them usually appear wherever there is decaying organic matter. Several kinds of water molds are known, and other parasitic forms which resemble *Saprolegnia* are the cranberry-gall fungus (*Synchytrium Vaccini*), which attacks the stem, leaves, flowers, and fruit of the cranberry plant; the "damping-off" fungus (*Pythium DeBaryanum*), which, in plant-house seed beds and sometimes in open fields, kills seedling plants by attacking their cells at or near the soil, thus causing them to wilt; the brown rot of the lemon and other citrous fruits (*Pythiacystis citrophthora*), which is especially injurious in California and is often a forerunner of the blue mold (*Penicillium*). Important plant parasites which in structure and habit resemble the grape mildew and potato blight are the white or downy mildew (*Cystopus candidus*, sometimes called *Albugo candida*) of plants of the mustard family (*Cruciferæ*), as shepherd's-purse, the common radish, horse-radish, cress, mustard, and turnip; also another white mildew (*Peronospora parasitica*) which infests many members of the mustard family, including most of those mentioned for *Cystopus*, as well as others; downy mildew (*Plasmopara cubensis*) of the cucumber, pumpkin, and watermelon; onion mildew (*Peronospora Schleideni*); downy mildew of lettuce (*Bremia Lactucæ*) and downy mildew of lima beans (*Phytophthora Phaseoli*).

216. Summary of phycomycetes. In structure and methods of reproduction this group resembles some of the green algæ. The frequently occurring cœnocytic body suggests *Vaucheria* and its relatives among the green algæ. In reproduction zoöspores, zygospores, and oöspores are formed, and the specialized sex organs, oögonium and antheridium, are present. In some of the phycomycetes specialized asexual structures, the conidia, are formed, and these germinate, usually producing one or more zoöspores. Evidently these conidia are sporangia which fall from the parent plant before the spores that develop within them are set free. A careful review of type plants used in the study of green algæ and phycomycetes will show striking similarity in reproductive processes.

The saprophytic and parasitic habits of living of this group give them very great economic significance. Agriculture, horticulture, gardening, fish industries, and water supplies are seriously affected by members of the group.

217. The groups of fungi. The classification of dependent plants into saprophytes, parasites, mutualists, and helotists is based entirely upon the ways in which plants live. Fungi are also classified upon the basis of their structure, and this classification is the one generally used in speaking of them.[1] The leading groups or classes are the phycomycetes, ascomycetes, lichens, and basidiomycetes. The schizomycetes (bacteria) are sometimes treated in this connection, but by reason of similarity of structure and methods of reproduction they and the blue-green algæ are now discussed together (Chapters XI and XII). The last part of the name of each class (mycetes) means "fungi," and the first part refers to a distinguishing

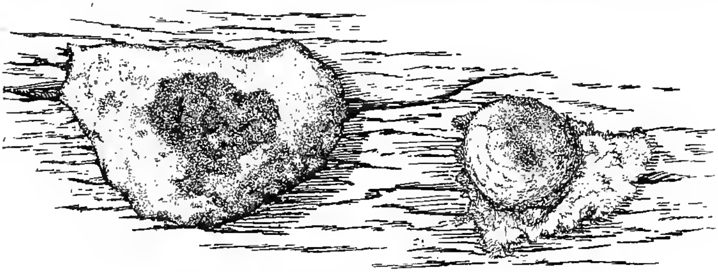

FIG. 182. Slime mold (*Fuligo*) growing from a decaying board

Two masses have exuded from the crevices of the board and are rounded into position for forming spores. Natural size

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[1] The simplest acceptable classification of fungi has been adopted. Certain technical groupings that are quite proper in a more advanced treatise are omitted from this elementary statement.

characteristic of the class. Thus phycomycetes literally means "seaweed fungi," and we call them algæ-fungi; ascomycetes means "sac fungi," since some of the spores are formed in a peculiar sac; and the basidiomycetes are the "stalk fungi," or "club fungi," since some of the spores are borne upon a stalk or club-like base. In each of these classes many kinds of fungi are found, but only a few kinds in each class can be considered in an elementary treatment.[1] The lichens are peculiar plants, which are treated in this connection merely for lack of better classification for them, as will appear later.

218. Classification:

Thallophytes
  Algæ
  Fungi
    Class I. Phycomycetes. Leading genera used as illustrations, — *Rhizopus* (bread mold), *Saprolegnia* (water mold), *Plasmopara* (grape downy mildew), *Phytophthora* (potato blight), *Cystopus*, and others
    Class II. Ascomycetes
    Class III. Lichens
    Class IV. Basidiomycetes

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[1] The "slime molds," or myxomycetes, are usually classed with the fungi, though some students regard them as animals. They often appear as gelatinous, sticky, yellow, brown, or brightly colored masses exuding from crevices in old stumps, logs, old board walks, upon decaying leaves, and sometimes upon very rich soil (Fig. 182). At other times these masses produce stalks, globules, or one or a few rounded masses. These are the spore-producing structures. So different are these two stages — one motile like some of the lower animals, the other forming spores like some plants — that students formerly thought the two stages were different organisms, of which one was animal, the other plant.

CHAPTER XV

THE SAC FUNGI (ASCOMYCETES); THE LICHENS; THE BASIDIUM FUNGI (BASIDIOMYCETES)

THE SAC FUNGI (ASCOMYCETES)

219. General characteristics. More of the fungi belong to this class than to any other, and since most of the ascomycetes are parasitic, it is evident that the class is one of great importance. There is wide variation in form and structure in this group. The mycelium of the parasitic forms grows mainly upon instead of within the host, and sends into it short haustoria which absorb food material. The hyphæ of the mycelium are divided into many cells, and branch extensively. Many of the known structures are difficult to understand, and many of the facts are not known regarding the life cycles of some of the plants which belong in this class. In a general way, the fungi of this class are subdivided into two groups,— those which have their spore-forming sacs opening into cup-like structures, and those which have the spore sacs inclosed, or almost inclosed, in heavy-walled and more or less spherical cases. Common illustrations of the class are the mildews which grow upon leaves of the plantain, smartweed, and lilac, the cup fungi, the morel, and yeasts. Of the many representatives, but a few types will be used to give some general notions of the structure and importance of the class.

220. *Peziza* and *Sclerotinia*. In damp soil, attached to decaying sticks or roots, may be found the pink or reddish cup fungus, *Peziza*. *Peziza* plants sometimes appear singly and sometimes in clusters or rows, and in color some of them are very striking.

Growing from old plums and peaches which have shriveled and dried (become mummified), sometimes there are found similar though brownish cups, which contain the reproductive organs of another ascomycete, *Sclerotinia* (Fig. 183). In case of both *Peziza* and *Sclerotinia*, the cups are external indications of a much larger internal growth of the fungus. In *Sclerotinia*, commonly called the brown rot of the stone fruits (peach, plum, apricot, cherry), the infection of the host long precedes the production of cups. Mycelial hyphæ penetrate the fruit or the flower and grow extensively in it, often extending to the twig. After a period of such growth there appear upon the surface of the fruit, which is now shriveling or decaying, many tufts of light-brown hyphæ. Among these tufts are conidiophores, upon which conidia are produced. These conidia are scattered by wind, by contact with insects, etc., and, alighting upon favorable growing places, produce new mycelial growths. It is thought possible that these conidial spores may persist throughout the winter. Infected fruits may become dried and shriveled, and hang upon the tree or fall to the ground. When favorable growing conditions return in the next season, or even in a later season, the brown cups are produced from the mass of mycelium in the old fruit. These cups are composed of many hyphæ closely pressed together. In the tips of some of these hyphæ in the bottom of the cups the spores

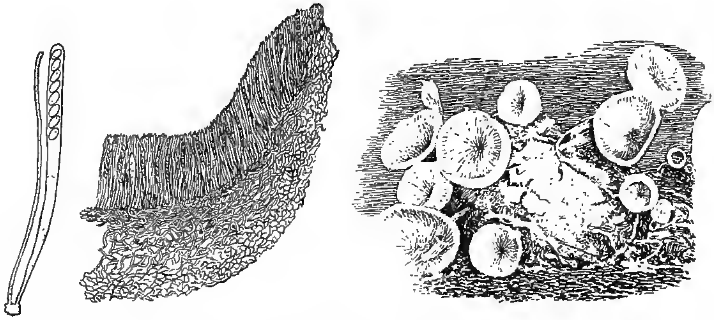

FIG. 183. Brown rot (*Sclerotinia*) growing upon old plums

At the right are some of the fruiting cups; in the middle is a greatly magnified portion of the cup, showing the spore-bearing areas; and at the left is one of the spore-bearing threads still more magnified. After Duggar are formed (Fig. 183). The wall of a spore-containing hypha is the sac or ascus, and the spores which are formed therein are the *ascospores*, or *sac spores*. These spores, when favorably placed, again produce the mycelium of the parasite. This represents the chief method of spring and early summer infection of fruits with the brown rot.

221. Destructiveness of *Sclerotinia*. All kinds of stone fruits seem to be susceptible to attacks of this disease. It is said[1]: "It would appear that among peaches the sorts densely covered with hairs or down, such as Alexander, Hill's Chili, and Triumph, are usually susceptible. Among the more resistant sorts are to be found the Carmen, Early Crawford, Elberta, Chinese Cling, and some others. Among the plums the Japanese varieties suffer generally in most sections of the country. The American group of plums is also susceptible, and apparently more susceptible at the South than farther north. The Wild Goose and Marietta plums are much less affected in all regions. The native cherries are more resistant than such as the Montmorency." The total amount of the damage is enormous. In 1887 Maryland and Delaware were reported to have had a peach-crop shortage, from this cause, of 800,000 baskets of fruit. In 1900 Georgia had an estimated loss of 40 per cent of the peach crop, or a money loss of between $500,000 and $700,000.[2] The disease may be checked

FIG. 184. A group of "morel" mushrooms (*Morchella*)

Note the depressions in the surface, in which the sacs and ascospores are formed. Three fourths natural size

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[1] Duggar, Fungous Diseases of Plants. Ginn and Company, Boston, 1910.

[2] "The Brown Rot of Peaches, Plums, and Other Fruits," *Bulletin 50*, Georgia Agr. Exp. Sta., 1900.

by destroying the infected fruits and twigs. Spores are so generally distributed that spraying is also necessary. Different sprays have been used, but with such varying success that the advice of local experiment stations should be sought for the special needs in each state.

222. The morel (*Morchella*). Another representative of the open-fruiting ascomycetes is that commonly called the "morel mushroom" (Fig. 184). Its mycelium grows in earth that is very rich with decaying organic matter. It is usually found in woods among the leaves and about old logs and stumps. The fruiting body, the mushroom, is the only part usually noticed, and under favorable conditions of moisture and temperature it develops in a very short time, growing at the expense of food material that is gathered by the underground saprophytic mycelium. In the deep, wrinkle-bordered pits of the mushroom are the ascus-bearing hyphæ. The ascospores form in great numbers and are so light that they may be widely distributed.

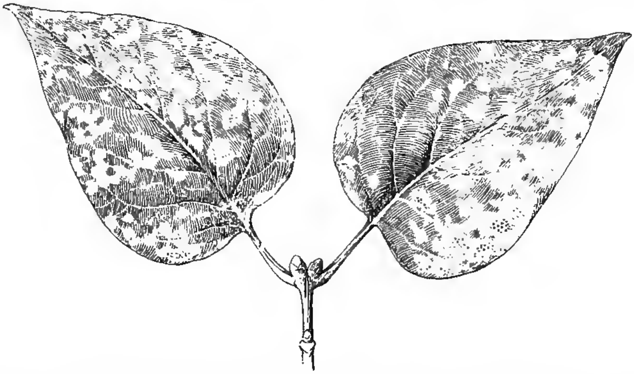

Fig. 185. Leaves of lilac upon which lilac mildew appears in whitish patches. Also the small dark reproductive bodies are shown

223. The powdery mildews: lilac mildew (*Microsphæra alni*). Good illustrations of the inclosed-fruited ascomycetes are had in the powdery mildews. They are frequently found upon the surfaces of leaves of lilac (Fig. 185), and related mildews are found upon the willow, oak, some of the smartweeds, and upon many other plants. The powdery mycelium lives upon the surfaces of the leaves. Haustoria, by means of which nutrient material is extracted from the host, are sent into the leaf from the superficial hyphæ. The fungus is therefore a superficial parasite.

At times upright hyphæ form transverse walls, cutting from their tips rows of small cells, the conidia. The powdery appearance of the mildews is due largely to the presence of large numbers of these conidia. The conidia, if favorably placed, are the means of producing new growths of the mildew. Another complex method of reproduction results in forming ascospores. Two superficial hyphæ unite their tips, and fusion of the nuclei of these tip cells takes place. Then there grows, as a result of this fusion, a relatively large, heavy-walled body, the *ascocarp*, so called because it is the hard-walled body which contains the asci and ascospores. Within the developing ascocarp, division of the tissue finally results in forming several asci, in each of which there are four to eight ascospores (Fig. 186). In late summer the ascocarps may, without magnification, be seen as small black bodies upon the surface of lilac leaves. From the walls of the ascocarp peculiar arms extend, and in the lilac mildew and some other kinds these have strikingly branched tips, which sometimes serve as one means of distinguishing the species.

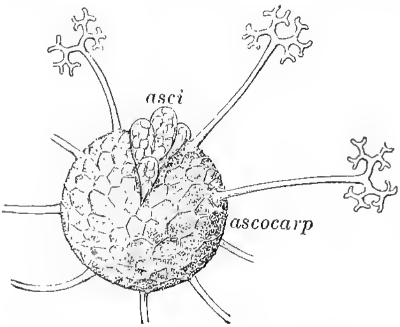

FIG. 186. The spore-sac case of lilac mildew (*Microsphæra alni*)

The central, heavy-walled body (ascocarp) contains the sacs (asci) in which spores are formed. Upon the wall of the ascocarp are stalks, sometimes called arms, which have peculiar branches at their tips. About 60 times natural size

The heavy-walled ascocarp is resistant to unfavorable climatic conditions, and may pass through the winter and in the following spring break open, thus freeing the thin-walled asci. Upon escaping, the spores may be blown or carried about and germinate upon new host leaves.

224. Blue mold or green mold (*Penicillium*). This mold frequently appears upon discarded leather, upon shoes or gloves which when damp have been left in a dark warm place, upon old lemons, and upon cheese and other dairy products. Various species have distinct shades of color, so that the common names of blue or green mold can be taken only as applying in a general way. Certain species of *Penicillium* are supposed to give characteristic flavors to cheese in which they grow, as *Penicillium Roqueforti* of Roquefort cheese and *Penicillium Camemberti* of Camembert cheese. These species are widely distributed, however, and are found growing upon many substances other than cheese. It has been suggested that these are not different species, but that they merely show different features, dependent upon the kind of material upon which they grow. While it is true that these as well as species of other molds do show different characteristics when grown in different ways, recent investigations indicate that the species are distinct.[1]

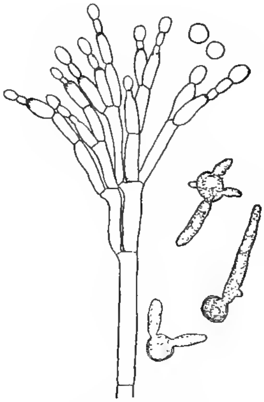

FIG. 187. The blue mold (*Penicillium*)

At the left is the tip of a hypha, with the characteristic branches, on the ends of which are the spores; at the right are germinating spores. After Thom. Much magnified

Penicillium is an ascomycete which has almost lost the habit of reproduction by means of ascospores, the ascus being

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[1] An interesting discussion of various species and their cultural reactions is "Cultural Studies of Species of Penicillium," by Charles Thom, Ph.D., Mycologist in Cheese Investigations, *Bulletin 148*, Bureau of Animal Industry, U. S. Dept. Agr., 1910.

rarely formed. It reproduces itself very abundantly by means of conidia. Plants branch profusely at their ends, and from the tips of these branches conidia are formed (Fig. 187). The number of these conidia is often so large that when the substance supporting the plants is slightly shaken a small cloud of spores arises.

225. Yeasts. The yeasts (*Saccharomycetes*) constitute a group of plants of somewhat doubtful classification. Since occasionally they form an ascus-like sac in which spores are formed, they are often classed with the ascomycetes. They are extremely simple, and are more interesting because of their manner of life than because of their structure. A yeast plant is a single cell (Fig. 188). It usually reproduces itself by a method of vegetative reproduction known as budding. The buds, before becoming separated from the parent cells, may bud again and again until a chain of plants is formed. If a cake of commercial yeast is examined, it is found, in addition to the large starch grains nearly always occurring in yeast cakes, to consist of thousands of yeast cells, some single and some in process of budding. If a cake of yeast is kept at room temperature, the plants soon continue their growth, and other organisms (bacteria and molds) also grow, so that the yeast "spoils."

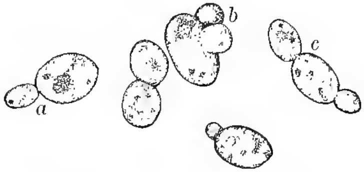

FIG. 188. Yeast plants (*Saccharomycetes*)

a, a plant from which a bud has begun to grow; *b* and *c*, plants with two buds. Note the vacuoles in the plants. Greatly enlarged

When yeast plants are placed in dough they grow with great rapidity. They live upon the solutions in the dough, and in so doing break down the sugar, thus forming from it small quantities of alcohol and carbon dioxide. The carbon-dioxide gas forms the "air spaces" in the dough, which cause the phenomena known as "rising."[1] In cooking the dough

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[1] Salt-rising bread owes its peculiar quality to the fact that instead of yeasts certain bacteria produce a putrefactive fermentation within the dough.

the air spaces are enlarged and at the same time the alcohol is evaporated. In former methods of bread baking pure cultures of yeast were less likely to be secured,—"wild" yeasts very frequently appearing. With modern methods, quite similar to those used in bacteriology, pure cultures may be obtained, and it is therefore possible to secure the exact kind of fermentation of the dough that is desired.[1]

The processes of fermentation by yeasts are used in the manufacture of alcohol, wine, beer, and other liquors which contain alcohol. Certain definite kinds of yeasts produce certain kinds of alcoholic fermentation, and it is necessary for the brewer to keep pure cultures of the desired yeasts in order to insure the particular quality of his product. It is worthy of note that the difficulties which brewers formerly had from impure yeasts furnished the occasion for the development of the basis of modern bacteriology. The brewers of Germany appealed to the great scientist, Louis Pasteur, to assist them in this difficulty. He succeeded, in 1856, in devising methods of pure culture by isolating single yeast plants and growing a colony from each. Thus the particular result to be secured could be determined by the kind of yeast selected for use in fermentation. It was this method of pure culture which opened the way for bacteriological investigations.

226. Other ascomycetes. The number of destructive ascomycetes is too large even to be enumerated in this elementary treatise. Some of the more important ones besides those discussed above are here given. Upon heads of rye the disease known as ergot (*Claviceps purpurea*) sometimes develops. Its mycelium infests the whole plant. Within and about the developing grains masses of summer spores are formed. Later the same mycelium produces dark compact masses (Fig. 189), which completely replace some of the grains. These fall to the ground and lie dormant through the winter, and from them in the spring the ascospores for new growth develop. The spore

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[1] An especially interesting paper is "Bread and the Principles of Bread Making," by Helen W. Atwater, *Farmers' Bulletin 112*, U. S. Dept. Agr., 1900.

masses are poisonous, and, as *ergotine*, are sometimes used for medicinal purposes. A parasite known as root rot (*Thielavia basicola*) attacks the roots of tobacco, horse-radish, and violets, and of peas and other leguminous plants.[1] The rose and peach mildew (*Sphaerotheca pannosa*),[2] which occasionally appears as light-colored downy patches upon the fruit of the peach, attacks the leaves of roses and is very destructive. The wilt disease of cotton, cowpea, and watermelon (*Neocosmospora vasinfecta*)[3] is widely distributed over the Southern states and attacks the vascular bundles in such a way as to cut off the plant's water supply. A common disease of plum and cherry trees is black knot (*Plowrightia morbosa*).[4] The familiar and very destructive dark and shrunken patches on the fruit of the apple are due to bitter rot (*Glomerella rufomaculans*).[5] The value of fruit destroyed by it sometimes amounts to millions of dollars in a single year.

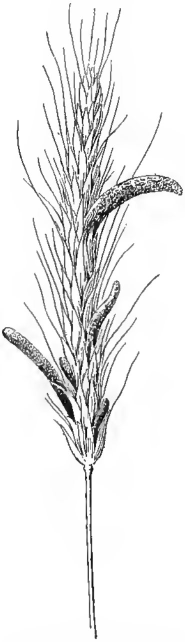

FIG. 189. Ergot which has grown on a head of rye

After Duggar

In addition to the conidial forms already considered in connection with their ascosporic forms and used as types of their respective groups, there remain thousands of species whose life histories are not known. Many are saprophytes and many are parasites, some of which are very destructive to crops.

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[1] Clinton, G. P., "Root Rot of Tobacco," Conn. Agr. Exp. Sta., 1906.

[2] "Peach Mildew," *Bulletin 107*, Colo. Agr. Exp. Sta., 1906.

[3] "Wilt Disease of Cotton, Watermelon, and Cowpea," *Bulletin 17*, Division of Vegetable Pathology, U. S. Dept. Agr., 1899.

[4] Lodeman, E. G., "Black Knot," *Bulletin 81*, Cornell University Agr. Exp. Sta., 1894.

[5] "The Bitter Rot of Apples," *Bulletin 44*, Bureau of Plant Industry, U. S. Dept. Agr., 1903.

LICHENS

227. General characteristics. The lichens are not simply fungi. A lichen is not even a single plant, but is a combination of fungi and algæ living together in such a close relationship that it looks like a single plant. There may be many individual fungi and many individual algæ in this relation, but the combination is spoken of as the lichen plant. The fungal part of the lichen is usually, though not always, a member of the ascus-bearing class of fungi, and consequently lichens are often classified with ascomycetes. This is obviously a somewhat questionable classification, but for lack of a better one we shall discuss the class in this connection. The algæ that enter into the formation of lichens are usually unicellular forms resembling *Pleurococcus*, but may be filamentous green algæ or even some of the blue-green algæ.

FIG. 190. A foliaceous lichen (*Parmelia*) upon a piece of bark

Natural size

Lichens live upon bark of trees, stones, and upon soil (Fig. 190). They thrive under conditions of exposure and in moisture and temperature variations which do not permit most plants to grow. They are found at as great altitudes and with as great range north and south as any plants.

In stony places lichens often form heavy mats made up of lichen bodies, mosses, and decomposed rock. These masses when upon upright faces of rock may by their own weight fall and become the soil for growth of other plants. New growths soon start where the old ones were, and by a continuation of this process these plants may slowly wear away large masses of stone. It is probable that considerable chemical action is exerted upon the rock by the hyphæ, resulting in decomposition of the substratum. Examination of almost any stone pile that is but a few years old will show the presence of these forerunners of other plant life. We have, therefore, a combination of alga and fungus, neither of which alone could keep alive in places of such great exposure, living together and instrumental in building up soil where at first no other plants could live.

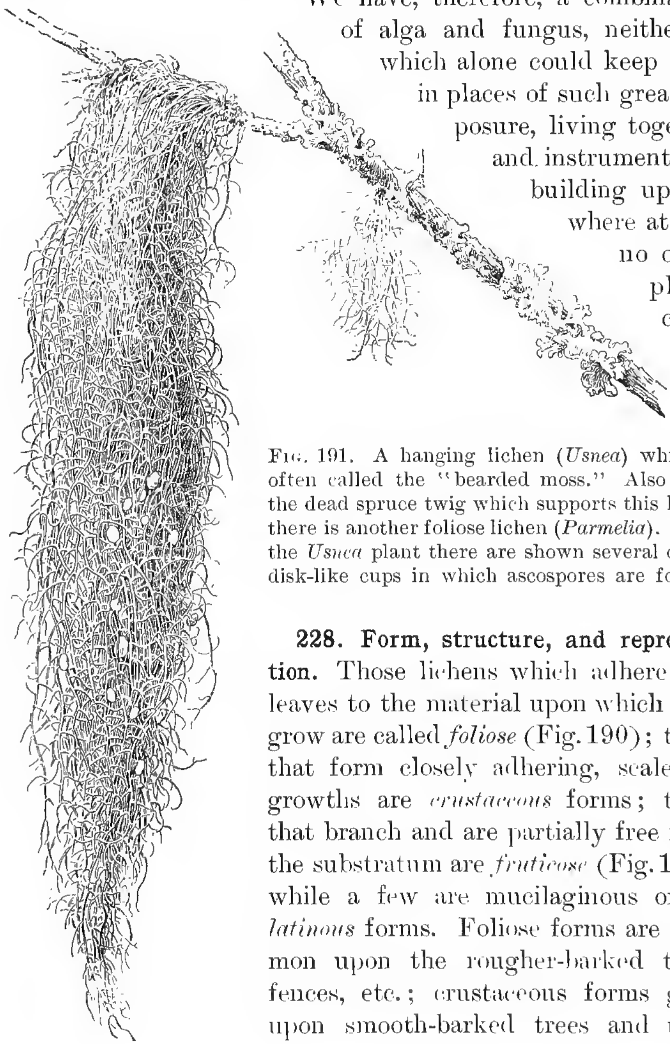

FIG. 191. A hanging lichen (*Usnea*) which is often called the "bearded moss." Also upon the dead spruce twig which supports this lichen there is another foliose lichen (*Parmelia*). Upon the *Usnea* plant there are shown several of the disk-like cups in which ascospores are formed

228. Form, structure, and reproduction. Those lichens which adhere like leaves to the material upon which they grow are called *foliose* (Fig. 190); those that form closely adhering, scale-like growths are *crustaceous* forms; those that branch and are partially free from the substratum are *fruticose* (Fig. 191); while a few are mucilaginous or *gelatinous* forms. Foliose forms are common upon the rougher-barked trees, fences, etc.; crustaceous forms grow upon smooth-barked trees and upon stones; while fruticose forms grow upon the ground or hang from branches of trees. Illustrations of the latter group are the reindeer moss (*Cladonia rangiferina*) and other cladonias (Fig. 193), and the bearded moss (*Usnea barbata*).

In sections or carefully made dissections of a lichen body usually the fungus is seen to compose the outer covering for the whole body. The algæ are within, and often closely wound about by the hyphæ of the fungi (Fig. 194), which absorb food from the cells of the algæ.

The fruiting cups usually resemble some of those of the ascomycetes. Within the base of the cup in most lichens the fungal hyphæ form asci and ascospores, as do many ascomycetes. These spores belong to the fungus. The algal part of the lichen when it is a one-celled alga like *Pleurococcus* reproduces by division, as we have already found that it does in the green algæ. This reproduction of the alga occurs quite independently of the reproduction of the fungus.

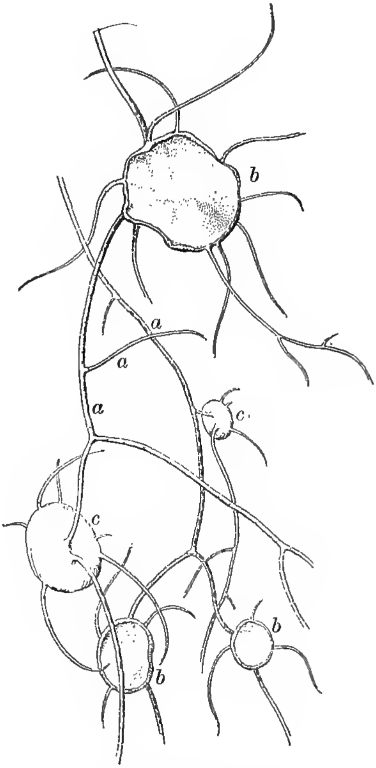

FIG. 192. A detail of a small piece of *Usnea barbata*

The branches bear the fruiting cups, and branches may also grow from the cups. The open sides of the cups are shown in *b*, and the reverse surfaces in *c*

229. Economic importance of lichens. Probably the greatest economic importance of lichens is found in their relation to formation of soils. Any freshly bared rock soon becomes the home of small crustaceous lichens. As these grow, die, and decay, and are replaced by others of their kind, the living and decaying bodies tend to disorganize the rock. Weathering processes also assist in crumbling the rock, and after a time there is soil enough to permit the growth of other lichens and mosses and finally of larger plants. These pioneer plants are eventually driven from the rock by others that can live in the meager soil that is produced by the lichens and mosses. Certain kinds of crustaceous lichens are looked upon as the forerunners of higher vegetation in rocky regions which are too bare to permit other forms of vegetation to live. They are almost universally distributed over the earth. The time required for the production of soil sufficient for the growth of other plants depends largely upon the nature of the rock and upon the climate. Upon some lava beds it is said[1] that after almost two hundred years from their formation crustaceous lichens in places are still the only plants to be found.

FIG. 193. A cup lichen (*Cladonia*)

This lichen often appears on moist ground, and at times forms the cup-like reproductive bodies, even sometimes having some of these form upon other cups. Two and one-half times natural size

Lichens as food for herbivorous animals are of considerable importance in regions where other foods are scanty or where for parts of the year cold and snow render other vegetation

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[1] Warming, Œcology of Plants, chap. xvii.

unavailable. Reindeer moss (*Cladonia rangiferina*) grows upon earth and rocks in great abundance throughout the north temperate and frigid zones, and at high altitudes in most mountain ranges. In winter it is eaten by animals, which find it green and nutritious when they remove the snow from above it.

A few lichens are sometimes used as food for men, though they are not especially nutritious. A mucilaginous and starchy food is prepared from *Cetraria islandica*, a lichen which is known as Iceland moss. This and other food lichens are more or less bitter, and when used regularly in large quantities are said to have caused disagreeable intestinal disturbances. Other lichens have been ground with wheat in making wheat flour, as in parts of northern Africa. The lichens, while adding some nutrient matter, also add considerable non-nutritious calcareous material, so that altogether the bulk of the flour is increased at the expense of the quality. In Sweden one very bitter lichen (*Sticta pulmonacea*) is sometimes used as a substitute for hops in processes of brewing.

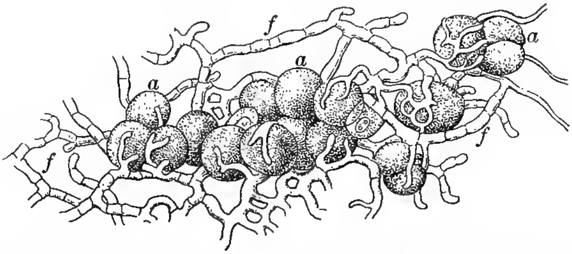

FIG. 194. A small piece of a lichen, showing in detail the relation that exists between the mycelium of the fungus (*f*) and the algal cells (*a*)

Magnified 500 diameters. After Bonnier

Various dyes are prepared from lichens. These were once more commonly used than they are to-day, and are known in the markets under the names of *orchil* and *cudbear*. Litmus, used in preparing litmus or blue test paper, a common and fairly delicate test for the presence of acids, is prepared from lichens.

BASIDIOMYCETES

230. Different groups of basidiomycetes. The prominent groups of basidiomycetes are: the *smuts*, which frequently appear in the heads of oats, wheat, and barley, and upon the ears and stalks of corn; *rusts*, which are universally distributed wherever wheat is grown, and which also grow upon many other hosts; the *toadstools*, *mushrooms*, and *puffballs*. Next to the ascomycetes, this is the largest class of fungi, and is one of great economic importance.

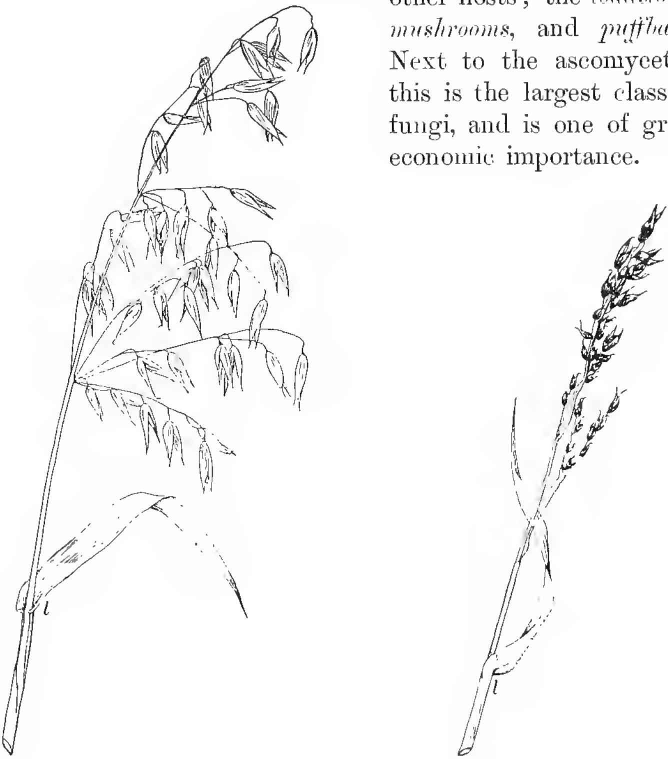

Fig. 195. Sprays of oat plants (*Avena sativa*)

The grass-like leaf character *l* is well known in this plant; the plant at the left has developed normally, while in that at the right the grains have been destroyed and replaced by oat smut and the growth of the entire plant is checked. Both one third natural size

231. The smuts. All the smuts are parasitic. They are particularly destructive to the grains and are widely distributed. In the United States it is estimated that the injury caused by smuts to wheat, oats, and barley exceeds $25,000,000 annually. The oat smut (*Ustilago Avenæ*) is present in almost every field of oats. It is generally recognized by means of the black sticky masses of spores that form in the positions previously occupied by the developing grains (Fig. 195). The spore mass, however, is the external indication that the smut mycelium has previously permeated the host. The smut usually matures at about the time the oat heads are in full flower, and prevents the normal development to such an extent that the annual damage in this country is estimated to reach $6,500,000. Upon germination of these heavy-walled spores a short hypha is produced. This soon produces four thin-walled spores (Fig. 196). Since these thin-walled spores appear at about the same time that oat seedlings are growing, they produce hyphæ which penetrate the host plant. Under favorable growing conditions the smut mycelium, which continues its growth throughout the host, does not markedly retard the growth of the infected oat plants.

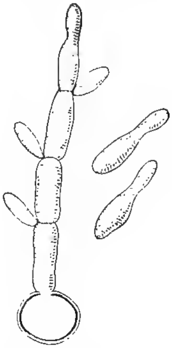

FIG. 196. A stage in the loose smut of oats (*Ustilago Avenæ*)

The small hypha that is produced by the germinating spore soon produces bud-like conidia. Greatly magnified. After Duggar

The spores that are formed in the heads have heavy resistant walls. They may adhere to the grains, lie in the granaries, or lie upon the ground in the fields until favorable conditions for growth occur. Probably the grain used for seed is itself one of the chief means of spore distribution. It has been found that by treating seed oats with hot water (132° to 133° F.), or with water containing four tenths per cent formalin, the smut may be killed.[1]

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[1] "The Grain Smuts," *Farmers' Bulletin 75*, U. S. Dept. Agr., 1898; "The Smuts of Grain Plants," *Bulletin 122*, Minn. Agr. Exp. Sta., 1911.

Corn smut (*Ustilago Zeæ*) infests many of the corn plants in an ordinary field, and when abrasions of the plants occur the unattractive smut masses frequently appear. They most often appear in the tassel or ear, and may completely or partially destroy both (Fig. 197).[1]

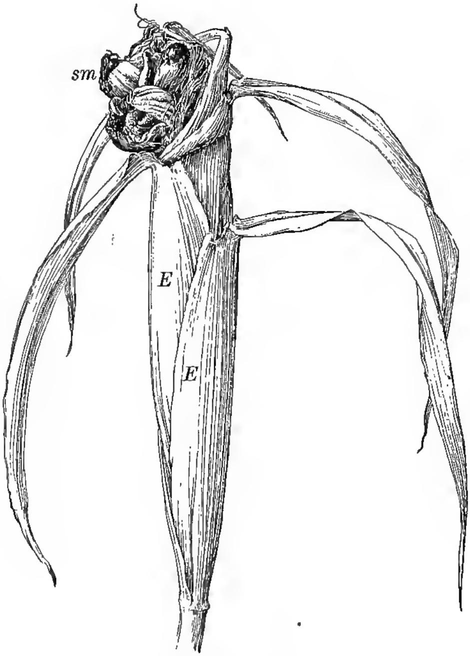

Fig. 197. An ear of corn within and upon which corn smut (*Ustilago Zeæ*) has grown

The bracts which inclose the ear (*E*) have peculiar leaf-like extensions of their tips. Masses of the spores of the smut (*sm*) have grown and extruded at the tip of the ear

232. The rusts. The intricate structures and habits of living of the rusts are objects of great interest to botanists. Their effect upon useful and decorative plants that serve as their hosts gives them great economic importance. A given species of rust may live for a time upon one kind of plant and later upon host plants that belong to other groups. In each of these stages the parasite has distinctly different structures and produces quite different effects upon its host. So unlike are these stages that formerly they were named as distinctly different plants, and it is only recently that enough has been learned about them to enable us to know some of the different appearances they may assume.

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[1] "Corn Smut," Ind. Agr. Exp. Sta., 1900.

233. Black rust of grain (*Puccinia graminis*). Wherever wheat and oats are grown, black rust, sometimes called red rust, is a dreaded pest. It also grows upon many other grasses, including barley and other cereals. The damage done to the world's crops by this fungus is very large indeed, and in the United States it has been estimated to exceed $15,000,000 in a single year. Much money has been expended in making studies of the life habits of this parasite, with the hope that means of preventing its ravages may be discovered.

The first conspicuous appearance of rust in the late spring or early summer is in the form of reddish-brown patches upon stalks and leaves of wheat and oats (Fig. 198). The patches are composed of large numbers of "summer spores" (*uredospores*). A section cut through the host leaf (Fig. 199, *A*) enables one to see that the uredospores are formed upon the ends of hyphæ. The spore-bearing ends of hyphæ are continuations of hyphæ which have pushed their way among the leaf cells from which they have absorbed their nourishment. At the time uredospores are formed the host plant is usually thoroughly infested with the mycelium. The uredospores are readily carried about by currents of air or contact with animals. If placed upon wheat or oat plants, these spores germinate, and the young hyphæ penetrate the host and produce new mycelium.

Later in the summer the same mycelium which produced uredospores may produce a heavy-walled two-celled spore (Fig. 199, *C*) known as the "winter spore" (*teleutospore*). When formed in large quantities these spores

FIG. 198. A piece of a stalk of wheat upon which spots of the rust parasite have formed

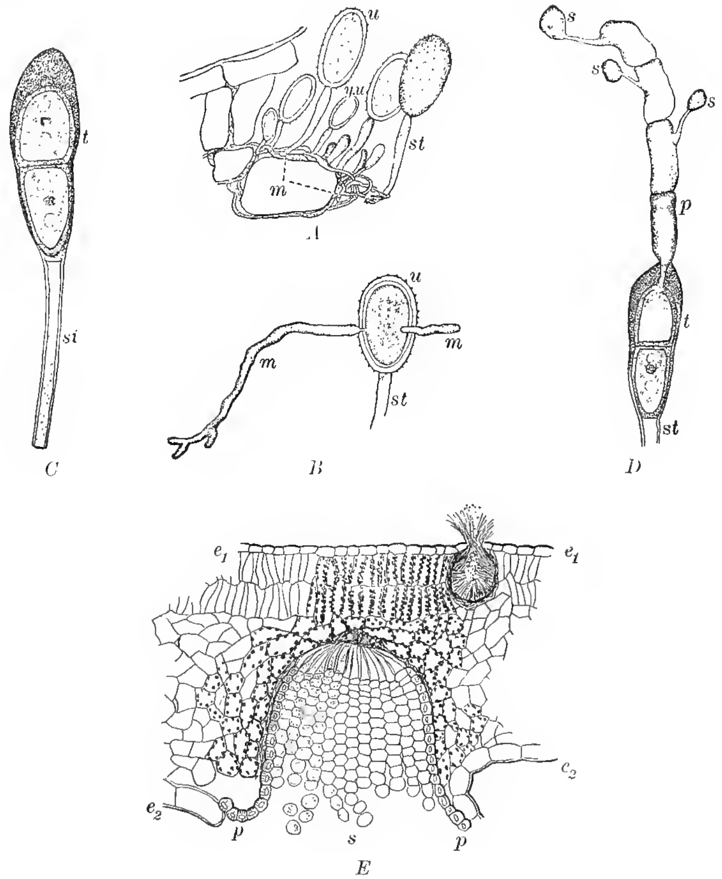

FIG. 199. Black rust (*Puccinia graminis*)

A, A small section of a wheat leaf upon which the parasitic rust is growing: *m*, mycelial hyphæ of the rust; *y. u*, young summer spore, or uredospore: *u*, fully formed uredospore; *st*, upright hypha upon which uredospore is formed. *B*, germination of uredospore: *st*, old hypha; *u*, old uredospore wall; *m*, new mycelial hyphæ. *C*, winter spore, or teleutospore: *st*, hypha; *t*, two-celled spore. *D*, germination of teleutospore: *st*, old hypha; *p*, new hypha, or the promycelium; *s*, spores or sporidia. *E*, section of the barberry leaf showing æcidiospore stage of rust: e_1 upper epidermis, and e_2 lower epidermis; *p*, wall of cup or æcidium; *s*, æcidiospores. Rearranged from Duggar's "Fungous Diseases of Plants." All much enlarged appear as blistery patches, much like those made by the reddish spores except for the difference in color. The teleutospores are scattered over the ground and upon wheat and oat straw. After a period of dormancy, usually lasting through the winter, these spores germinate. From each cell of the teleutospore in the spring there grows a small hypha (Fig. 199, *D*), quite resembling the one which grows from the smut spore (Fig. 196). Similarly, each cell of this hypha may form one of the thin-walled spores (*sporidia*).

Puccinia graminis sometimes has another stage in its life cycle. In regions — as in the New England States — where a shrub known as barberry is common, the sporidia when alighting upon leaves of the barberry may grow and produce within the leaf an extensive growth of mycelium. When this mycelium produces spores they appear in a peculiar cup on the underside of the barberry leaf (Fig. 199, *E*). These spores being different from any of the three described, and being formed in a cup, are called *æcidiospores*, or *cup spores*. Æcidiospores may reproduce the rust plant upon wheat and oats. When the life cycle of black rust was first being discovered, it was thought that all four stages are necessary, and that if any one stage could be destroyed, the others would of course be destroyed. Therefore attempts were made to kill the barberry plants so that æcidiospores could not be formed. About this time it was discovered that the barberry stage can be omitted. Uredospores persist through the winter in sufficient quantity to reproduce the rust upon oats and wheat in the following spring. No satisfactory preventive for this fungus has been discovered. Some progress has been made by learning which varieties of wheat and oats are most resistant to attacks by the parasite.[1]

234. Other rusts. Upon the leaves and stems of carnations an injurious rust (*Uromyces caryophyllinus*) sometimes appears. Asparagus rust (*Puccinia Asparagi*), probably introduced into this country from Europe but a few years ago, is now generally

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[1] "Rusts of Cereals," *Bulletin 109*, S. Dak. Agr. Exp. Sta., 1908.

distributed over asparagus beds.[1] The hollyhock and many other members of the mallow family (*Malvaceæ*), to which the hollyhock belongs, are often all but destroyed by the hollyhock rust (*Puccinia Malvacearum*). Æcidial stages of other rusts appear upon many common plants, as the May apple, jack-in-the-pulpit, burdock, sunflower, and blackberry.

FIG. 200. A "cedar-apple" parasite (*Gymnosporangium*) as it appears in winter condition upon its host, the red cedar (*Juniperus Virginiana*)

Natural size

Apple rust and "cedar apples," produced by the rust *Gymnosporangium macropus*, offer a striking life cycle. Upon red cedar trees in the late autumn, winter, and early spring branches may be found with hard brownish knots upon them (Fig. 200). The knots are outgrowths produced by the internal mycelium of the rust. Near or before the period in the spring when apple trees are in flower or setting young fruit, the brownish knots or "cedar apples" become gelatinous, and from them yellow projections protrude (Fig. 201). These projections are made up of hyphæ bearing teleutospores. The teleutospores germinate at once, producing from one to three hyphæ from each cell. Sporidia are formed, and since these are blown about in great profusion, some of them alight upon young leaves, flowers, or

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[1] "The Asparagus Rust: its Treatment and Natural Enemies," *Bulletin 129*, N. J. Agr. Exp. Sta., 1898.

fruit of the apple tree, or other members of the apple family. The apple tree is thus infected, and during the summer the cups bearing æcidiospores are formed. Some of the æcidiospores may fall upon the cedar and reinfect that host. In late summer and autumn "cedar apples" are again produced.[1]

235. Toadstools and mushrooms. These fungi are characterized in general by the fact that the mycelium lives entirely within the material which furnishes its nourishment, and occasionally sends up into the air the spore-bearing structure that is called the toadstool or mushroom. Scientifically there is no accepted distinction between toadstools and mushrooms.

FIG. 201. A "cedar apple" (*Gymnosporangium*) in its spring condition

The extrusions are made up of hyphæ and teleutospores. Three eighths natural size

Those forms that are known to be good to eat are popularly spoken of as mushrooms, while those that are not edible, or that are poisonous, are called toadstools. Even this distinction, which is wholly popular and was made solely upon the basis of real or supposed edibility, is not easily applied, since little is known regarding the edibility of many species. Furthermore, in a given genus some species may be excellent for food, and others poisonous. Certain edible species are easily learned and are not readily confused with those which are poisonous.[2] There are over one thousand edible fungi which grow in the United States.

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[1] "The Cedar-Apple Fungi and Apple Rust in Iowa," *Bulletin 84*, Iowa Agr. Exp. Sta., 1905.

[2] The United States Department of Agriculture publishes several bulletins upon poisonous and edible fungi.

236. Toadstools and mushrooms: structure and reproduction. The mycelium often becomes very extensive, and may form moldy or cobweb-like threads within the rich earth, decaying wood, or other nourishing substratum. When it grows, the mycelium helps to bring about the decay of the material which nourishes it, and therefore may be very destructive. The mushroom spawn, which is sometimes especially prepared and sold in bricks to those who wish to grow mushrooms, is simply a mass of mycelium. At times there form aggregations of the mycelium, which are whitish, bud-like growths called "buttons," and which are the beginnings of the structures known as toadstools or mushrooms. They grow and push their way to the surface. As the "button" elongates, its top begins to expand into the umbrella-like form, and finally opens out as the *crown* or *pileus*, with its center attached to the upper

FIG. 202. A large toadstool

Note the stalk, the ring, the crown, and the gills. One third natural size end of the *stalk* (*stipe*) (Fig. 202). As the pileus opens, it is joined to the stalk beneath by means of a layer of hyphæ (the *veil*). This in some species, in breaking away from the pileus, forms a ring or *annulus* about the stalk.

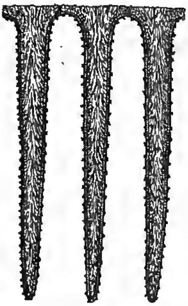

FIG. 203. Gills of a toadstool

On the faces of the gills the spores are formed. Seven and one-half times natural size. After Buller

The underside of the pileus is made up of plate-like growths (*gills*), which radiate from the point of attachment to the stalk. The flat surfaces of the adjacent plates face one another (Fig. 203). Some of the hyphæ which compose the gills grow in such a way that their tips extend a little way from the surface of the gill. Upon this extended tip (*basidium*) four (rarely two) branches are formed, and upon the tip of each branch a spore (*basidiospore*) is formed (Fig. 204). When the spores fall upon moist, warm, nutrient material, they produce a new mycelium. By cutting the pileus of a ripe toadstool from the stalk and placing it with the gills downward upon a piece of ordinary white or black paper, after a few hours there will be made a "spore print" composed of thousands of spores.

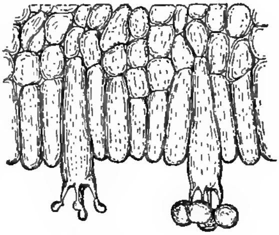

FIG. 204. Basidia and spores of a toadstool

Three hundred seventy times natural size. After Buller

237. Toadstools and mushrooms: different forms and habits. The type form just described is representative of the most common toadstools and mushrooms. The commonest cultivated mushroom (*Agaricus campestris*) has long been a well-known article of food. Some of the same type of toadstools form "fairy rings" (Figs. 205 and 206), which in constantly widening circles may appear in the same locality year after year. The phenomenon is doubtless due

FIG. 205. A group of toadstools

Note the stalk, crown, ring about the stalk, and the gills

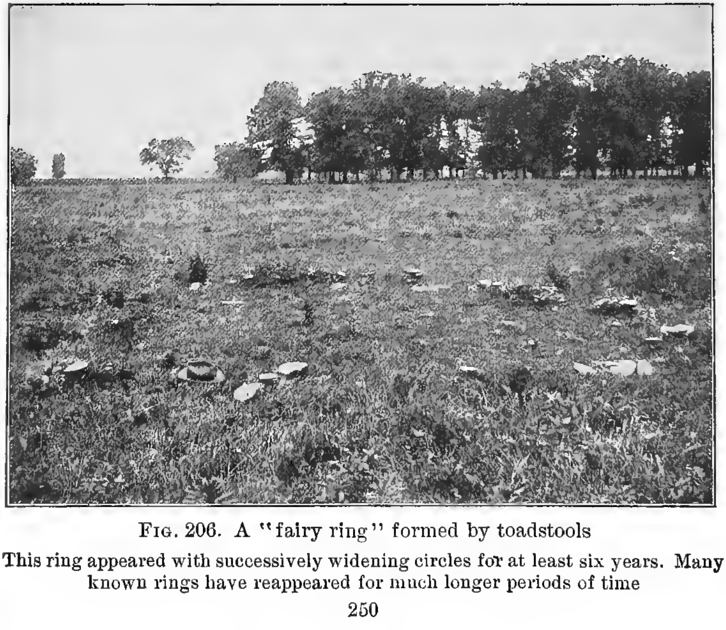

FIG. 206. A "fairy ring" formed by toadstools

This ring appeared with successively widening circles for at least six years. Many known rings have reappeared for much longer periods of time to the fact that the underground mycelium either exhausts all available food, or deposits within the circle secretions which for a few years prevent further growth of this fungus.

Upon logs, trees, and stumps many kinds of toadstools are found, as those shown in Figs. 207 and 208. But most abundant are the various species of *Polyporus* (meaning many pores) and other genera (Fig. 209). These often are hard and woody, and instead of gills they have many small pores upon the under surface, within which the basidia bear the spores. In some species of *Polyporus* the reproductive body may continue its growth annually for many years. Meantime its mycelium, which feeds it, has been growing within the tissues of the host and gradually bringing about its decay. Another toadstool (*Hydnum septentrionale*), the mycelium of which produces the heart rot of the sugar maple, forms a reproductive body which, though its general form is like the

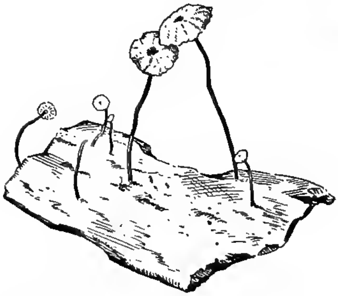

FIG. 207. A group of small toadstools (*Marasmius*) growing from decaying wood

Natural size

FIG. 208. The oyster toadstool growing upon the dead and decaying branch of a tree

Three eighths natural size

FIG. 209. A tree-destroying fungus (*Polyporus sulphureus*) growing at the base of a red-oak tree

About one sixth natural size

common mushroom, has its spores produced upon spines. In deep, moist woods, upon old logs, a species of the *Hydnum* sometimes produces an immense (twenty to twenty-five pounds) edible, coral-like, reproductive body. A coral-like toadstool is *Clavaria* (Fig. 210).

FIG. 210. A coral-like toadstool (*Clavaria*)

One half natural size

The toadstools and mushrooms, both saprophytic and parasitic, are widely distributed. Forest and orchard trees are in great danger of infection by them whenever open wounds are left from broken limbs or pruning. It has been shown[1] that a single *Agaricus campestris* may produce not less than 2,000,000,000 spores; that the "shaggy-mane" mushroom (*Coprinus comatus*) may produce 5,000,000,000 spores; and that *Polyporus squamosus* may produce 11,000,000,000 spores. It is also interesting to note that the same authority estimates that in *Polyporus squamosus* one spore in about 1,000,000,000,000 has a good chance to start a new life cycle.

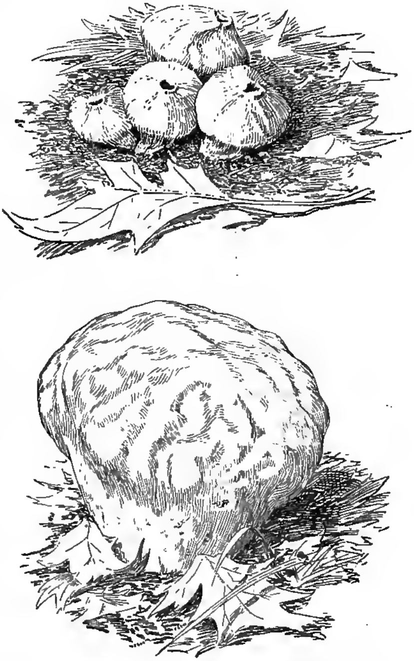

FIG. 211. Two species of puffballs of the genus *Lycoperdon*

Those above are one half natural size, and that below is two ninths natural size

238. The puffballs. These are basidiomycetes whose mycelium usually grows in rich soil, and which have a globular reproductive body that incloses the basidia and spores. Puffballs may range from the size of a pinhead to those that are a foot in diameter (Fig. 211). When ripe they burst open, usually at the top, and small clouds of spores may be emitted at intervals for months and even years. The largest known puffball is *Lycoperdon giganteum*. One specimen of it which measured sixteen by eleven inches was estimated[2] to contain 7,000,000,000,000 spores. It was also estimated that some of the puffballs

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[1] Buller, A. H. R., Researches on Fungi. Longmans, Green, and Company, 1909.

[2] Buller, A. H. R., loc. cit.

may each shed spores at the rate of 1,000,000 per minute, and may continue this for several days. Another puffball is called the "earthstar" (*Geaster*). It grows in sandy and waste places. When its reproductive body is mature the outer surface peels back from the tip, thus exposing the central body, which contains the spores. A closely related form is the stinkhorn fungus (Fig. 212).

The nest fungi are peculiar puffballs which grow within and upon rich earth, well-decayed wood, old manure piles, etc. The reproductive body opens, and resembles a small cup or nest. Within the nest are a few egg-like bodies (Fig. 213), each of which contains a mass of spores.

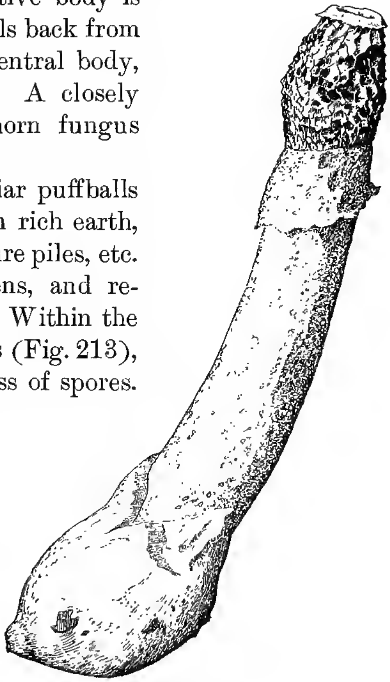

Fig. 212. The stinkhorn fungus (*Phallus*)

At its spore-forming period this has a very foul odor, that attracts flies, which are said to distribute the spores. When young the whole body is a whitish, egg-shaped mass. From this there emerges the stalk, upon the end of which is the spore-bearing crown. One half natural size

239. Summary of the fungi. Because of their extreme simplicity and their close relation to the blue-green algæ the bacteria or schizomycetes were treated first in this series of classes. Then in the chapter following the algæ the class of fungi called phycomycetes, which in many respects resemble green algæ, was discussed. In this chapter classes that are very unlike algæ — the ascomycetes and basidiomycetes and the lichens — are discussed. The bacteria are so simple in structure that they are generally regarded as the simplest living organisms. They reproduce themselves almost wholly by vegetative processes, occasionally by simple resting spores. In their life processes they are of the greatest importance, since they are instruments of decay and soil enrichment, and bear an important relation to various industries. As producers of diseases of plants, animals, and men, they have great significance.

Phycomycetes are sometimes saprophytic and sometimes parasitic. As saprophytes they are instruments of decay, and as parasites they often kill their hosts and then as saprophytes disorganize them. The simpler phycomycetes, as bread mold, reproduce themselves by asexual spores and by forming zygospores, as do some of the green algæ. One of the more complex forms, water mold, lives in the water and reproduces by means of zoöspores; it also forms oöspores by means of special sex organs. Sometimes its oöspores are produced without fertilization. Such forms as the downy mildew of the grape are parasites. They bear conidia, or sporangia-like bodies, upon the leaves of their hosts, and produce oöspores within these leaves.

Fig. 213. Nest fungi growing in soil in which is decaying wood

Within the cup-like plants are the egg-like bodies which contain the spores. Natural size

Ascomycetes have conidia, but are distinguished by the fact that some of their spores are formed in sacs at the tips of hyphæ. These sacs are in open cups, as in *Morchella*, ***Peziza***, and *Sclerotinia;* or inclosed, or almost so, as in the lilac mildew. Some forms (*Penicillium* and yeasts) seem to have lost part of the usual ascomycete life cycle. The life habits of ascomycetes are of great importance in relation to dairy industries, fermentation, and to diseases of economic plants.

Basidiomycetes comprise extremely diversified forms, many of which (smuts and rusts) are not conspicuous except in their spore formation. Striking polymorphic life cycles are shown in the rusts. The rusts and smuts are destructive parasites of the greatest importance. The toadstools and mushrooms, though representing a very large number of forms with world-wide distribution, have a comparatively simple life cycle. They are chiefly saprophytic, though several forms, as the tree-destroying fungi and others, attack living hosts. Puffballs are almost exclusively soil saprophytes.

The lichens exhibit a remarkable case of mutualism or of slavery in which algæ and fungi live together in such a way as to compose a new organism. In these organisms the algæ do the necessary chlorophyll work, and the fungi, it seems, protect the whole organism, thus making life possible in places and under conditions that would otherwise be impossible for both mutualists. Algæ and fungi of the lichen combination reproduce themselves in the ways that are peculiar to the algæ and fungi, and not as a new lichen organism.

240. Classification

Thallophytes
- Algæ
- Fungi
  - *Class I.* Phycomycetes
  - *Class II.* Ascomycetes. Leading genera used as illustrations, — *Peziza* (cup fungus), *Sclerotinia* (brown rot), *Microsphæra* (lilac mildew), *Morchella* (morel), *Penicillium* (blue mold), *Saccharomyces* (yeast), *Claviceps* (ergot), etc.
  - *Class III.* Lichens. Leading genera used as illustrations, — *Parmelia*, *Usnea* (bearded moss), *Cladonia*, etc.
  - *Class IV.* Basidiomycetes. Leading genera used as illustrations, — *Ustilago* (smut), *Puccinia* (rust), *Uromyces* (rust), *Gymnosporangium* (cedar apple), *Agaricus*, *Polyporus*, *Hydnum* (toadstools or mushrooms), *Lycoperdon* (puffball), etc.

CHAPTER XVI

MOSSES AND LIVERWORTS (BRYOPHYTES)

241. Introductory statement. There are two classes of this division of the plant kingdom, — the mosses (*Musci*) and liverworts (*Hepaticæ*). The name *Bryophytes* means "moss plants." Liverwort literally means "liver plant" or "liver root," so called from the supposed resemblances in form between the liverwort plants and the human liver. There is a rather common flowering plant (*Hepatica*) which is sometimes called liverleaf or liverwort. This flowering plant should not be confused with the true liverworts. Also there is a common habit of calling all small green plants "mosses," but when we discover what kind of plants mosses are, we shall find the proper use of this term.

In some respects liverworts are simpler than the mosses, and they are given as the first or lowest class. But it is so much easier to get clear notions of some aspects of bryophytes by a study of mosses that we shall first consider them.

MOSSES

242. The moss plant: the protonema. Mosses of various kinds are widely distributed. Careful observation of a moss plant enables one to see that it has green leaf-like structures arranged around a very small stem. Sometimes also there appears upon this leafy stem a slender stalk with a swollen pod-like tip or capsule (Fig. 216). In this tip are many simple asexual spores, and we shall begin the life cycle by following the germination of one of them.

When an asexual spore germinates there grows from it a filamentous, branching body. Its cells contain chloroplastids and closely resemble cells of many of the green algæ (Fig. 214, *A*). Mats of this growth form upon or within such substances as soil, logs, etc., which are moist and shaded. These

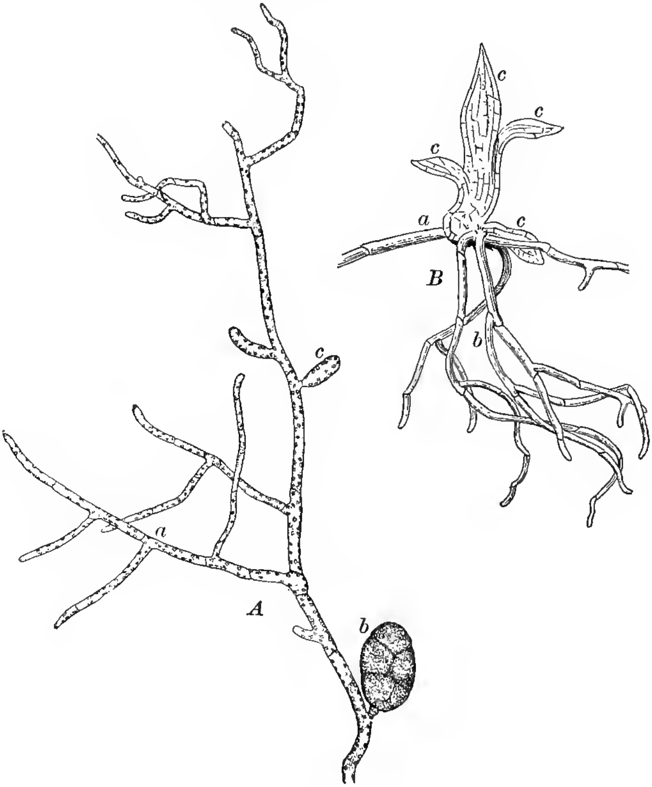

FIG. 214. The moss plant

A, the alga-like protonema with branches (*a*); a young bud (*c*), and one (*b*) which has divided and produced several cells. *B*, a bud which has grown until young leaves (*c*) and rhizoids (*b*) are formed. The old protonema (*a*) is still seen. Both considerably enlarged

growths are so alga-like that in the absence of considerable magnification it is not possible, ordinarily, to distinguish them from the algæ. At times some of the cells become swollen, divide by oblique walls, and form buds (Fig. 214, *A*, *b*). These buds continue to grow, the outermost cells develop leaves, the central ones become the stem, and from the lower ones root-like hairs (rhizoids) descend into the soil (Fig. 214, *B*, *b*). The buds, therefore, are the beginnings of the leafy moss plant (Figs. 215 and 216). Young buds may grow directly into leafy plants, or become dormant for a time and then resume their growth. Since the alga-like growth is that which precedes and produces the leafy moss plant, it is called the *protonema*, meaning "going before the moss."

FIG. 215. A fully formed leafy moss plant

l, leaves; *s*, stem; *r*, rhizoids. Ten times natural size

243. The moss plant: nutrition. Dense growths of moss plants may form from a single mat of protonema. The rhizoids, embedded in soil, humus, or decaying timber, bring these plants into close relation with the water supply. The whole dense growth may serve as a sponge, so that the plants may then be virtually immersed in water. Some mosses really live part or all of the time in streams or bodies of still water. In exposed regions mats of moss may become dry enough to crumble into powder when handled, but, if undisturbed, may proceed with their growth upon the return of moisture. Some mosses also show remarkable ability to withstand extremes of heat and cold.

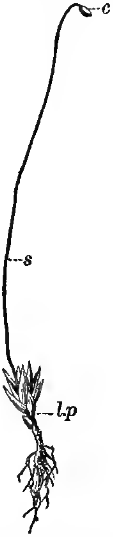

FIG. 216. A leafy moss plant upon which the sporophyte has grown

l.p, the leafy plant; *s*, seta; *c*, capsule. Five times natural size

The stem and leaf arrangement that exists in the mosses exposes chlorophyll to the light in a different way from that which was found in the algæ. With the leaves arranged radially about the stem much more chlorophyll is exposed than could be exposed in the same space by a prostrate plant. The importance of the stem in holding these leaves up into the air, thus making the radial arrangement possible, is evident. It is also possible that no less importance should be attached to transportation of water through the stem to the leaves, though it is not known to what extent moss leaves get their water directly through their surfaces or through the stem. The expanded portions of the leaves are a single layer of cells in thickness, while the median portion may consist of several layers of cells. In the middle (*midrib*) there are rows of elongated cells running from base to tip of the leaf. These constitute the vein of the leaf.

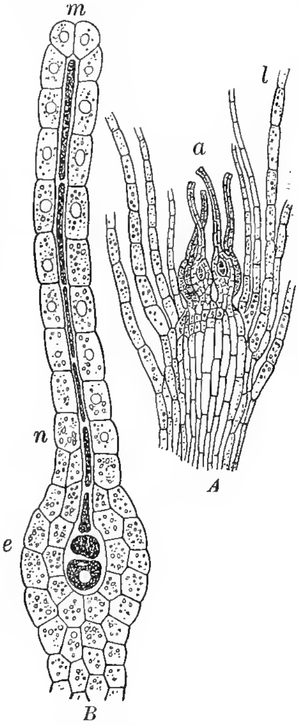

FIG. 217. Archegonia of a moss

At *A* is shown the tip of a stem of a leafy moss plant, with the fragments of leaves (*l*) surrounding a group of archegonia (*a*). At *B* is an enlarged archegonium, in the swollen part of which is the egg (*e*), above it the neck (*n*), containing the neck canal cells, and at the end of the neck are the cells (*m*) which later open to form the place of entrance for sperms. *A*, magnified 100 times; *B*, magnified 500 times. After Sachs

244. The moss plant: sexual reproduction. The sex organs are borne upon the upper end of the stem. If the terminal leaves are carefully removed from plants that are in reproductive condition, two kinds of sex organs together with some sterile filaments (*paraphyses*) may be found. In some kinds of mosses but one kind of sex organ grows upon a single plant, while in other kinds both may grow upon the same plant. Magnification is needed in studying them.

One of the sex organs, the *archegonium*, is flask-like, the neck being greatly elongated (Fig. 217, *A* and *B*). In the swollen part of the archegonium the female gamete or egg is formed. When the egg is mature the central cells in the neck disorganize and the tip of the neck opens, thus leaving a gelatinous passageway into the open end of the archegonium and through the neck to the egg. The other sex organ, the *antheridium*, is club-shaped (Fig. 218), being attached by its smaller end to the end of the stem. Within each antheridium thousands of male gametes or sperm cells form. When abundant moisture is present (dew or rain) the antheridium swells, its tip bursts open, and the contents escape. The biciliate sperms swim about actively, and if some of them come into the vicinity of the archegonium neck they make their way down through the gelatinous passageway. One of the sperms unites with the egg, thus producing the oöspore. It is evident that the difficulty of securing fertilization of the egg in this case is greater than in such plants as *Vaucheria* and *Œdogonium*. But the very large number of sperms produced in moss antheridia helps to make it possible for sperms to be widely spread, thus making fertilization more probable.

FIG. 218

An antheridium (*a*) of a moss. From its tip the sperms (*b*) are escaping, and one of them is shown enlarged at the side (*c*). *a* and *b*, magnified 350 times; *c*, magnified 800 times. After Sachs

245. The moss plant: the oöspore and its product. The oöspore begins to grow almost as soon as formed. It grows from the place in which it was formed, and soon elongates and thickens until its lower end pushs down into the end of the stem upon which the archegonium grew. This gives the lower end a foothold in the stem, and by reason of its close contact this end, or *foot* as it is called, absorbs food material from the stem. The young stalk also bears chlorophyll and may manufacture some of its own food. The upward end elongates rapidly and carries up with it the old archegonium wall, which meantime has grown somewhat (Figs. 216 and 219). This elongated structure is called the *seta*, which means a "bristle" or "hair." Since this old archegonium now changed is like a hood, it is called *calyptra*, which means "hood." Beneath the calyptra, at the end of the seta, there is formed the enlarged *capsule.* Within the capsule, by division of certain specialized cells, large numbers of spores are formed. At the extreme tip of the capsule, beneath the calyptra, is the mouth, or *peristome*, which is covered by a lid known as the *operculum*, meaning the "cover" or "lid." When the spores are ripe the calyptra may fall off and the operculum be thrown off by swelling of the cells immediately below it. There then appears around the margin of the mouth a row of teeth (Fig. 220). The number of teeth in a capsule is definite for each species of moss, and sometimes special students of

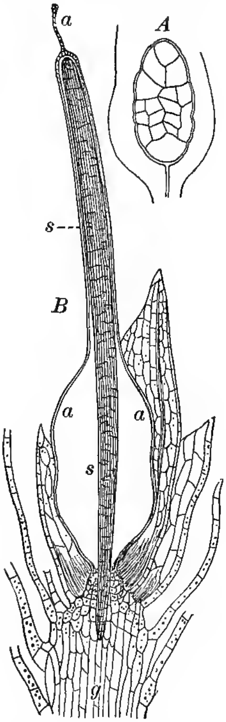

FIG. 219. Growth of the moss oöspore to form the sporophyte

At *A* is a diagram of the oöspore after it has gone through several cell divisions and has spread the archegonium wall. *B* shows the tip of a plant stem with parts of leaves about. The oöspore has grown into a stem-like structure (*s*), has its lower end inserted in the old plant stem (*g*), and the other end has carried up the enlarged archegonium wall (*a*) as the hood or *calyptra*. After Sachs mosses use this number as the basis of distinguishing one species from another. On account of the regular thickenings upon the teeth they are readily affected by moisture changes; that is, they are hygroscopic. When they extend within the capsule the spores adhere to them. As they straighten and extend outward they move with a jerking motion which serves to throw the spores about. A moss may be made to repeat the characteristic tooth movements under a hand lens or low power of a microscope, by being moistened and then fanned until dry.

The spores developed within the capsules are made entirely by cell division and are therefore asexual spores. As seen in Section 242, they may germinate and produce protonema. Because of the large number and wide distribution of asexual spores, abundant production of protonema occurs when the favorable conditions of moisture, light, and temperature exist.

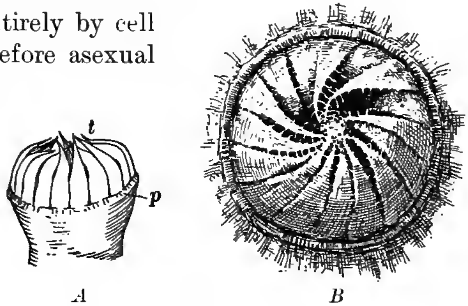

FIG. 220. Tips of moss capsules

A, a side view of a moss capsule showing the teeth (*t*), and the mouth or peristome (*p*), to which the teeth are attached. (Considerably enlarged.) *B*, an end view of a moss capsule. Note the peculiar spiral arrangement of the teeth and the transverse thickenings upon them. (Greatly enlarged)

246. The moss plant: alternate stages in the life cycle. It is evident that in the mosses sexual and asexual reproduction are limited, each to a distinct part of the life cycle. It is also evident that each of these parts of the life cycle forms a kind of spore which, upon germination, produces not the same part of the life cycle, but the other part. The asexual spore that is formed in the capsule germinates and produces protonema, which, by means of buds, produces the leafy plant; the oöspore, which is produced by union of gametes, — the egg and sperm, — germinates and produces the foot, seta, and capsule. The part of the life cycle which produces the asexual spores is called the *sporophyte*, meaning an asexual spore-producing plant. The part which produces the oöspore is called the *gametophyte*, the gamete-producing plant. The sporophyte, therefore, is the asexual generation of moss, and the gametophyte is the sexual generation. The relation that these two bear to one another in the complete life cycle is called the *alternation of generations.*

The fact that the protonema and leafy shoot are distinct structures does not introduce a third generation, since one of those structures grows from the other without the intervention of

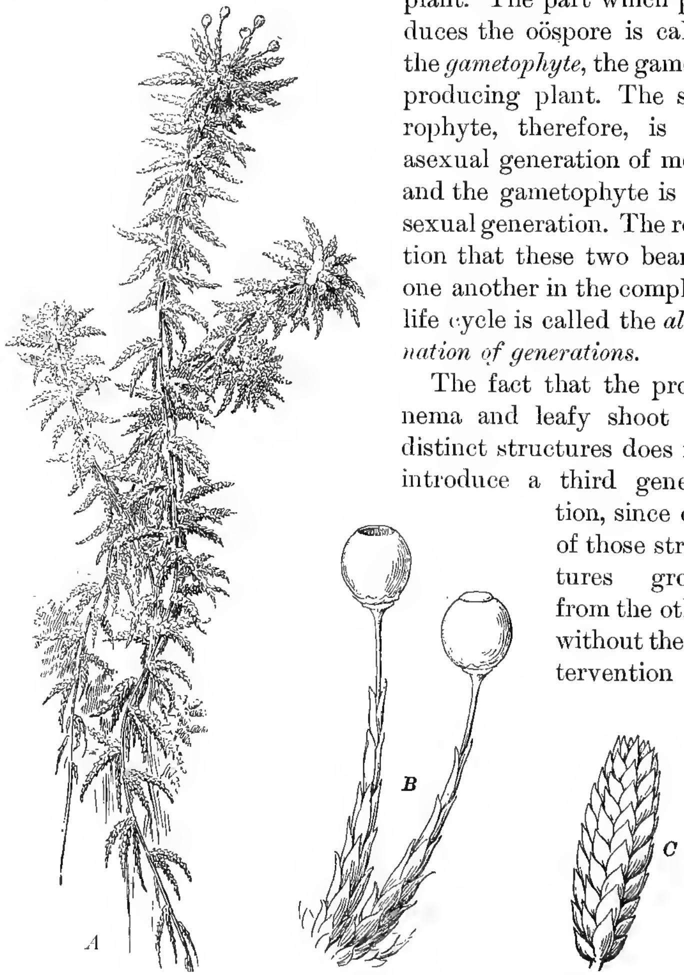

FIG. 221. *Sphagnum*

A, an entire plant which bears capsules upon its tallest branch (natural size); *B*, two sporophyte capsules and stalks enlarged; *C*, tip of a vegetative branch enlarged a spore. It must also be kept in mind that alternation of generations refers to alternation between the sexual generation and the asexual one. In case of several kinds of asexual spore reproduction, such as were seen in some of the parasitic fungi, the term alternation of generations does not apply in its usual meaning, though obviously in such cases there is a series of stages that make up the life round. A more detailed discussion than we have given might show a real alternation of generations in algæ and fungi, but for an elementary study this is not advisable.

247. Kinds of mosses. There are hundreds of different species of mosses, and nearly all of them follow closely the life cycle already outlined. The moss used for the illustrations (Figs. 215–220) is *Funaria hygrometrica*. Another common moss and one of the larger ones is pigeon-wheat moss (*Polytrichum*). In forests it commonly produces thick cushiony patches, and when sporophytes are present they are quite prominent and bear unusually large calyptras.

Peat-bog moss (*Sphagnum*) is a very striking form, which with other plants may form peat. It is common in bogs everywhere, and grows about the edge of the water or upon the extremely wet soil that has been formed by the partial decay of plants. Due to the peculiar structure of the leaves these plants hold water in great quantities, and from a handful of the plants water may be pressed as from a wet sponge. The gametophyte or leafy shoot of *Sphagnum* continues its growth at the plant tip from year to year, and the older buried or submerged portions gradually become partially decayed and intermingled with other plant material. Dense peat masses are thus formed. Such material forms peat fuel, which is compressed, dried, and kept for sale in some markets. The sporophyte of *Sphagnum* is quite unlike that of the moss described above, since it is merely a spherical capsule upheld by the elongated stem of the gametophyte (Fig. 221). *Sphagnum* is used quite commonly as a packing material; it is also used as a covering for holding moisture within the soil of potted plants.

LIVERWORTS

248. ***Riccia.*** Among the bryophytes the liverworts are simpler than the mosses, and some of the liverworts are extremely simple. Upon moist soil at the margins of ponds and streams and sometimes free-floating in quiet water, the small, green, disk-like *Riccia* or *Ricciocarpus* plants may be seen (Fig. 222). Upon careful observation, root-like projections (*rhizoids*) may be observed upon the lower surface. The plant is two-lobed, with a depression or notch between the lobes. This body is frequently spoken of as a *thallus*, though it is not like the thallophyte body. The rhizoids extend downward and backward from the notch. The upper surface of *Riccia* is greener than the lower surface. Near its margin the plant may be but one or a few layers of cells in thickness. Evidently *Riccia*, though a prostrate plant, is much more complex than any of the algæ. It is more complex in that it has distinct upper and lower surfaces, with root-like hairs growing from the lower surface. It is also to be noted that it has a distinct apical or growing end and a basal end. Chlorophyll is borne in the compact body cells, and living as the plant does, upon damp earth or in water, it can readily secure the materials from which foods are manufactured. It is more complex than the protonema of moss, but less so than the leafy shoot.

FIG. 222. A simple liverwort (*Ricciocarpus*)

It has distinct upper and lower surfaces, bears rhizoids (*r*) on the under surface, and branches from a midrib into leaf-like structures (*l*). About five times natural size

In reproducing itself each individual plant of *Riccia* forms within its tissues both kinds of reproductive organs. One of these is an archegonium, the tip of which just reaches the upper surface of the plant. In the swollen part of the archegonium is the large egg cell, which is therefore deeply embedded in the plant tissues. The antheridia also open to the upper surface. From these there escape large numbers of cells, each of which produces a sperm. Sperms enter the neck of the archegonium and one unites with the egg, thus producing an oöspore.

The oöspore does not grow directly into a new plant, but produces an enlarged spherical body which is embedded in the tissues. After a time all of this spherical body except a single layer of outside cells divides into spores. These escape by the breaking down of the tissues of old plants. They may grow into new *Riccia* plants.

The main *Riccia* body is the gametophyte, since it produces the gametes which form the oöspore. The sporophyte which develops from the oöspore is very simple. It is entirely embedded within the gametophyte body. All of it forms spores except a single outside layer of cells. Alternation of generations is as truly present as in the mosses but is not nearly so conspicuous.

249. *Marchantia*: vegetative characteristics. This liverwort grows in moist places, such as swampy regions, shaded river banks, and protected rocky ledges. Sometimes it forms extensive mats, completely covering the material upon which it grows. Single plants may become several inches in length and breadth and many layers of cells in thickness. Its well-differentiated upper and lower surfaces, apical and basal regions, and masses of rhizoids, which are sometimes an inch or two in length, are features which were less developed in *Riccia*. The plants grow forward, the lobes continuing to branch, until at times quite extensive growths are produced (Fig. 223). Older portions may die, leaving the younger branches as new and independent plants.

The nutritive tissues of *Marchantia* are highly developed. There are chains of special chlorophyll-bearing cells in the upper tissues. These semi-open spaces or chambers are near the upper surface of the plant. The surface outline of these is diamond-shaped. Each diamond-shaped superficial layer of cells has in its center a chimney-like pore through which there is atmospheric contact with the internal chlorophyll region. The lower layers of tissue bear less chlorophyll, but they compose the main supporting part of the plant. From these the rhizoids descend. In vegetative structure *Marchantia* is more complex than *Riccia*, or perhaps than mosses, and very much more complex than any of the green algæ.

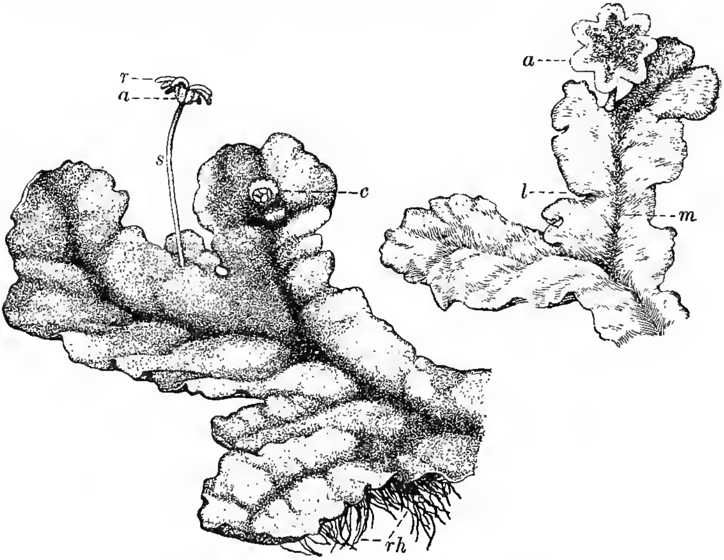

Fig. 223. A common liverwort (*Marchantia*)

The plant shown at the left is an archegonial or female plant: *rh*, rhizoids; c, cupules, in which are buds or gemmæ; *s*, stalk of the archegonial branch; *r*, radiating, finger-like projections of the head; *a*, region in which the archegonia are borne. At the right is an antheridial plant: *a*, antheridial head. Both plants show the leaf-like expansion (*l*) and the midrib (*m*). About one and one-half times natural size

250. *Marchantia*: vegetative reproduction. Upon the upper surface of *Marchantia* in the midrib region there are frequently developed cup-like outgrowths (*cupules*), within which many buds (*gemmæ*) are formed (Fig. 223, *c*). The gemmæ grow upon small stalks from the bottom of the cupules. In a given cupule there may be gemmæ ranging in size and age from those that consist of one or a few cells to those with dozens of cells. These older mature gemmæ are flat, and have two marginal notches, between which there is a marginal scar showing where the gemma was attached to the stalk upon which it grew. The gemmæ may grow directly into new *Marchantia* plants, the notches being the points at which growth begins. Whichever side is adjacent to the earth develops rhizoids and becomes the ventral side, while the other becomes the dorsal side. One can determine which side of a gemma shall develop rhizoids or air chambers by the side of the gemma which is placed next to the soil. Even after growth has begun, if the gemmæ are overturned, the development from and within the surface tissues will change to that which is characteristic of lower and upper surfaces respectively. Formation of gemmæ provides *Marchantia* with a ready and abundant method of vegetative reproduction.

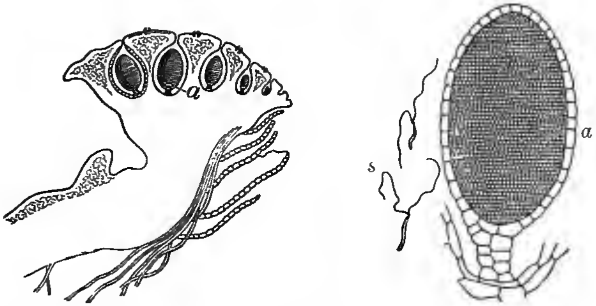

FIG. 224. *Marchantia* antheridial head, antheridia, and sperms

At the left is a section of an antheridial head, showing several antheridia (*a*) embedded near the surface. At the right is shown one antheridium in detail, and at its side are two sperms (*s*) somewhat enlarged. After Sachs

251. *Marchantia:* sexual reproduction. From the midrib region of the flat *Marchantia* body there sometimes grow upright stalks (Fig. 223). The tips of these stalks bear heads of two distinct kinds. One head (antheridial) is flat above and has a slightly indented or wrinkled margin. The other (archegonial) is more drooping and has finger-like rays extending from its main body.

Embedded in the antheridial head are the antheridia (Fig. 224), which open and discharge their sperms in very large numbers upon the upper surface. The archegonia hang downward from the underside of the archegonial head (Fig. 225). The sperms swim, or perhaps are carried by contact with bodies of small animals until they come into the vicinity of the archegonia. They enter the neck and one fertilizes the egg. The oöspore, therefore, is produced in the archegonium, which is pendent from the underside of the archegonial head.

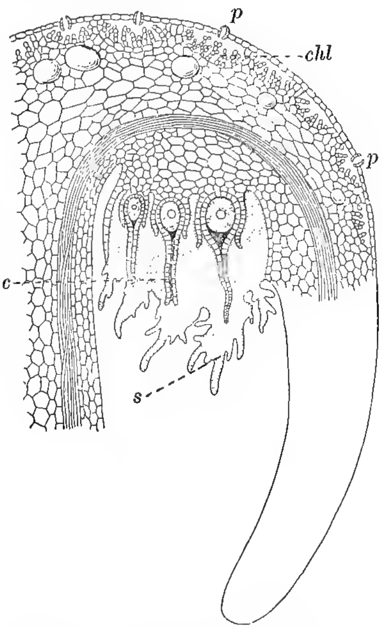

Fig. 225. Part of an archegonial head of *Marchantia* in diagram so as to show the archegonia (*c*) hanging down from the underside of the head. The air pores (*p*), the chlorophyll cells (*chl*), and the loose tissue (*s*) which surrounds the archegonia are also shown

Modified from Bonnier and Sablon

252. *Marchantia*: asexual reproduction. The oöspore begins to grow in the position in which it is formed, and soon produces an oblong body, one end of which is the foot and the other the capsule. The foot absorbs nourishment from the archegonial head at the old archegonial base. Within the capsule many spores are produced by division of the interior capsule tissues. Also some of these interior cells form elongated spiral threads, which, when the capsule bursts, twist and squirm about as they dry or become moist. This twisting motion throws the spores from the open tip of the capsule. These spiral filaments which assist in the distribution of spores are called *elaters*, meaning "drivers," or "hurlers."

The asexual phase or sporophyte of *Marchantia* is not conspicuous, though when mature it sometimes may be seen without magnification. It is evidently a little more complex than the corresponding stage in *Riccia*. This asexual generation has a foot and capsule, while in *Riccia* it consisted of a capsule only. But the moss sporophyte is much more complex than either, since it is much larger, has a foot, seta, and very complex capsule, and bears chlorophyll by means of which it may do photosynthesis.

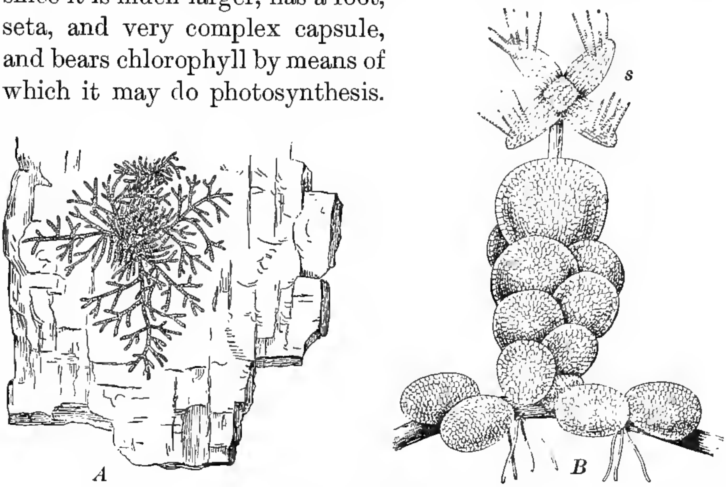

FIG. 226. A leafy liverwort (*Frullania*)

At *A* is a plant about natural size as it appears growing upon a piece of maple bark ; at *B* is an enlarged piece of the same plant, showing its leaves, rhizoids, and the peculiar stalked spore-capsule. Modified after Kerner

253. Other liverworts. There are many kinds of liverworts and they are world-wide in distribution. They are usually found in damp and shady places. A few species live in the water. In the moist tropics they may be found upon the trunks or even the leaves of trees.

The liverworts may have flat dorsiventral bodies, such as were seen in *Riccia* and *Marchantia*, or they may be differentiated into stem and leaf-like organs (Fig. 226), with the rhizoids at or near the basal end of the plants. It is sometimes difficult for any one except a specialist to distinguish some of the leafy liverworts from some of the mosses except when the sporophytes are present. In one group of liverworts, of which the horned liverwort (*Anthoceros*) is the commonest representative, the gametophyte is strikingly simple and the sporophyte equally striking in its complexity (Fig. 227). This plant is widely distributed upon damp rocks, banks of streams, and often in open meadows. The gametophyte is small and extremely thin. The simple antheridia and archegonia are embedded in the gametophyte. After the oöspore is formed, it germinates and produces a sporophyte, which consists of a large swollen foot region and prominent stalk. The foot is well fitted to absorb nourishment from the gametophyte and the stalk bears chlorophyll. The presence of stomata in the stalk further suggests ability to do chlorophyll work. Indeed, if the sporophyte could live with its foot in the soil, it might live independent of the gametophyte. The entire stalk becomes a kind of capsule, part of its tissues forming spores, first at its tip, then lower and lower down to the base. It is the supposed resemblance of the sporophyte to a horn which gave the name horned liverworts to the *Anthoceros* forms.

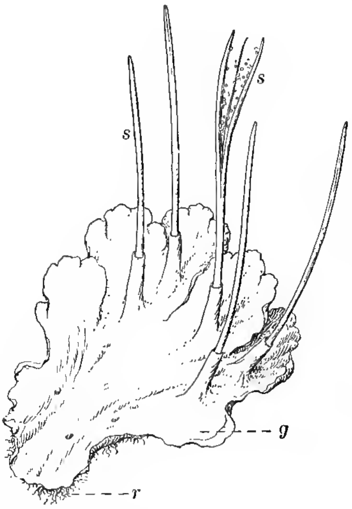

Fig. 227. *Anthoceros*, a liverwort with very simple thallus and complex sporophyte

254. Summary of the bryophytes. The bryophytes are in many respects higher plants than the thallophytes. Sexual reproduction by means of complex archegonia and antheridia occurs upon one phase of these plants, and asexual reproduction by means of special capsules occurs upon a distinctly different part of the plant's life cycle. This constitutes alternation of generations. In the mosses the two generations are easily observed. There is a gradual development of the sporophyte from the very simple condition in *Riccia* through many intermediate forms, one of which is *Marchantia*, to the relatively complex condition in *Anthoceros*. From an entirely dependent sporophyte which is embedded within the tissues of the gametophyte, such as is seen in *Riccia*, there is an increase in complexity of the sporophyte until it becomes an upright, chlorophyll-bearing, almost independent structure. Although almost all of the *Riccia* sporophyte produces spores, the capsule is so small that the total number of these spores is not large. As the sporophyte increases in size and becomes more specialized, proportionately less of it is devoted to spore production, but actually very many more spores are formed, since the whole spore-producing part of the sporophyte is so large. The gametophyte is the chief chlorophyll-working generation in bryophytes, and the sporophyte depends upon it for all or most of its nourishment. Special structures for the performance of nutritive work by the gametophytes exist. These are rhizoids, leaves, and stems. It is worthy of note that in none of the succeeding groups of plants is the gametophyte so well equipped for independent nutritive work as in the bryophytes.

255. Classification:

Bryophytes
- *Class I.* Hepaticæ (liverworts). Leading genera used as illustrations, — *Riccia, Marchantia, Anthoceros*
- *Class II.* Musci (mosses). Leading genera used as illustrations, — *Funaria, Sphagnum, Polytrichum*

CHAPTER XVII

THE PTERIDOPHYTES

256. Introductory statement. This division of the plant kingdom is usually spoken of as the ferns. It must be understood at the beginning of the study, however, that the true ferns constitute but one class of pteridophytes. Two other classes are the scouring rushes, or horsetails, and the club mosses. There are other classes of pteridophytes, but since they are represented by only a few highly specialized plants, and since these are not often observed by general students, they are not of great importance in an elementary treatise. There is abundant evidence that ferns were formerly more numerous upon the earth, and some of them of much larger size than those that now exist. Some of these ancient forms doubtless represented classes that are now extinct, and others were the older members or the ancestors of the classes which we now have, and which in some cases are now represented by only a few kinds of plants.

THE TRUE FERNS (FILICINEÆ)

Those plants which are ordinarily regarded as ferns belong to this class. They may grow in almost any region where any plants are found. Most ferns grow in moist regions, but some species occur in peculiarly dry situations. Although they show considerable variation in form, they can, in nearly all cases, be distinguished from other plants by their greatly divided, feather-like leaves (Fig. 228). There is much range in size of ferns, from very small, lowly plants to those as high as a man's head, and to tree ferns that may be forty feet or more in height (Fig. 229). In some regions dense thickets of ferns are formed.

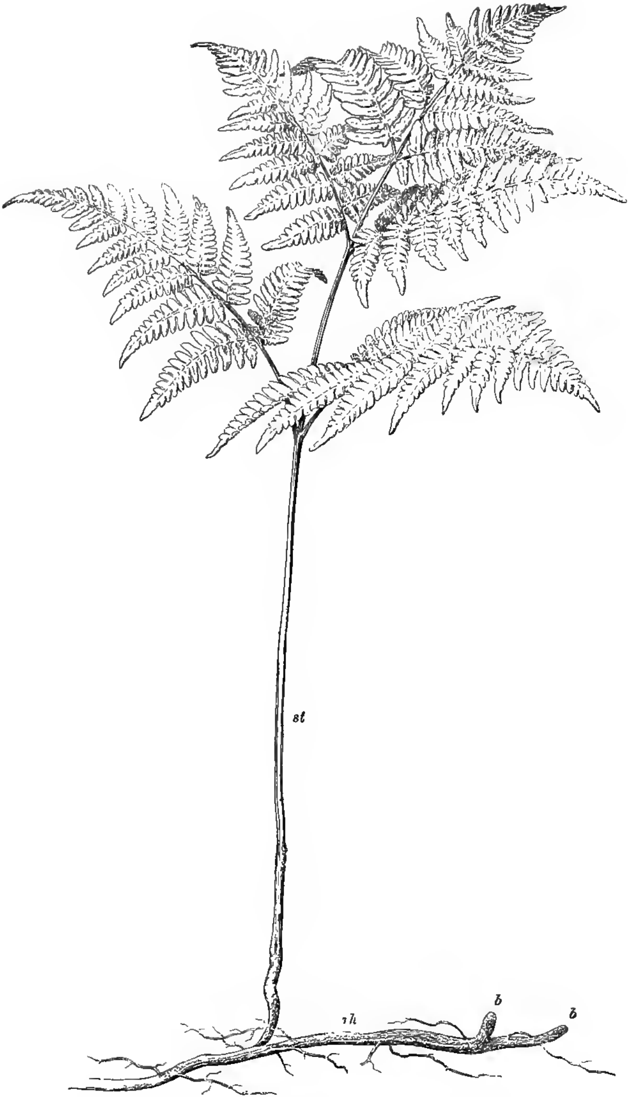

FIG. 228. The bracken fern (*Pteris aquilina*)

The rootstock (*rh*) is horizontal and grows underground; upon it are the buds (*b*) and the upright leafstalk (*st*)

In all except the tree ferns, the parts of the plants that we see are the leaves, the stems and roots being underground. We shall understand the fern class as a whole better if we study one plant in detail, and then consider other forms.

FIG. 229. Tree ferns (*Alsophila*) upon the bank of a stream in Mexico
The larger plant is almost 40 feet in height. Photograph by W. J. G. Land

257. A fern plant: the rootstock (*rhizome*). If we carefully remove the soil from the underground part of one of the common ferns, we shall find the horizontal rootstock (*rhizome*)

(Fig. 228). The lower side of the rhizome gives rise to the roots, and the upper side bears the leaves. At the tip of the rootstock is the bud, by means of which growth is continued from year to year. By carefully studying the leaf scars or the bases of old leaves upon the rootstock, it is usually possible to determine the age of the latter, — that is, the age of this particular fern plant. The terminal bud grows forward each year from a fraction of an inch in some ferns to several inches in others, and at the beginning of each season it sends up one or a few new leaves.

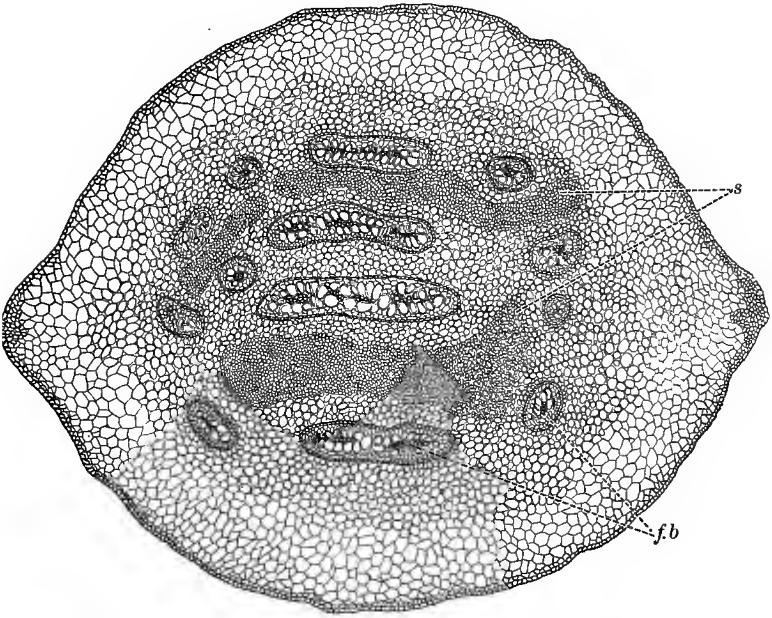

Fig. 230. Diagram of a cross section of the underground stem of a fern

The outer part of the stem is made up of hard tissue and in the interior are also bundles of hard tissue (*s*) known as sclerenchyma; numerous woody bundles (*f.b*) are also surrounded by the large amount of pith

The rhizome of the fern presents the first really complex stem structure that we find as we study the groups of plants in the order of their increasing complexity. This is a woody stem composed of several kinds of stem tissues. Some of these tissues are very heavy-walled and give rigidity to the stem. The heavy-walled cells (*sclerenchyma*) may be around the outside as well as within the stem (Fig. 230). Other tissues are composed of large pithy cells with thin walls (*parenchyma*). These cells are sometimes stored full of food in the form of starch. Still other tissues consist chiefly of rounded, fiber-like bundles which extend lengthwise throughout the stem. These are the *fibrovascular bundles*, which means "fibrous bundles of vessels." A careful inspection of one of these bundles discloses two kinds of tissues composing it, — one usually of large cells with hard, heavy walls (the *xylem*), and the other with thin-walled cells (the *phloëm*). It is customary to speak of the xylem bundle and the phloëm bundle, in which case we should have in the fern a compound bundle, the phloëm being arranged concentrically about the xylem. About these is a layer of cells known as the *endodermis*, meaning "inside epidermis." The fibrovascular bundles are special conducting tissues. Through these water and materials in solution in it are carried to the leaf, and manufactured foods are carried back to stem and roots. It is thought that the water is carried upward chiefly through the xylem, and that manufactured food is carried downward through the phloëm. The fibrovascular bundles extend throughout the roots and leaves.

258. The fern plant: the leaf. By means of a transverse section of the leafstalk it is seen that conducting bundles and sclerenchyma are present as in the rhizome, though the arrangement differs in some ways. The hard surface of the leafstalk is due to the presence of sclerenchyma, and its strength partially to sclerenchyma and partially to fibrovascular bundles. The fibrovascular bundles extend by branches into the green leaflets, where they are recognized as the *veins* of the leaf.

By removing the leaf surface (epidermis) and examining with a microscope its structure may be seen. It consists of a single layer of cells whose irregular walls fit into one another quite closely. In the lower epidermis, rarely in the upper, are the stomata. By means of a transverse section of a leaflet (Fig. 231) the other leaf tissues are seen to be (1) the veins, which appear in cross section as bundles of very small, heavy-walled cells; and (2) the chlorophyll-bearing cells. The uppermost chlorophyll-bearing cells are long and stand close together (*palisade tissue*), with their ends at right angles to the surface. The other chlorophyll-bearing cells are loosely arranged, (the *spongy tissue*) and between them are many air spaces.

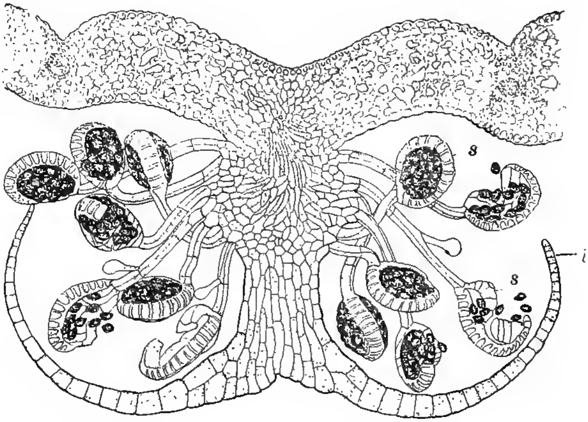

FIG. 231. A cross section of part of a fern leaf, showing the indusium (*i*) and sporangia (*s*) on the underside

After Engler and Prantl

259. Importance of introduction of fibrovascular tissue. It is evident that a fern leaf exposes much chlorophyll to the light, — much more than did any plant among the bryophytes. The strong supporting and conducting tissues of the leaf uphold the chlorophyll tissues in such a position that they may receive light; at the same time, through the fibrovascular bundles of the leaf, soil water may be transported up to the chlorophyll tissue. The root system anchors the plant in the earth and absorbs the water needed in food manufacture.

In general, plants which rise above the soil and into the air must be supported, and must secure water from some source. The climbing vines which are dependent upon other plants are supported by plant tissue, though it is not their own. Most vines procure their supply of water from the soil and transport it by means of their own vascular tissues. Fibrovascular tissue makes possible the upright position and is essential, as is also the absorbent and anchoring root system, alike to the fields of upright grain and to the forests.

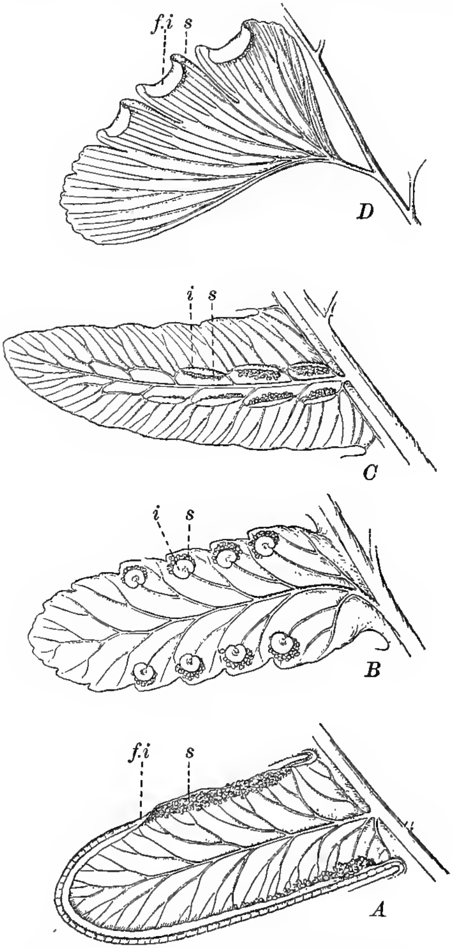

FIG. 232. Leaflets from four kinds of ferns

In the different specimens the sporangia are at *s*, the indusium at *i*, and the false indusium at *f.i.* *A*, bracken fern; *B*, shield fern; *C*, spleenwort; and *D*, the maidenhair fern

260. The fern plant: asexual reproduction. On the undersides of the fronds or leaves of most common ferns there may at times be found small brownish dots (*sori*) composed of sporangia. These dots may each be covered by a shield-like outgrowth from the epidermis (the *indusium*) (Fig. 231), or by the recurved leaf margin, which is known as a false indusium (Fig. 232). Each species of fern has a regular position in which its sori appear, and in some cases their arrangement and relation to the veins are used in distinguishing species from one another.

In most of the common ferns the sporangia are of the form shown in Fig. 233. Each consists of a stalk, at the free end of which is a flattened capsule. Within the capsule, by division of the tissues, numerous asexual spores are formed.

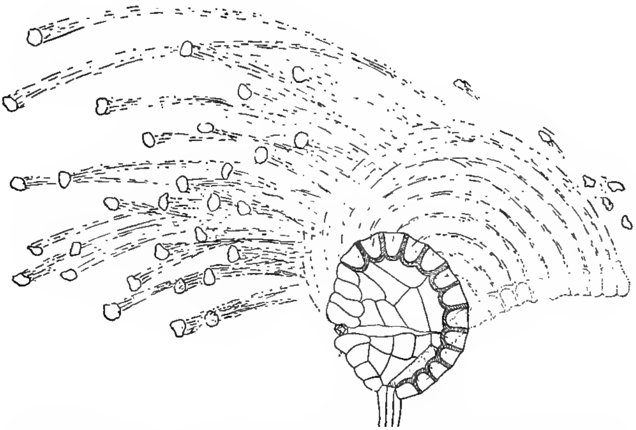

Fig. 233. A fern sporangium, showing its behavior in the process of distributing its spores

Much magnified. After Atkinson

The capsule wall is extremely thin and consists of a single layer of cells. From the end of the sporangium stalk over the capsule, and halfway to the stalk again, is a row or ring (*annulus*) of cells, which have heavy walls on all but the outer side. At the tip of the annulus is the capsule mouth, about which are two pairs of specially formed cells known as the lip cells.

· When the spores within the capsule are ripe, the indusium becomes dry and turns up sufficiently to expose the sporangia. The annulus upon a ripe capsule then begins to dry. Its outer wall, being thin, permits its cells to contract as the whole annulus opens outward. The capsule is torn open at the mouth, and its entire upper half may thus be turned back with the annulus; this occurs so slowly that part or all of the spores within the upper part of the sporangium may be carried back within it. The annulus becomes tense, like a tightly drawn elastic spring,—then flies again into its original position, and in so doing throws spores with considerable force. By mounting sporangia under a low-power microscope, moistening them, and then watching them as they become dry, their action will be seen; but the closing of the sporangia often happens so suddenly as to elude the careless observer, and the spores are usually thrown so far that they are altogether lost.

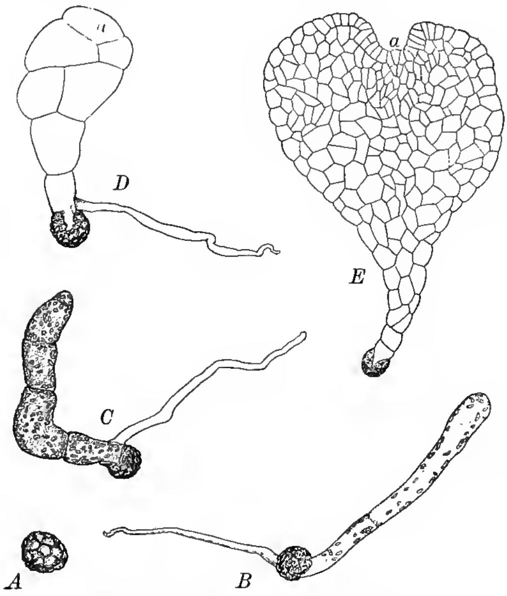

Fig. 234. Development of the fern gametophyte

A, an asexual spore; *B* and *C*, asexual spores germinating, each having produced a green filament and a rhizoid; *D*, the broadening of the green filament and the differentiation of an apical cell (*a*); *E*, a well-formed fern gametophyte; *D* and *E* are diagrams and *E* is made on a much smaller scale than the others. All considerably enlarged

Since these spores are formed within a capsule by division of the tissues, it is clear that they are asexual spores. The complex leafy fern plant is the sporophyte, since it forms asexual spores. It produces these in very large numbers, thus providing abundantly for possibilities of gametophyte production.

261. The fern plant: the gametophyte and sexual reproduction. Upon moist earth, pots in greenhouses, etc., the asexual fern spores germinate. First a stout green cell is produced, and at its base there appears a hair-like cell, the first rhizoid (Fig. 234, *B* and *C*). The green cell grows rapidly and soon divides to form a row of cells (Fig. 234, *D*).

Thereafter the tip, by means of a special apical cell, expands into a broad, heart-shaped plant (Figs. 234, *E*, and 235, *A*). At the margin this plant is one layer of cells in thickness, but along the midrib quite a cushion of cells is formed. From the underside and near the base many rhizoids grow. The presence of chlorophyll, and contact with moist surfaces necessary for water supply, aid the gametophyte in manufacturing its own food.

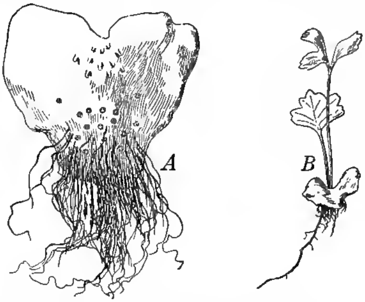

FIG. 235. *A*, a diagram of the underside of a fully formed fern gametophyte, showing rhizoids, antheridia, and archegonia; *B*, a fern gametophyte from which a young sporophyte is growing

Both somewhat enlarged

262. The fern plant: sexual reproduction. Antheridia may be developed upon the filamentous green cells before the heart-shaped gametophyte is formed, or upon the older gametophyte they may develop toward the basal region and on the underside (Fig. 235). The antheridium is a globular structure with a single layer of wall cells (Fig. 236, *A*), and a central cell in which usually thirty-two or sixty-four sperms are formed. In size and number of cells this antheridium is much simpler than that seen in bryophytes. The sperm is, however, quite complex and seems well constructed for swimming (Fig. 236, *B*).

Also on the underside of the gametophyte and nearer the apical region are the archegonia (Fig. 235). Only the necks extend out from the surface, and these usually turn backward toward the antheridia. The enlarged part of the archegonium, where the egg is formed, is embedded in the tissue of the gametophyte. The neck opens (Fig. 237), sperms enter, and one of them unites with the egg. The resulting oöspore is consequently formed within the gametophyte tissue.

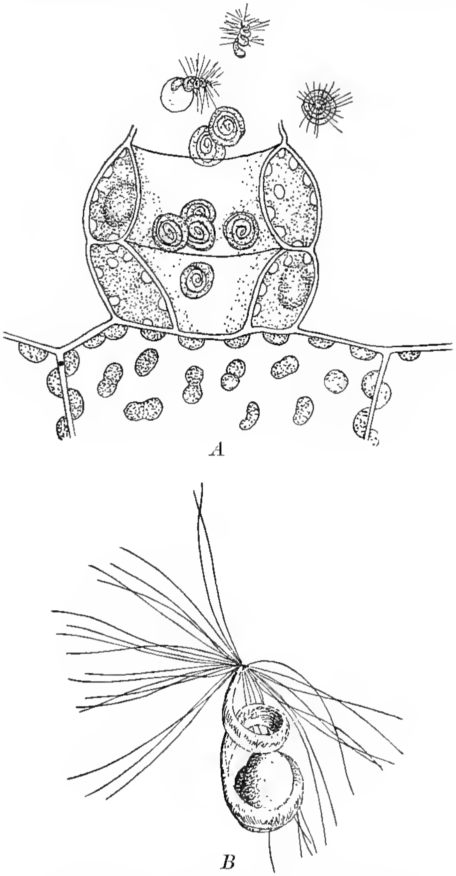

Fig. 236. Fern antheridium and sperms

A, an antheridium from which the sperms are escaping; *B*, one enlarged sperm. All greatly magnified. After Luerssen

263. The fern plant: the young sporophyte. The oöspore begins its growth while still within the gametophyte. It soon produces a foot, which absorbs nourishment out of the gametophyte. It also produces a root, stem, and leaf, and these beginnings of the leafy plant are called the sporophyte embryo. In most ferns the embryo root soon dies and the stem becomes a prostrate underground rootstock from which the new roots grow. The leaf arises into the air and the new sporophyte is thus established (Fig. 235, *B*) as the chlorophyll-working fern of our common observation.

264. The fern plant: gametophyte and sporophyte. Each generation of the fern produces chlorophyll and can manufacture its own food material. In a sense each is an independent plant, but the gametophyte is too delicate to undergo severe climatic conditions. It resembles some of the liverworts, but its sexual reproductive structures are different. The embryo sporophyte that begins to grow within the gametophyte is complex, consisting of foot, primary root, stem, and leaf, though but two of these persist in the adult sporophyte.

This embryo begins its life entirely inside of the gametophyte, but soon emerges and becomes a sporophyte plantlet.

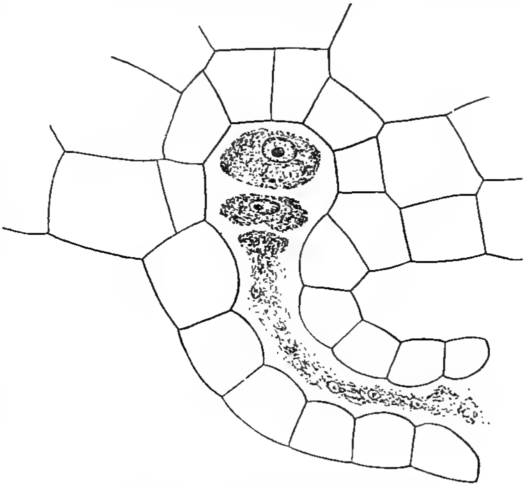

FIG. 237. A fern archegonium

In the neck are the neck-canal cells, and at the base of the neck is the egg. Greatly magnified

It should also be noted that in ferns there is a great reduction in the number of sperms produced in an antheridium as compared with bryophytes, but each sperm is more complex. Reduction in number seems to be balanced by the increased efficiency of those that are formed.

The sporophyte is the prominent fern plant and the chief chlorophyll-working generation. It introduces new sporophyte structures and habits, supporting and conducting tissues, and the upright habit. This condition was forecasted in the sporophyte of *Anthoceros*, but fern sporophytes are very much more complex than those of *Anthoceros*. Though many asexual spores are produced, a comparatively small part of the sporophyte is given to spore formation, most of it doing nutritive work. The fern sporophyte may grow from year to year (is perennial), producing new leaves, a new supply of food, and new crops of spores each year.

The complexity and prominence of the fern sporophyte and the comparative simplicity and inconspicuousness of the gametophyte are forerunners of the greater increase in sporophyte and decrease in gametophyte that is to be found later in higher plants.

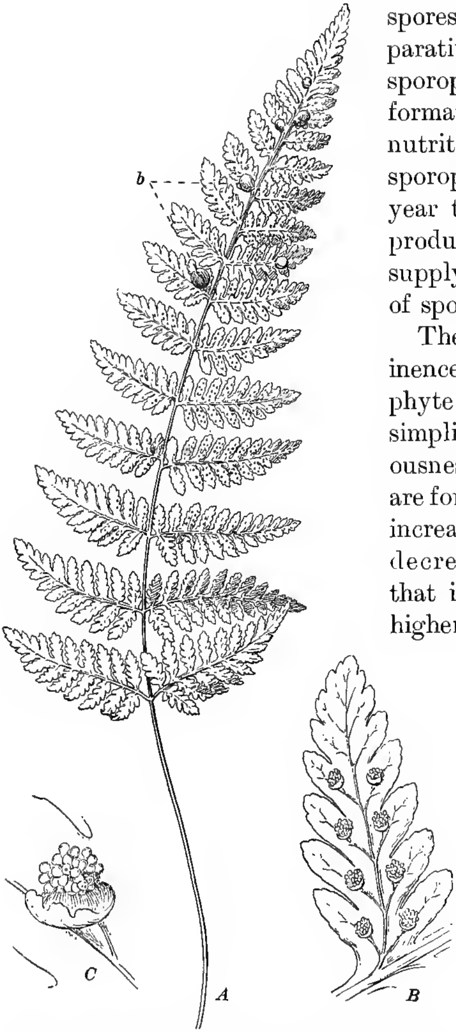

FIG. 238. The bulblet fern (*Cystopteris bulbifera*)

A, a leaf upon which vegetative reproductive growths or bulbs (*b*) are formed; *B*, a section of the leaf on the underside of which groups of sporangia (indusia) are borne; *C*, one indusium in detail

265. Types of ferns. Ferns are usually distinguished from one another by the leaves, the sori, and the sporangia. There is considerable variation in position and arrangement of sori in different ferns (Figs. 232, 238, 239). In some the sori are regularly placed dots upon the leaf. In others, as the maidenhair fern (*Adiantum*)

FIG. 239. At the left is the "interrupted fern," or Clayton's fern (*Osmunda Claytoniana*), in which sporangium-bearing leaflets (*sp*) are distinct and intermediate with foliage leaflets. At the right is the royal fern (*Osmunda regalis*)

A, a leaf with sporangium-bearing leaflets at its tip. *B*, *C*, *D*, stages in the development of sporangium-bearing leaflets from foliage leaflets. Both about one third natural size

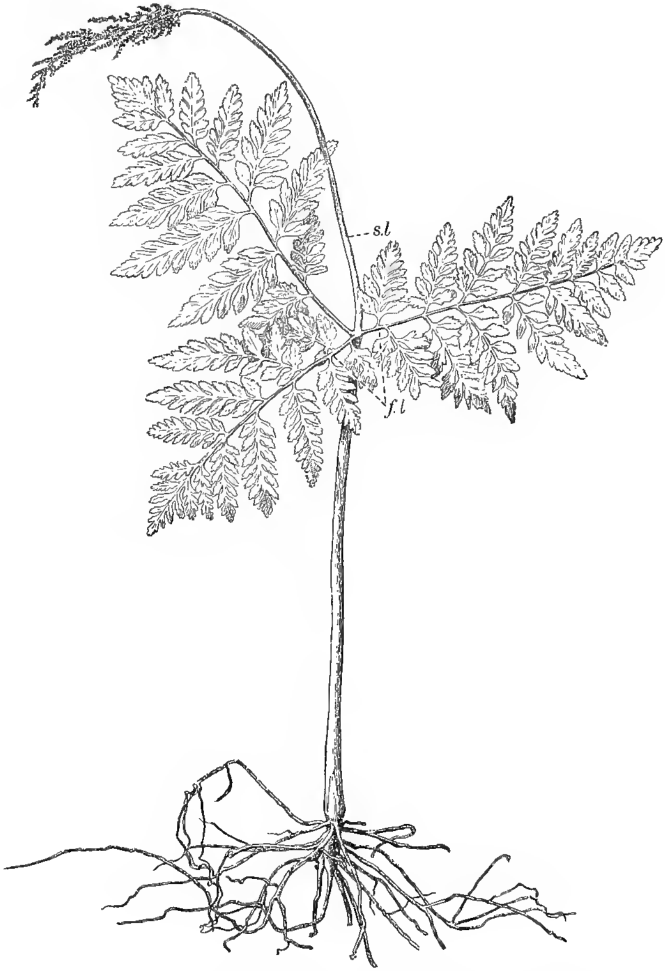

FIG. 240. The Virginia grape fern (*Botrychium virginianum*)

The spore-bearing part of the leaf, sporophyll (*s.l*), is differentiated from the foliage part of the leaf (*f.l*). One fourth natural size

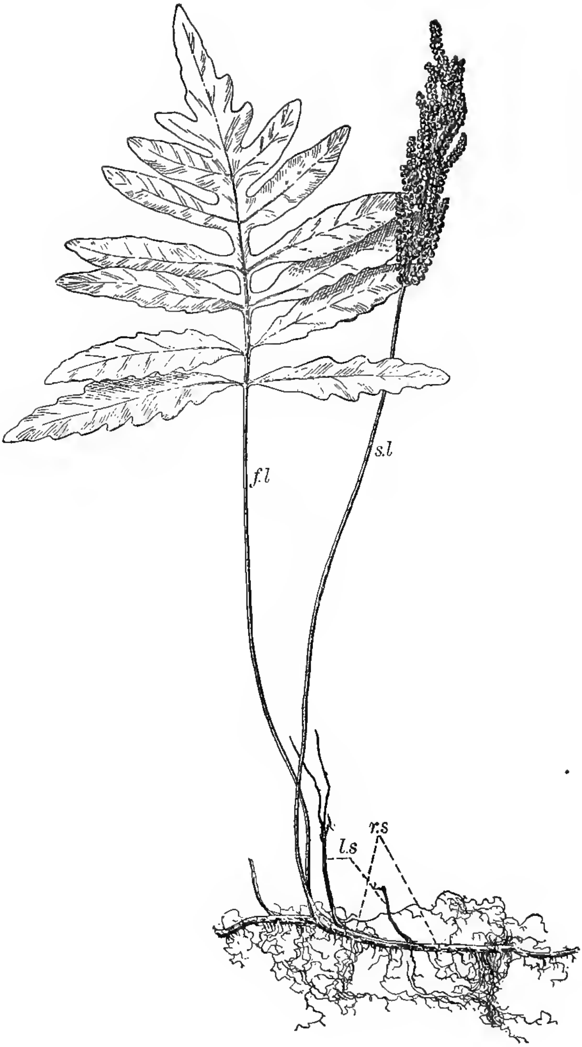

FIG. 241. The sensitive, or oak fern (*Onoclea sensibilis*)

r.s, rootstock or rhizome; *l.s*, leaf bases of former years; *f.l*, foliage leaf; *s.l*, sporangium-bearing leaf. One fourth natural size and the bracken fern (*Pteris aquilina*), and other species of *Pteris*, the sporangia are covered by the folded leaf margins. In the walking fern (*Camptosorus rhizophyllus*) sori are in long slits arranged diagonally to the midrib.

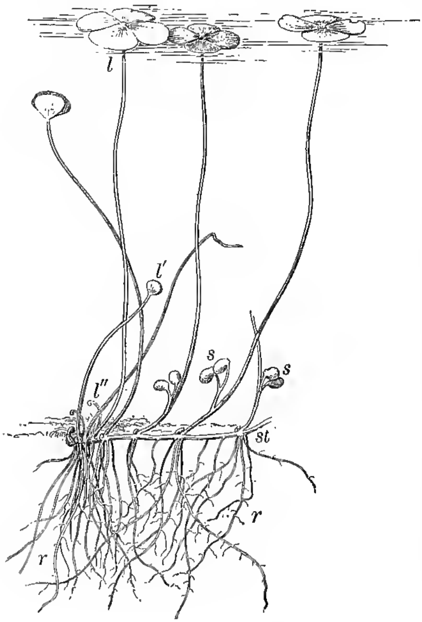

FIG. 242. A water fern (*Marsilia*)

The rootstock (*st*), with the descending roots (*r*), grows in the soil at the bottom of shallow pools of standing water. From the rootstock the leaves (*l*, *l′*, and *l″*) arise. The expanded part of the leaf may float upon the surface of the water, or at times may stand above the water. Special spore-bearing cases (*s*) are borne upon short branches from the leafstalk

In the royal fern (*Osmunda regalis*) (Fig. 239) sporangia are borne only upon tip leaflets. Such leaflets usually bear dense masses of sporangia and do little or no chlorophyll work. Often, however, one may see a single plant exhibiting the following gradation in the development of sporangium-bearing leaflets: (1) chlorophyll leaflets; (2) chlorophyll leaflets with one margin bearing a few sporangia; (3) one entire side of a leaflet bearing sporangia; (4) the entire leaflet bearing sporangia (Fig. 239, *B*, *C*, *D*).

In Clayton's fern, or the "interrupted" fern (*Osmunda Claytoniana*) (Fig. 239), a group of intermediate leaflets are entirely sporangium-bearing. In the Virginia grape fern (*Botrychium virginianum*) (Fig. 240) the leaf is differentiated into a spore-bearing branch and a three-parted chlorophyll branch. In such cases the former is called the *sporophyll*, meaning "spore leaf," and the latter the *foliage leaf.* In the sensitive fern (Fig. 241) and ostrich fern and some others the sporophyll and foliage branches rise separately from the rhizome. This division of labor in fern leaves, resulting in development of distinct sporophylls and foliage leaves, is a great advance. Setting apart special structures for special pieces of work (division of labor) ordinarily increases the quality and quantity of work done.

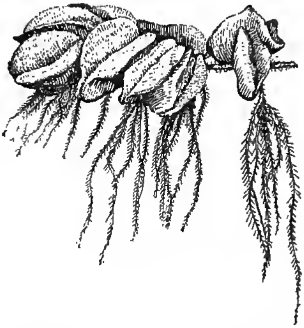

FIG. 243. A water fern (*Salvinia*)

The plant has two rows of hairy leaves and one row of water leaves (which look like roots). Natural size

266. The water ferns. The water ferns are not really members of the true fern class but are closely related thereto. Their water habitat is striking. *Marsilia* (Fig. 242) has peculiar leaves, looking like the four-leafed clover, and these float upon water or stand slightly above it. The plant is fairly abundant in greenhouses and park pools. *Salvinia* (Fig. 243) and *Azolla* are also widely distributed free-floating water ferns.

HORSETAILS OR SCOURING RUSHES (EQUISETINEÆ)

267. General characteristics. This class now consists of one genus (*Equisetum*) and a few species (variously estimated at from twenty to thirty). The class and closely related classes were once abundantly represented, and as tree-like forms were a prominent part of the earth's flora. Fossil remains of equisetums and their relatives tell interesting stories of these tree-like forms which lived during the chief coal-forming periods. In studying present-day forms we are observing the remnants of the former abundant plant life of this class.

Equisetums now live chiefly in regions unfavorable to most plants, — around open marshes, in sandy wastes, and along railway embankments. They have hard, rough, siliceous, and usually unbranched stems. The small leaves form a sheath about the joints of the stem (Fig. 244, *A*, *B*). Most of the chlorophyll is borne in the stem, and little or no chlorophyll work is done by the leaves. The commonest form now living is known as the *Equisetum arvense.*

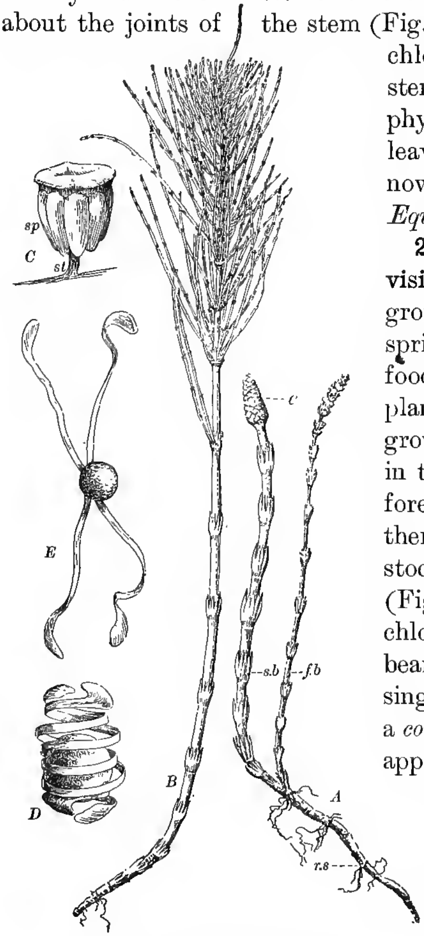

FIG. 244. *Equisetum arvense*

A, a plant in early spring condition; *r.s*, rhizome; *s.b*, spore-bearing branch, with the collection of sporophylls (strobilus or cone) at its tip; *f.b*, foliage branch, which later expands as in *B*; *C*, one sporophyll from the cone, showing the stalk (*st*) and several sporangia (*sp*). *D* and *E*, spore with elaters. *A* and *B* one half natural size, *C* magnified about twenty times, and *D* and *E* greatly enlarged

268. *Equisetum arvense:* division of labor. The underground rootstock is, in early spring, stored with starchy food that was made by the plant during the preceding growing season. Very early in the spring, sometimes before the last snows are gone, there grows up from the rootstock one sporophyll branch (Fig. 244, *A*). This has no chlorophyll, and at the tip bears the sporophylls in a single dense spike known as a *cone* or *strobilus.* Soon there appears from the rootstock another branch which bears chlorophyll. The sporophyll branch soon dies, but the chlorophyll branch subdivides extensively, producing a heavy, bushy plant, —the "horsetail" (Fig. 244, *B*). This grows throughout the season and manufactures food, some of which is deposited in the rhizome and used in producing next season's sporophyll branch. In all the other known species of *Equisetum* the sporophylls grow upon the same branch that does the chlorophyll work.

269. *Equisetum arvense:* reproduction. At the tip of the sporophyll branch is the collection of sporophylls. Each (Fig. 244, *C*) has an outer shield-like surface which grows at the end of the sporophyll stalk. From the under surface of the sporophyll the sporangia grow. The spores are peculiarly wound about by elaters (Fig. 244, *D* and *E*), which, as they unroll and twist about, may assist in spore distribution.

These asexual spores germinate almost immediately when ripe, and develop into gametophytes, each one of which produces but a single kind of sex organ; that is, a gametophyte is male (produces antheridia) or female (produces archegonia). After fertilization the oöspore germinates and produces a new sporophyte, thus completing the life cycle.

THE CLUB MOSSES (LYCOPODINEÆ)

270. This class includes the two genera *Lycopodium* and *Selaginella*, though fossils show a former abundance of related genera. Both are very widely distributed and have many species. At Christmas time these plants are often used for decoration and are called "club moss" or "ground pine." The rootstock of *Lycopodium* often grows upon or just beneath the old leaves, frequently sending upright branches (Fig. 245) into the air.

Selaginella often has an almost upright stem. Roots may arise from portions of this stem that are in the air. Leaves are spirally arranged. In some of the more prostrate *Selaginella* forms the leaves have become differentiated so as to appear in two small and two large rows.

271. Reproduction in *Lycopodium* and *Selaginella*. At the tips of branches strobili, or cones, are formed in most species by ordinary foliage leaves becoming sporophylls without losing their chlorophyll. These sporophylls are closely appressed (Fig. 245), thus forming a dense cone. In a few species the sporophylls are loosely arranged. In the axils of leaves sporangia are formed, and in these are large numbers of asexual spores. So numerous and so light are these spores that they have been used as the commercial article now known as *Lycopodium* powder. When these spores germinate they produce underground tuberous gametophytes, upon one of which both sex organs may form. Fertilization, which is extremely difficult to study in this genus, occurs underground. The oöspore produces the young sporophyte, which grows up from the ground somewhat as does the seedling of higher plants.

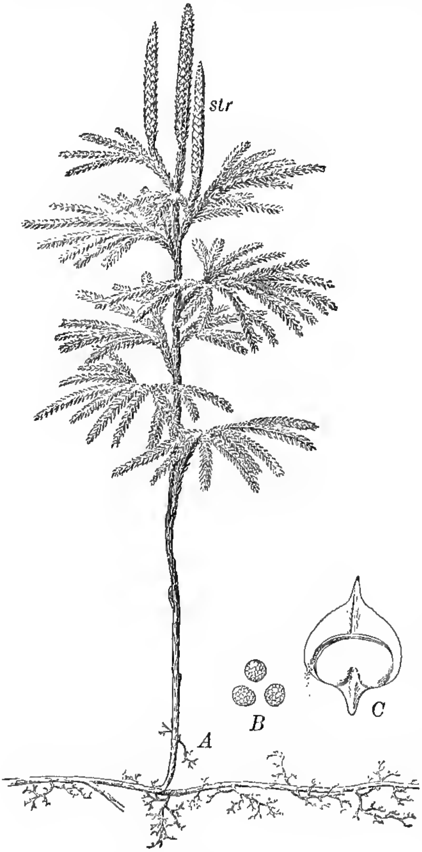

FIG. 245. A club moss, or ground pine (*Lycopodium*)

The horizontal rootstock with its roots grows within or upon the humus. The upright branches (*A*) bear green leaves and strobili (*str*), also called spikes or cones, in which spores are formed. At *C* is shown one leaf from the strobilus, and upon this leaf is a sporangium. From the partially opened sporangium spores escape. At *B* enlarged spores are shown

The reproduction of *Selaginella* differs from that of *Lycopodium* in the important fact that the asexual spores are of two kinds, one very small and one very large.

This results in the production, from the small spore, of a small gametophyte, which produces sperms; and from the large spore, of a large gametophyte, which produces the egg, and upon which thereafter the young embryo *Selaginella* plant is developed.[1] All the groups of plants higher than pteridophytes have two kinds of asexual spores.

272. Pteridophytes of past ages. The surface of the earth has undergone many changes since plants began to live upon it. In some periods of the earth's history conditions favored certain kinds of plants and these flourished. When less favorable periods came these successful plants were greatly reduced in number or completely exterminated. We have records of what some of these former plants were. These records were made by the plants themselves, for when they died they sometimes became fossilized, or made prints in soft mud or other substances which afterward hardened. By means of fossils much is being learned about the kinds of plants that used to exist. In many cases great detail of structure has been preserved, and many important facts are thus established with reference to the history of our existing plants. The study of

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[1] In some cases it may be wise to go more into the details of the reproduction of *Selaginella*, and for such use the following facts are added: The terminal cones or strobili of *Selaginella* resemble those shown in *Lycopodium*. In *Selaginella*, however, two kinds of sporangia with two kinds of spores are formed. One sporangium contains large numbers of small spores, while the other sporangium contains four large spores. Both kinds are asexual, since both are formed upon the sporophyte by cell division. The small spore is called the *microspore*, meaning "little spore"; the large one is called the *megaspore*, meaning "big spore." Similarly, the names of other structures relate to the size of the spores; as, the *megasporangium* which produces the megaspore is borne upon the *megasporophyll*, and the *microsporangium* which bears the microspores is borne upon the *microsporophyll*. We have in *Selaginella* different kinds of spores, or *heterospory*, as compared with similar asexual spores, or *homospory*, as seen in the other ferns that we have studied. Each spore produces a particular kind of gametophyte, one of which bears the egg and the other the sperm. The egg is fertilized while within the female gametophyte, and the new plant begins to grow from the same position. If the structures around the embryo should become dry and hard, and if the whole should undergo a resting period, we should have the structure that we call the seed in the next great group of plants.

fossil plants, or *paleobotany* as it is called, offers a field of great interest to the specialist.

Ferns and their relatives are among the principal fossil plants concerning which paleobotany has given us information. The introduction of vascular tissue furnished structures better fitted for preservation than there were in the less rigid bryophytes and thallophytes. It has been definitely determined that pteridophytes and other plants resembling them were once more abundant and larger than those now living. These ancient ferns were widely distributed over the earth. Certain periods (as the so-called Carboniferous Period) were peculiarly favorable in temperature and abundant moisture to the growth of pteridophyte types of plants, and they grew in size and profusion much greater than even our present tree fern forests of the moist tropics. Their range extended much farther than at present. Many of these giant forms were very unlike our existing ferns, horsetails, and club mosses, but they are the ancestors from which our present forms have descended.

During these periods there also lived plants which are closely related to some of the seed plants.

273. Coal formation. There have been several coal-forming periods during the history of the earth. The Carboniferous age, however, is the period of chief coal formation. During this time almost unimaginably large quantities of plant life matured and fell in the immense swampy areas in which they grew. As is true when *Sphagnum* and other plants in peat bogs decay but partially, and under moderate pressure become peat, it is thought that in the same way these much larger masses of plant life formed immense beds of partially decayed plant material. After a long period of such growth and deposition of plants conditions changed, and these masses of plant material became submerged and then buried beneath layers of rock and earth. The surplus water in the beds of plants was driven away, the carbonaceous material was pressed into solid masses, the oily materials were pressed out, or, as has been said, under the pressure the coal "wept bitter tears of petroleum."[1] *Hard coal* is carbon, with some ash-forming substances, while *soft coal* contains ash-forming substances and volatile matter which produces smoke when the coal is burned.

The amount of plant material required to form an ordinary bed of soft coal 10 feet in thickness is estimated to be about 1500 feet in thickness. There may be several layers of coal separated by layers of rock. When we recall that the United States has several hundred thousand square miles of coal lands, we obtain some notion of the enormous amount of plant growth necessary to form this deposit. It has been estimated that the body of a tree, which when dry weighs 11,000 pounds, contains 5500 pounds of carbon. A piece of ordinary soft coal 10 feet high and 1 foot square might weigh as much as 8750 pounds. The pteridophyte plant body is not nearly so solid as our woody trees, thus necessitating greater bulk to secure a corresponding amount of carbon.

274. Summary of pteridophytes. The true ferns are widely distributed and successful plants. The possession of fibro-vascular tissue enables these plants to assume a position of prominence and to expose chlorophyll to the light in greater abundance than is done by bryophytes. Well-organized woody stems and elaborate leaf structures are further suggestions of increased ability to do the work of plants.

Both generations of the true ferns bear chlorophyll. The gametophyte is simpler than that of bryophytes, but has all the structures requisite to enable it to live for a time in an independent way. The embryo sporophyte originates from the oöspore within the gametophyte tissue. The sporophyte is the prominent (often perennial) generation of the plant. It is very much more highly differentiated than the same generation in the bryophytes. Its complex sporangia, formed upon specialized areas of the leaf, produce and distribute spores in very large numbers. In some species special sporangium-bearing leaves (sporophylls) are produced.

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[1] Jordan, David Starr, Science Sketches, essay upon "The Story of a Stone.'

Pteridophytes once were much more abundant than they now are, and were prominent in the earth's flora during the chief coal-forming ages. Some classes have ceased to exist and others are now represented by relatively few species.

Once the horsetails, or scouring rushes, and the club mosses, or ground pines, contained many tree-like forms. Now the first class contains but one genus and a score or more of species, and the second contains two genera and several hundreds of species. The water ferns consist of four highly specialized genera. In the Equisetineæ and the Lycopodineæ sporophylls are arranged in a spike or cone (strobilus). In one genus (*Selaginella*) of the class Lycopodineæ two kinds of asexual spores are borne, — one which, upon germination, produces the male gametophyte, and one which produces the female gametophyte. Within this female gametophyte the embryo sporophyte is produced.

275. Classification:

Pteridophytes

- *Class I.* Filicineæ (the true ferns). Leading genera used as illustrations, — *Pteris* (the bracken fern), *Alsophila* (a tree fern), *Adiantum* (maidenhair fern), *Camptosorus* (the walking fern), *Osmunda* (royal fern and Clayton's fern), *Botrychium* (the grape fern), *Onoclea* (sensitive fern and ostrich fern), *Salvinia* and *Marsilia* (water ferns)
- *Class II.* Equisetineæ (scouring rushes, or horsetails). Genus used as illustration, — *Equisetum* (the only living genus of the class)
- *Class III.* Lycopodineæ (club mosses, or ground pines). Leading genera used as illustrations, — *Lycopodium* and *Selaginella* (the living genera of the class)

CHAPTER XVIII

GYMNOSPERMS

276. Introduction to spermatophytes. The highest division of the plant kingdom is the *seed plants*, or spermatophytes. The name means "seed plants." This is the division usually thought of when people speak of plants, since in it are the forms that make up the conspicuous flora of the earth, as well as those that furnish most of our food, timbers, fibers, etc. It is the division with which agriculture, horticulture, gardening, and many of the industries are chiefly concerned. It is highly important botanically as well as economically.

There are two great classes of the division, — the gymnosperms, or naked-seeded spermatophytes, and the angiosperms, or inclosed-seeded spermatophytes. In this chapter we shall discuss the gymnosperms.

277. The pine. There are over four hundred living species of gymnosperms. Of these the most widely distributed member is the pine (*Pinus*, Fig. 246). There are many species of pines, and while but a few kinds are usually found in one locality, the resemblances between all of them are such that one is likely to recognize a pine if once he has carefully noted the characteristics of any species.

Sometimes pines form dense forests of tall, straight trees. They often stand close together. It is only when they grow thus crowded that they become tall, since when growing alone in open regions they secure ample light without attaining such a height. In German, American, and other forest plantations young pines are planted close together; then when they have reached toward the light and have acquired a medium height, some are removed and used, and their removal gives the remaining trees more space in which to spread. Finally, new young trees are planted, and they attain considerable height by the time the last of the oldest crop are harvested (see Chapter XXII).

278. The vegetative plant. The plant has a heavy central taproot (Fig. 247), which extends deep into the soil. From the taproot there develops an extensive system of roots, some reaching downward, and even more outward, into the soil, in this way forming an abundant root system that anchors the plant and distributes the youngest rootlets in favorable positions in the soil.

FIG. 246. A white pine (*Pinus Strobus*)

The stem is almost straight, the branches stand approximately at right angles to the stem, and the top is irregularly conical

The stem is generally straight and the branches usually rise in whorls. Sometimes in older trees many branches have died, and but one or two of each whorl are left. The lower branches are usually longest, the top ones shortest, and the intermediate ones grading between these extremes, so that the whole tree top is often quite cone-like in outline. The stem and branches are covered by a heavy bark, and the roots by a bark which is usually not so thick. The leaves are on the younger branches. The *needle leaves* are most conspicuous, and at their bases and on the terminal buds are the brownish *scale leaves.*

The needle leaves (Fig. 248) are borne in pairs, in threes, in fives, etc., the number varying with the different species. The number of leaves in a cluster is one of the distinguishing characteristics of species; for example, the white pine (*Pinus Strobus*) has five leaves in a cluster, the scrub pine (*Pinus divaricata*) and others have two leaves in a cluster, the Georgia long-leaf pine (*Pinus palustris*) has three, and others may have a variable number (2–5) in each cluster.

FIG. 247. An old pine tree (*Pinus Strobus*), from whose roots the sand has been blown away, thus exposing the taproot and killing the tree

The lateral roots have been removed from one side, but they show at the right of the picture

If one of the clusters is pulled from the branch and stripped of its basal scale leaves, there will be seen a very small whitish branch upon which the needle leaves grow. The needle leaves are really continuations of these small branches. The inward faces of the leaves are so arranged that all of one cluster when put together compose a cylindrical leaf mass.

That is, when two leaves compose the cluster, the leaf branch is divided into halves; when three or five are in one cluster, the branch is divided into three or five parts.

Leaves of pines are not literally *evergreen*, as is sometimes supposed. In different pines the leaves remain on the branches different lengths of time. In all species, after a period ranging from two to four years the older leaves fall. There is no definite brief period when all the leaves are discarded, as in *deciduous* plants, but they fall a few at a time.

FIG. 248. A branch of a pine

At the left (*c*) is a one-year-old cone, and at the tip of the shoot (*s*) a very young cone (*yc*) just open and ready to receive pollen. On the young shoot are the young needle leaves, and at the tip is the bud (*b*), which continues the growth of the stem

The leaf bases are spirally arranged upon the branches. This may be observed either on the leafy branch or by means of the leaf scars left upon branches from which the leaves have fallen.

279. The structure of needle leaves. The hard surface of the leaves is due to the very heavy-walled epidermis and several underlying layers of heavy-walled strengthening cells (sclerenchyma) (Fig. 249). Stomata in the epidermis are deeply placed, and oftentimes their pores are clogged with dust so that they appear quite dark. Beneath the strengthening tissue is the chlorophyll tissue, through which run the resin ducts. In the interior of the leaf is the pith region, through which run two groups of fibrovascular bundle cells.

The well-protected chlorophyll tissue seems able to withstand severe conditions. Its temperature changes probably occur very slowly. It conserves its water supply in such a way that it lives through conditions that would kill deciduous leaves. The leaf surface is greatly reduced. The leaf seems to have secured protective form and covering at the expense of abundant chlorophyll exposure. It can perhaps begin to work earlier in the season and work later than can deciduous leaves.

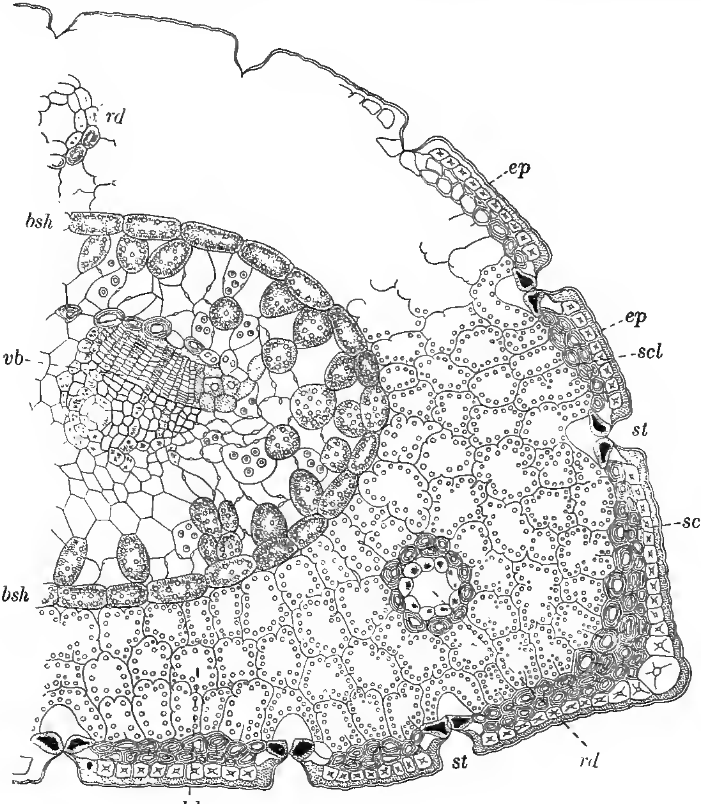

FIG. 249. Part of a cross section of a pine needle leaf

ep, the epidermis, upon which is a layer of cuticle; *scl*, a layer of heavy-walled cells, or sclerenchyma; *st*, stomata with deeply placed guard cells; *chl*, chlorophyll-bearing tissue; *rd*, resin ducts or channels; *bsh*, bundle sheath which incloses two vascular bundles, one shown at *vb*

280. The branch and stem. By means of transverse sections of branches of different ages the general structures of the stem may be observed. Innermost is a small pith region, which in older stems is compressed until it is not usually noticeable. Around this is the woody tissue, — the xylem of the fibrovascular bundles. The xylem from all bundles is joined in such a way as to form a solid woody (xylem) cylinder. It is possible to determine the age of the twig by counting the layers or rings of wood. If two distinct growth periods occur, as rarely takes place in one season, two rings of wood are formed; hence this is not always an absolutely accurate method of determining the age of a stem. At the outer edge of the woody tissue is a thin layer of cells, the *cambium*, which separates the xylem and phloëm cells. The cambium is actively growing tissue which produces new xylem within and new phloëm without. The tissues outside the phloëm, which we need to notice in this connection, are the green bark and dead bark. Dead bark is constantly being formed from green bark within, as green bark is from tissues within itself. This results in making the dead bark constantly thicker, until finally in older branches and stems light penetrates through it poorly if at all, and chlorophyll ceases to be developed.

FIG. 250. The "grizzly giant big tree" (*Sequoia Washingtoniana*)

The 20 × 100 foot scale will help to show the size of the tree, especially if one pictures the height of some known object at the side of this scale. This tree is 275 feet high, 93 feet in circumference at the base, and 64 feet 3 inches in circumference at 11 feet from the ground. Original negative by Mode Wineman

The ridging of bark is due to the fact that bark on young branches and stems, when the stem enlarges and produces new tissue, is so spread that longitudinal crevices are formed. As more new wood and bark is built within, the spreading and thickening are increased and ridges and crevices become more pronounced.

281. New vegetative growth. The production of branches and needle leaves begins in the late summer and autumn. When winter arrives, within the large buds the next year's growth is complete in miniature. The next spring the bud opens, the new branch extends (Fig. 248), and its needle leaves begin to elongate. In a very short time the elongation is complete, and within a few weeks the young needle leaves are full-grown. By observing the number of terminal bud scars from the tip to older portions of a branch the age of a branch may be determined. It will be interesting to ascertain how many years' growth can be determined by counting the bud scars.

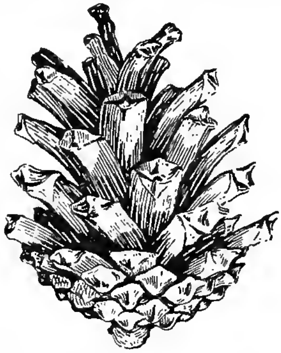

FIG. 251. An old pine cone which has opened and dropped its seeds

One half natural size

282. Significance of the stem. In the series of groups of plants that we have hitherto studied, no plant stem is nearly so complex as that of the gymnosperm trees. In the ferns we had vascular tissue, but in pines and their relatives the vascular tissue is organized into a massive woody stem, one often of immense height and thickness (Fig. 250). In the struggle for light these plants have been highly successful. Such great height and thickness as are attained involve an equally well-developed root system.

To industry the gymnosperm stem is of immense significance. Pines and some other gymnosperms and many angiosperms have stems upon which much of the world's work depends. All sorts of useful and ornamental manufactured products depend upon these timbers, and it is not easy to overestimate their value to mankind.

283. Asexual reproduction. Two kinds of cones are borne upon a pine plant. One is the seed cone (Fig. 251) and the other is the staminate cone. An examination of a young seed cone will at once show structures somewhat similar to those of *Lycopodium* and *Selaginella.* The cone is composed of leaf-like structures, on the upper sides of which ovules (megasporangia) (Fig. 252) are borne. In the ovules large cells, the megaspores, are formed, but one in each megasporangium. The spore does not escape from this megasporangium. Before relationships between spermatophytes and pteridophytes were known, the megasporangium was always called an *ovule*, a name which is still largely used.

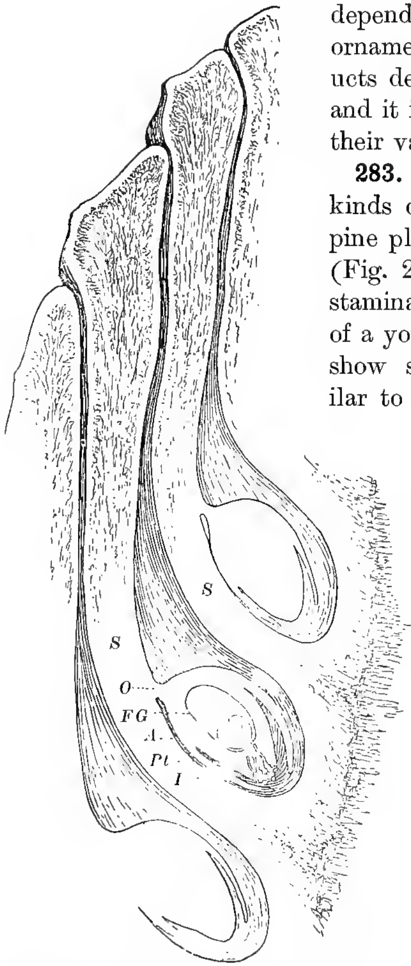

FIG. 252. Diagram of part of a seed cone of a pine, with ovules in normal position

S, sporophylls, or leaf-like parts of the cone; *O*, ovule (megasporangium); *I*, the covering of the ovule, called the integument; *FG*, the female gametophyte, which bears the archegonium *A*, in which the egg is formed; *Pt*, pollen tubes from pollen grains which lie upon the tip of the ovule

The staminate cones bear the microsporophylls or stamens (Fig. 253), upon which are borne microsporangia. In the microsporangia, microspores or pollen are formed. They have peculiar wing-like outgrowths (Fig. 254), which help to buoy them upon the wind. The pollen is shed in great quantities and may be carried long distances by currents of air. Indeed, so extensive are the showers of microspores of pines at times, that ignorant people have imagined that they were showers of sulphur from some distant active volcano. Early names and more recent ones, all of which are still used for the structures of the staminate cone, are *stamen* for microsporophyll, *pollen* or *pollen grains* for microspores, *pollen sacs* for microsporangia, and *staminate flower* for the strobilus or cone, which bears the microsporophylls.

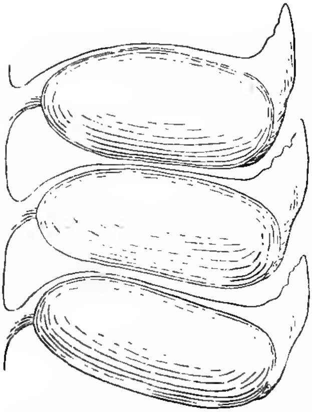

FIG. 253. A few of the stamens and pollen sacs from a staminate cone of the pine

Somewhat enlarged

284. Pollination. The pollen or microspores must be carried to the seed cone and properly placed before they can develop. The proper placing of pollen is called *pollination* (Chapter VIII). In pines, young seed cones stand upright and open (Fig. 248) at the time pollen is being shed. If pollen grains chance to come into the seed cones, they slide down upon the leaf-like parts to the base where the sporangia are borne. There by means of a sticky secretion they are caused to adhere to the tip of the megasporangium, and pollination is completed. Obviously, if wind-pollinated plants are to be successful, there must be enormous quantities of very light pollen, and ovule-bearing cones must be open to catch pollen that chances to fall upon them.

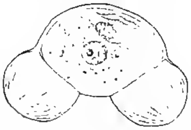

FIG. 254. An enlarged pollen grain of the pine

Much magnified

285. The gametophyte and fertilization.[1] It was stated in Sect. 283 that the megaspore does not escape from the megasporangium or ovule. It germinates therein and produces the gametophyte, which sometimes well-nigh fills the interior of the ovule. The old megaspore wall is now known as the embryo sac. At the end toward the open tip (the little gate or *micropyle*) of the ovule, this gametophyte develops archegonia, in each of which an egg is formed. This is therefore a female gametophyte.

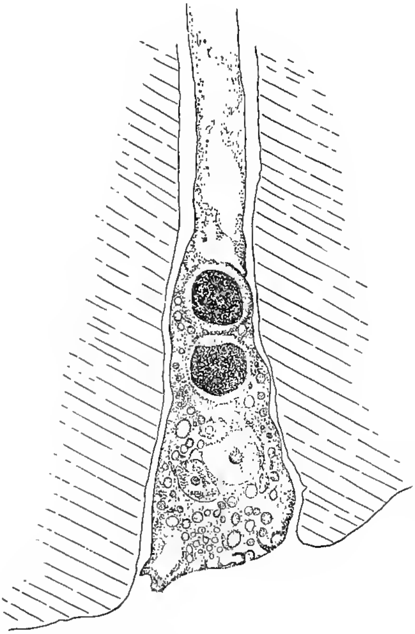

FIG. 255. The tip of a pollen tube of a pine at the time it has almost reached the egg

Just back of the two nourishing cells are the two darkly colored male cells, either of which may fertilize an egg. Much magnified

Obviously new difficulties in fertilization are presented in the pine, for here the egg is within the female gametophyte, which itself is inclosed by layers of ovule tissue. This inclosing tissue prevents the sperm from swimming directly to the egg, as in the pteridophytes. After the microspore or pollen grain falls upon the megasporangium its contents begin to produce several cells. From the wall of the pollen grain there grows a tube into which

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[1] Under ordinary circumstances it is not wise to attempt with secondary-school students to do detailed individual laboratory work upon the gametophytes and upon fertilization in gymnosperms and angiosperms. If important structures can be shown under a demonstration microscope, they will prove of interest and value.

pass the cells formed by the division of the nucleus of the microspore. This tube makes its way through the tissue of the ovule, toward the egg (Fig. 252). The pollen tube really begins to grow long before the egg is formed. Female gametophyte and pollen tube both develop slowly, so that it is twelve or thirteen months after pollination before the archegonium is reached by the tip of the pollen tube. The tip of the pollen tube opens and two of the cells that were carried down in it pass out (Fig. 255). Either of them may unite with the egg to produce an oöspore. The other one disappears after a time. These are the male cells. We should call them sperms, but they do not have cilia, — organs of locomotion which are parts of sperms. There are gymnosperms (Fig. 263) which have real sperms that are carried to the archegonia by pollen tubes. The pollen tube as a means of securing fertilization is of great importance, and this is shown in even a more striking way in angiosperms.

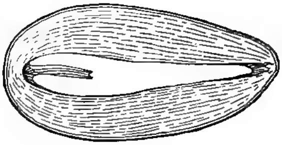

FIG. 256. Diagram of the seed of a pine showing the embryo (new pine plant) inclosed within the food material

At the right tip of this embryo is the root, and at the left are the seed leaves which inclose the small stem tip

286. Embryo, seed, and seedling. After fertilization, the oöspore develops into an embryo pine plant. It is developed within the old female gametophyte from which the developing embryo derives its nourishment. The wall of the female gametophyte is now known as the embryo sac wall. After a period of growth the embryo has developed root, stem tip, and leaves, all closely packed within the female gametophyte tissue. At this time the ovule wall becomes dry and hard and the embryo stops growing. The whole structure is now the *seed* (Fig. 256).

When the pine cone opens, two years or more after the spring when pollination occurred, the seeds fall from it. To each seed is attached a wing, which sometimes buoys the seed in the air, thus making wide distribution more probable.

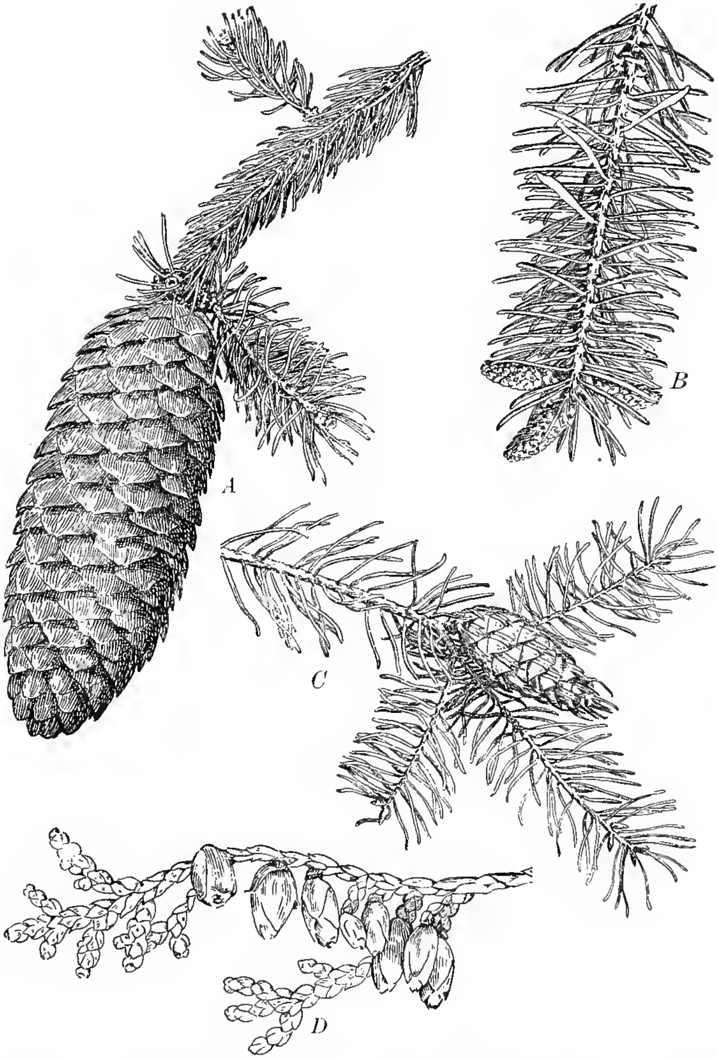

FIG. 257. A group of gymnosperm cones, of which all except *B* are carpellate

A, white spruce (*Picea excelsa*), one half natural size; *B*, white spruce; *C*, western hemlock (*Pseudotsuga taxifolia*), one fourth natural size, branch and staminate cones almost natural size; *D*, arbor vitae (*Thuja occidentalis*), almost natural size

The seed germinates when there are suitable climatic conditions. Its embryo swells, bursts the seed coat, sends the root down into the soil and the stem and leaves into the air, and is then known as the pine seedling. It may in time become a new pine tree, which will again bear cones and produce seed. It is worthy of note that in some pines, as the lodgepole pine of the Rocky Mountains, the cones may not shed their seeds for several years, sometimes not until the death of the tree.

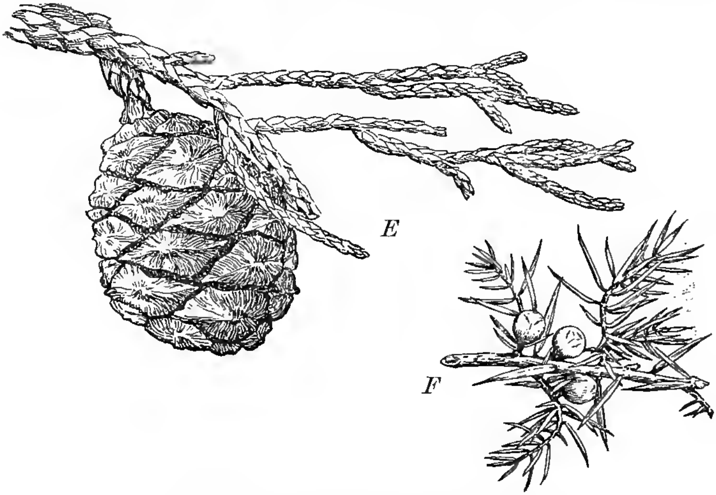

Fig. 258. Gymnosperm cones (continued)

E, "big tree" (*Sequoia Washingtonia*), two thirds natural size; *F*, common juniper (*Juniperus communis*), three fourths natural size

287. The Coniferales. The gymnosperms are subdivided into four living groups: the *Coniferales*, or cone-bearing gymnosperms; the *Cycadales*, plants which in general form resemble the tree ferns and some of the palms; the *Gnetales*, a group containing but three genera, which in form are so unlike one another that beginning students of botany would not think of classifying them together; the *Ginkgoales*, represented by one tree form. By far the largest group in number of genera and species and in number of individuals is the coniferales.

The coniferales are again divided into two families, the Pine family and the Yew family. Practically all gymnosperms commonly known in most parts of the United States belong to the Pine family. In addition to the widely distributed genus *Pinus* already discussed, there are the spruces (*Picea*), which have short, stubby needle leaves (Fig. 257, *A* and *B*), close-set branches, and long, generally pendent cones. The spruces are among our most beautiful trees, and appreciation of them is shown by the extent to which they are being planted for ornamental purposes. Their detailed structure and reproductive processes resemble those of pines. The *hemlock* trees (*Tsuga* and *Pseudotsuga*) (Fig. 257, *C*), *fir trees* (*Abies*), and the southern *bald cypress* (*Taxodium*) are members of this family. Bald cypress is one of the gymnosperms that can live in swampy places. Its roots spread enormously, near the surface. Often from these roots when in swampy regions there grow upward the peculiar, stump-like, woody structures (Fig. 19) known as the "cypress knees." The central tissues of these

FIG. 259. A large cedar tree (*Thuja occidentalis*)

The size of this tree is indicated by a comparison with the man standing at the right. Photograph by the Keyser Photo Company, Spokane, Washington "knees" are quite soft, and it is believed that they furnish a passageway by which air is conveyed to the roots. The *tamarack* (*Larix*) is common in bogs in the north temperate regions. It and bald cypress are deciduous conifers. The northern *white cedar*, or "arbor vitae" (*Thuja*) (Figs. 257, *D*, and 259), and southern *white cedar* (*Chamæcyparis*), which often are low shrubs but in forests become large trees, are other members of the family. The *red cedar*, *juniper*, and *low juniper*, all species of the genus *Juniperus* (Fig. 258, *F*), are some of this family's most widely distributed members. *Redwoods* and "big trees" (*Sequoia*) (Figs. 258, *E*; 250, and 260) are famous over the entire world, though they now grow only in the western part of North America. They have been the objects of many laudable efforts on the part of people who desired to preserve them.

FIG. 260. "Big trees" of California

The largest living trees belong to this group of gymnosperms. Original negative by Mode Wineman

The *American yew*, called "ground hemlock," is our only representative of the Yew family (*Taxaceæ*). It is low and sprawling in growth. Its branch resembles in form that of the true hemlock, but its leaves are distinctly pointed, while those of the hemlock are blunt. Its ripe cone consists of a central hard structure which contains a few seeds, and an outer coating which is pulpy and brilliant red in color.

288. Industrial importance of conifers. Several species of nut pine in western North America and one in southern Europe bear edible seeds, which are of considerable value as food.

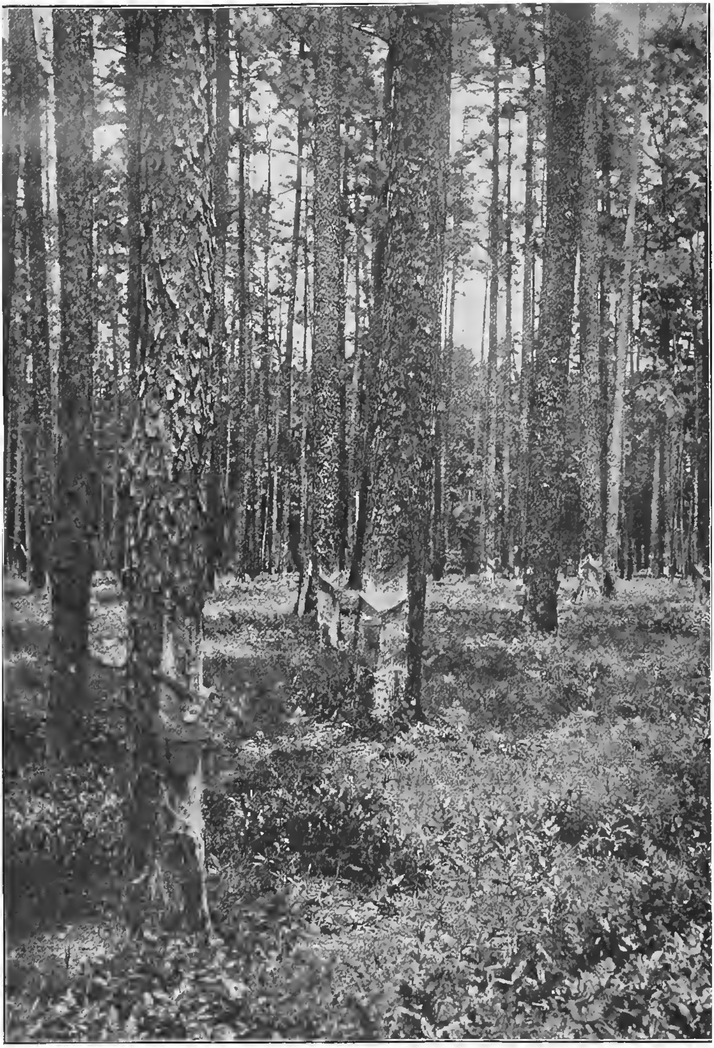

FIG. 261. The southern pitch pine, or long-leaf pine (*Pinus palustris*), which is used as a source of turpentine and pitch

Note the method of tapping the trees to secure the resinous secretion. Photograph by the United States Division of Forestry

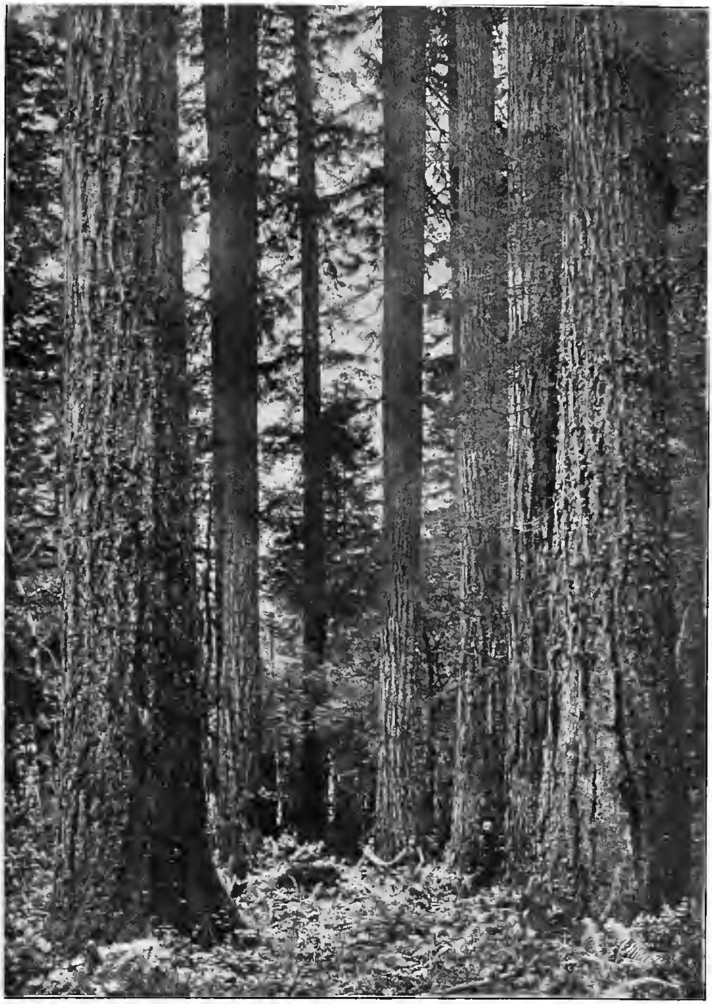

Fig. 262. The Douglas fir

A gymnosperm tree of immense size and great economic importance in the northwestern United States and Canada. Photograph by the Keyser Photo Company, Spokane, Washington

Pine tar, rosin, and oil of turpentine (commonly called spirits of turpentine) are valuable products, obtained in this country principally from the long-leaf southern pine (Fig. 261).

Timber is the principal product of our conifers. At present more than three fourths of the timber supply of the United States is furnished by various conifers, especially pines. During the early history of this country the white pine (*Pinus strobus*) was almost our only important soft wood. Now the long-leaf pine (*Pinus palustris*), the loblolly pine (*Pinus tæda*) of the southeastern states, and the bull pine (*Pinus ponderosa*) of the Pacific coast and the Rocky Mountain region are largely utilized.

Other important coniferous timber trees are two eastern species of true spruce (*Picea*), the western Douglas fir (Fig. 262), two other western firs (*Abies*), and the southern bald cypress (*Taxodium*). Considerable redwood (*Sequoia sempervirens*) lumber is made, though preservation of redwood forests is limiting their output. The cypress, larch, and most of the cedars, because of their durability, afford highly valuable timber for all kinds of out-of-door work, especially for posts and railroad ties. Red cedar is employed in making moth-proof chests, and is almost the only wood used for lead pencils.

Although the lightness of most coniferous woods makes them worth less for fuel (when bought by the cord) than the heavier deciduous-leaved species, still immense quantities of coniferous woods are used for fuel.

289. The Cycadales. This group includes nine genera. These are found in tropical and semi-tropical countries, and some of them are found only within comparatively small areas. The stem is straight, usually unbranched, and bears at its tip a crown of leaves, each of which bears many hard and rigid leaflets (Fig. 263). In some species the stem is almost or entirely embedded in the earth, and in such cases it is like a long tuber. The stem is used by the plant as a storage region for starch. In some countries these stems are collected for the starch, which after extraction is sometimes called *sago*, though the usual sago of commerce is made from a true palm. This practice exposes some cycads to danger of extinction, but others which are literally weeds, as *Zamia integrifolia* and *Zamia Floridana* in southern Florida, are too abundant to incur this danger.

FIG. 263. A cycad plant showing the straight stem, the crown of rigid leaves, and the seed cone

There is a common greenhouse cycad (*Cycas revoluta*) which is often improperly called sago palm, for it is not a palm at all. This plant bears large staminate cones, but the carpels (megasporophylls) are borne in clusters at the tip of the stem. Most of the cycads, however, bear their carpels in the form of immense cones (Fig. 263), the largest cone known in the plant kingdom being found in this family.

In details of structure of the vegetative body of cycads, and in their reproductive structures and processes, they are of great interest and importance to special students of botany. For our present purposes, however, there should merely be noted (1) the fern-like appearance of cycads; (2) the stem and leaves, which resemble the large and abundant plants of the Carboniferous age; (3) the fact that in some cycads (*Cycas revoluta*) the carpels are leaf-like, with sporangia at the margins as in some ferns; (4) that the megaspore, which is scarcely inclosed within the ovule, develops a female gametophyte, which bears several to many archegonia; (5) that the male gametophyte produces usually two but in some forms it produces several true sperms, provided abundantly with cilia and able to swim about with great vigor in the pollen tube. These facts show that in many respects cycads are more like ferns than are the pines. They are more like ancient forms of plants than like present-day ferns, and in ancestry are very old.

There were formerly many species of plants to which our present cycads are related, but most of them are dead and now represented only by their fossils. The cycads are therefore looked upon as the slowly disappearing remnants of a once abundant type of plant life.

290. Other groups. The *Gnetales* are now represented by but three very different genera, the remnants of once abundant and successful plants, but too highly specialized for use in this discussion.

The "maidenhair tree" (*Ginkgo*) — a tree with leaves (Fig. 264) that suggest the maidenhair fern — is becoming somewhat generally planted as a shade and ornamental tree. It is the only living species of a former abundant group (*Ginkgoales*) of gymnosperms.

291. Gymnosperms of past ages. It has been stated that pteridophytes were the dominant plants in the Carboniferous age. Fossils of ancestral seed plants also were formed during the same age, but gymnosperms did not become really abundant until after the time of the greatest profusion of pteridophytes. In this next age gymnosperm trees became dominant, and large numbers of fossil remains tell strange stories to those who can understand them; stories of many kinds of ancient seed plants, of giant tree trunks when gymnosperm trees first reached high into the air as a result of the struggle for light, and of seeds when the seed habit was first developing.

In those times gymnosperms were almost everywhere. The "big trees" and redwoods extended to Greenland, and cycads and other groups now well-nigh extinct grew in profusion over very wide areas. The Pine family was not so abundant then as were other gymnosperms, but became abundant later and to-day is a fairly successful group. This abundance of pines and their relatives in some regions may often be explained by the fact that in poor soil and under severe climatic conditions they are exposed to little competition with other trees.

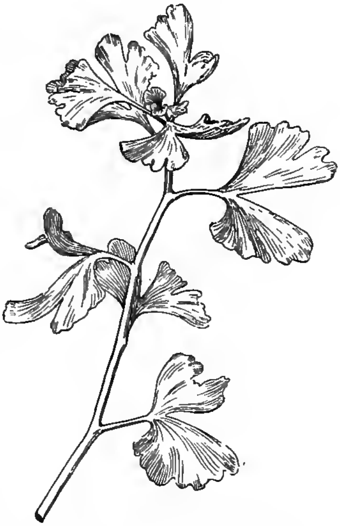

FIG. 264. A branch from the "maidenhair tree" (*Ginkgo*)

About one third natural size

These remnant forms of the formerly luxuriant gymnosperm groups have undergone many changes, but here and there over the earth they stand as still living evidences of the class of plants that dominated before the highest class, the angiosperms, became the leading plants of the earth. Changes in the climate and in the physical conditions of the earth, and the struggle for existence, has doubtless often reduced or eliminated one group of plants and made possible the dominance of another group.

292. Classification :

Spermatophytes
  Gymnosperms
    Class I. Coniferales. Leading genera used as illustrations,— *Pinus* (pine), *Picea* (spruce), *Pseudotsuga* (Douglas fir), *Tsuga* (hemlock), *Abies* (fir), *Taxodium* (bald cypress), *Thuja* (cedar), *Juniperus* (red cedar, juniper), *Sequoia* (redwoods and big trees), *Taxus* (yew)
    Class II. Cycadales. Genera used as illustrations,— *Cycas, Microcycas* and *Zamia*
    Class III. Gnetales. Not studied in any detail
    Class IV. Ginkgoales. Represented by *Ginkgo* as the only living genus

CHAPTER XIX

ANGIOSPERMS

COMPARISON OF THE DIVISIONS OF PLANTS[1]

293. The most diverse group of plants. The second class of spermatophytes, the angiosperms, is the highest group of the highest division of the plant kingdom. The number of individuals of this class is very great. Only one other group, the fungi, compares favorably with it in number of species and of individuals. There is a difference of opinion as to how many angiosperms there are, but all agree that there are over 100,000, and doubtless there are many undescribed species yet to be added. Not only is the number of species and number of individuals very great, but the variation in form and habit covers almost every imaginable condition. There are submerged water plants, free-floating plants, plants growing in water part of the time and on land part of the time. They grow in some regions so dry and so exposed that it would seem nothing could live; they thrive luxuriantly in the tropics, and they even live upon the ice in frigid regions. They may be epiphytic, may live as vines upon other plants, or may be parasites, saprophytes, and even carnivorous plants. In form the angiosperms range from diminutive floating disks to gigantic trees. In length of life they range from forms that pass from adult plant to plantlet and to adult again, several times each season, to individual plants which live to be several centuries old. The class contains plants that produce our most necessary foods, and others that are deadly poisons.

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[1] This chapter completes the study of the great groups (Chapters X–XIX) in the order of their increasing complexity. Since there have already been several chapters dealing with seed plants, the present one, while adding new material, is also somewhat in the nature of a summary.

294. The youngest and most successful group. As a group these are the youngest plants. Even within the fossil beds in which gymnosperms are abundantly represented there appear few structures that can be interpreted as belonging to the angiosperms. Geologically the angiosperms are of recent origin. The pteridophytes and gymnosperms in their periods of greatest luxuriance comprised many diverse forms and many individuals. In the present age it seems that we are witnessing the ascendancy of the highest and most successful plants.

295. The most complex group of plants. In Chapter II there were outlined the leading facts regarding the way in which angiosperms are nourished and in which they reproduce themselves. In subsequent chapters many details were given upon these two aspects of the work of plants. It has certainly been made evident that the structure and habits of life of angiosperms are complex, and enable them to live under a very wide range of conditions. There are genera and species of angiosperms some of which are able to live in almost any kind of environment in which plant life is possible.

The reproductive structures of angiosperms have much to do with the success of the class. Many other features of the group are of such importance as to demand an entire chapter, and these are fully discussed under separate chapter headings (Chapters II–IX, and XX–XXVI). Certain details of seed formation and the relations that angiosperms hold to other groups are presented in this chapter.

296. The angiosperm flower. Collections of sporophylls such as were seen in the pines are sometimes called flowers. In the angiosperms there are usually leaf-like organs about the sporophylls, and the presence of these is popularly considered as essential to the flower. These leaves or bracts are not necessarily colored, and indeed often are not so. Furthermore, there are angiosperm flowers that do not have floral leaves; consequently no closely drawn line can be placed between the strobilus, or cone of gymnosperms, and the flower of angiosperms. The essential structures of a flower are *stamens* or microsporophylls, and *carpels* or megasporophylls. The carpel is also commonly called a *pistil*. A carpel is one megasporophyll and a pistil may be one or several carpels joined together as was shown in Chapters II and VII.

The presence and nature of the floral structures and seeds in this group and in the gymnosperms has, at various times, given rise to different names for the division. *Flowering plants* or *seed plants* are the most common names, and are good names. *Phanerogams*, meaning "reproduction easily seen," was applied when less was known of the intricacies of reproductive processes. At that time pteridophytes, bryophytes, and thallophytes were classed together as *Cryptogams*, meaning "reproduction difficult to see." These names are still used by many people. An interchange of the names would better fit the facts.

297. The stamen and microspores. In Chapter II, Sect. 21, it was stated that the tip of the stamen is the *anther*. It is borne by a slender stalk (the *filament*). In a transverse section of an anther (Fig. 99) there appear the spaces in which pollen grains (microspores) are formed. In a young anther four spore-forming regions (sporangia) may be seen, but by the time each sporangium has matured its spores, pairs of sporangia have joined by the breaking down of the separating walls. In a mature anther, therefore, but two pollen sacs are present. Special arrangements exist for the opening or *dehiscence* of the anther (Fig. 100). The anthers may open lengthwise, by means of terminal pores, or in other ways.

Since they are formed by division of cells, it is evident that the pollen grains are asexual spores. When mature, each one consists of a heavy outer wall, an inner wall, cytoplasm, and nucleus. Often there are starch foods stored in the pollen grains. Frequently pollen grains begin to germinate before they leave the anther, so that two nuclei may be seen within the spore wall.

The pollen grains must be placed upon the tip of the pistil before further development occurs. This process constitutes pollination, to which a chapter has already been given (Chapter VIII).

298. The carpel, megaspore, and female gametophyte.[1] The carpel or pistil consists of three parts: the enlarged base which is the *ovary*, in which one, several, or many ovules are borne; the elongated portion above the ovary, the *style;* at the tip of the style, the *stigma*, which in different plants is divided or expanded in various ways (Figs. 110 and 111). When ripe, the stigma secretes a sticky fluid, or produces a coating of hairs by means of which pollen grains are caused to adhere to it. The style, which may have lifted the stigma into an exposed position, now serves as tissue through which pollen tubes may grow to the ovules. The ovary contains a special cavity in which ovules are borne in a variety of positions (Fig. 102). The ovule may be upright or more or less recurved toward its base. The surface of the ovule consists of one or two *integuments*, which at the tip do not quite cover the inner tissue. This open tip is the *micropyle*. Similar structures

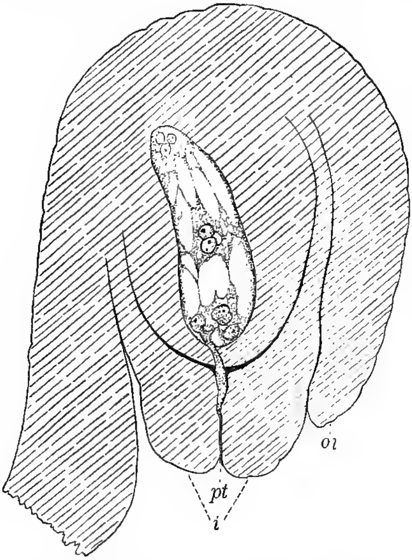

Fig. 265. Diagram of the ovule of an angiospermous plant, showing the parts of the ovule, the outer integument (*oi*), the inner integument (*i*), the micropyle which is the opening between the parts of the inner integument, and the pollen tube which has grown through the micropyle

In the interior of the ovule is the embryo sac, within which are the tip of the pollen tube, the egg and a sperm in process of uniting. Near the egg are the two synergid cells, in the center of the sac are the two embryo sac cells and the other male cell, which unite to form the endosperm cell, and at the end of the sac are the antipodal cells, which usually disintegrate after a time. After fertilization the egg proceeds to form the embryo of the new plant

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[1] See footnote at beginning of the chapter on Gymnosperms.

of the ovule were seen in the gymnosperms. Within the central tissue of the ovule a megaspore is formed. Upon its formation this megaspore at once proceeds to grow to produce the female gametophyte. The wall enlarges and elongates to form the embryo sac, and the nucleus divides. One new cell passes to each end of the developing sac and soon divides again, thus producing two cells at each end, or four in all. Each of these divides, thus producing eight cells in all. One passes from each end toward the center (Fig. 265), and these two unite to produce the *endosperm* cell from which the endosperm of the seed develops later. The female gametophyte at this time consists of seven cells inclosed within the old megaspore wall or embryo sac. In the micropylar end of the gametophyte are three cells, the central one of which is the egg, and on each side of the egg is a cell which resembles the egg. These are called the *synergids* or helper cells. They may nourish the egg, or possibly may assist in directing the pollen tube when it enters. In the opposite end of the embryo sac are three *antipodal* cells, which usually disappear soon after they are formed, and near the middle of the embryo sac is the *endosperm cell.*

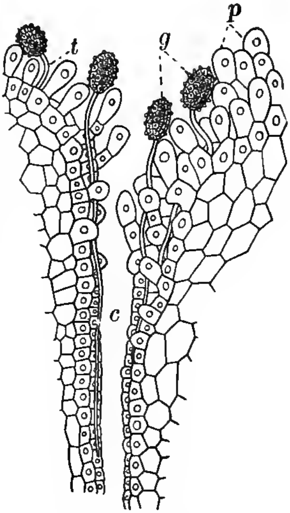

FIG. 266. Germinating pollen grains

The pollen grains (*g*) have been deposited upon the stigma. The roughened surface of the stigma is made by cell extensions or papillæ (*p*). Pollen tubes (*t*) grow from the grains through the tissue or along the central canal (*c*) until they reach the ovule. Only a small part of the stigma and style are shown in this cut

299. Fertilization. After pollen grains or microspores have fallen upon the stigma the outer spore wall breaks, and from the inner wall there extrudes the beginning of the pollen tube. The tube tip enters the stigmatic tissue and forces its way through the central softer tissues of the style. It does not make a passageway by forcing aside the tissue, but by means of its own secretions (enzymes) it breaks down these cells, and they doubtless furnish nourishment to the growing pollen tube (Figs. 107 and 266). The tube usually makes its way down the center of the style, then along the wall of the ovary cavity, and finally turns across to the micropyle of the ovule. It then grows through the tissues to the end of the embryo sac. In some cases (elm and walnut) the pollen tube grows down to the base of the ovule, then up through it, and finally reaches the egg.

While this long growth of the pollen tube has been taking place, development within it has also occurred. From the single-celled microspore there now have developed three cells, which are contained in the tip of the tube. Two of these are male cells and can function as sperms, though they are non-ciliated. The other is a nutritive cell, which goes forward within the tip of the pollen tube and is an important factor in its growth.

When the tube reaches the embryo sac it opens, the male cells pass out, and one of them unites with the egg (Fig. 265). In many cases, and perhaps generally, the other male cell passes down and unites with the endosperm nucleus, which was formed by the union of two female gametophyte cells. This results in a cell that is the union of three cells, — a phenomenon not known elsewhere in the plant kingdom. The ordinary fertilization of the egg and this added phenomenon of union of a male cell and the endosperm cell is known as *double fertilization.* Its significance is not understood, but it is notably true that angiosperms present the first case in seed plants wherein the female gametophyte has two periods of development, one before fertilization and one afterward, and it may be that double fertilization is related to this second period of growth of the female gametophyte. During the period while the oöspore is growing into the embryo plant, the endosperm cell is growing into the endosperm that is often found in ripe seeds (Figs. 125 and 128).

300. The embryo and seed. After its formation the oöspore at once proceeds to divide and to form the new plant. First it divides in such a way as to form a suspensor, which usually attaches the embryo to the wall of the embryo sac (Fig. 267). The other end of the embryo differentiates a root tip, a stem tip, and one or two (sometimes several) leaf tips. Sometimes there is but one leaf tip, which grows from the end opposite the root tip, while the stem is laterally placed. This is true in those plants which are called *monocotyledons* (meaning "one seed leaf"). In other plants, the *dicotyledons* (meaning "two seed leaves"), the two (rarely more) seed leaves arise laterally and the stem tip is terminal.

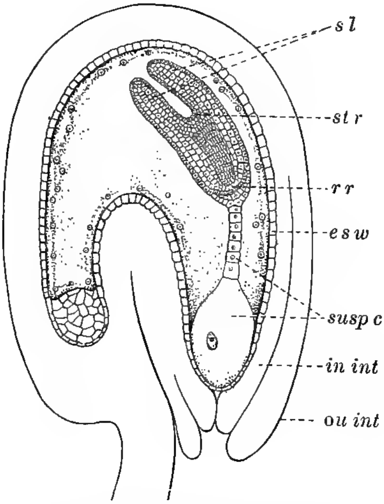

FIG. 267. Diagram of the ovule, embryo sac, and embryo of shepherd's-purse (*Capsella*)

The parts shown are the outer integument (*ou int*), inner integument (*in int*), embryo sac wall (*e s w*), suspensor cells (*susp c*), root region (*r r*), stem region (*st r*), and seed leaves (*s l*)

After these structures have been formed the integument walls become dry and hard, and the seed is completed. It may be shed and grow at once, or it may lie upon the ground until the next year. Some seeds lose their vitality soon after they are formed. In other cases (cocklebur and some desert plants) they may lie in the ground for one to several years and then grow. Some seeds may be kept for several years (wheat, corn, etc.) and retain in part or entirely their ability to germinate, but usually they lose their vitality after a few years at the most. The relations between seed and fruit are difficult to define. The ripened ovule is the seed. When any other structure is added the result is the fruit. For example, if the ovary wall hardens about the seed, as in the sunflower, we have the kind of fruit called an *akene.* In the stony fruits, as the peach, the ovary wall divides, the inner part produces a hard covering to the seed, and the outer part produces a pulpy flesh. In an apple the calyx is joined to the wall of the ovary, the seeds are inclosed within ovary cavities, the ovary wall ripens into the core, and the calyx ripens into the greater part of the apple fruit. A transverse or longitudinal section of an apple or pear will usually enable one to determine what part of the fruit is the ripened calyx and what part is the ovary wall. In general it may be said that the fruit is the seed plus anything else that ripens with it. In plants such as the bean (Fig. 15), while seeds are maturing the entire carpel grows and the ovary ripens into the fruit known as the pod. (See Chapter IX for discussion of the germination of seeds and the development of the parts of the adult angiospermous plant.)

301. The life cycle of angiosperms. The flowering plants which we ordinarily see are the sporophytes, since they produce asexual spores. Angiosperm sporophytes are highly organized, with complex and divergent types of roots, stems, and leaves, and living with almost every possible habit in every possible region. So varied in form and habit are these plants that no single type or few types can adequately represent them.

The flower is primarily organized to produce asexual spores, but later is also used for sexual reproduction. In fact so closely related are these two reproductive stages that people sometimes erroneously speak of the stamen as the male structure of the flower and the pistil as the female structure. No confusion need arise with the stamen, since it is the microsporophyll which produces the pollen grains. Later the pollen grain germinates and produces the male gametophyte. The pistil offers more difficulty, for although it first produces a megaspore, that cell produces the female gametophyte within the ovule. The pistil is primarily an asexual reproductive structure, and later is given the appearance of sexuality by the fact that the gametophytes develop within it instead of free from the sporophyll, as is true in the pteridophytes.

There is great reduction in both gametophytes. In gymnosperms there were more cells in the male gametophyte, and in some gymnosperms (*Cycads*) not only are true sperms present, but in some cycads there may be several sperms. In angiosperms there are but two male cells and one nutritive cell in the male gametophyte. The female gametophyte of gymnosperms, while inclosed in the ovule, is a compact tissue that bears several to many archegonia. In angiosperms, at fertilization time, the female gametophyte consists of but seven cells. The tissue is not compact. There is but one egg, and it is borne without an archegonium. Accompanying this great reduction of the female gametophyte are the added phenomena of double fertilization and the second period of gametophyte growth resulting in endosperm formation.

The ovules are inclosed within the sporophyll that bears them. This necessitates a much more extensive growth of pollen tubes in order that fertilization may be effected. The pollen-tube habit is so well developed in angiosperms that in some plants, whose styles are several inches in length, fertilization will have occurred within a few hours after pollination. This is of especial interest when we recall (1) that in the pine about thirteen months elapse after pollination before the pollen tube grows through the ovule tip to the egg; and (2) that in angiosperms the pollen grains sometimes alight at a distance from the egg that is hundreds of times greater than in gymnosperms, and grow fast enough to make their way to the egg within a few hours.

Gymnosperms are ancient plants, and seed-forming processes in them occur slowly. Angiosperms are recent plants, and seed formation in them occurs often very rapidly and in enormous quantity. The abundant and effective production of seed is an important factor in the present success of the angiosperms.

COMPARISON OF THE GREAT DIVISIONS OF THE PLANT KINGDOM[1]

302. Evolution of plants. The leading classes which compose the four great divisions of plants have been discussed, and type forms have been described in most of these classes. It has doubtless been made evident throughout Chapters X–XIX that some groups of plants have developed from others. This process is known as the evolution of plants. The oldest plants of the earth were very simple, and from them more complex ones have gradually developed. The simplest plants that are now living probably have changed greatly from the oldest simple plants. It is even probable that some simple plants that are now living have developed from complex forms.

While we compare one living group with another, we must keep in mind that a higher group of living plants has not necessarily developed from one of the lower living groups, but rather that often in past ages a common ancestry gave rise to both. The lower group has probably changed less than the higher one. While higher groups have evolved from lower ones, it is also possible that certain lower groups of dependent plants have evolved from higher groups. This means that evolution may lead toward greater complexity, as usually happens, or may lead toward greater simplicity in structure. In this summary of the divisions we shall have in mind chiefly two groups of characters, — those which relate to nutritive work and those which relate to reproductive work.

303. Thallophytes. The thallophytes live almost entirely in water or in moist situations, so that usually a fairly constant water supply is present. They are not differentiated into roots, stems, and leaves, and there is little difference between the cells that compose a plant. There are two subdivisions: the

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[1] In connection with this general summary the pupil should reread each of the summaries of groups and classifications as they are found at the close of chapters, and review briefly the laboratory work that has been done. Unless this is done with care the final summary will prove very difficult.

algæ, or chlorophyll-bearing thallophytes, and the fungi, or those which do not bear chlorophyll. One group, therefore, is independent in nutrition, the other dependent.

The fungi are thought to have descended from the algæ. On account of the dependent habit and the loss of chlorophyll there has been evolved this group of thallophytes which in structure and reproduction (*Mucor*, *Saprolegnia*)[1] often resemble algæ. Others live as saprophytes (many bacteria, *Mucor*, some toadstools and mushrooms, *Penicillium*, yeasts); others as parasites (many bacteria, *Saprolegnia*, grape mildew, lilac mildew, corn smut, wheat rust, tree-destroying toadstools); others as mutualists (the lichens). The dependent habit of living has often resulted in limiting parasites to a few kinds of host plants without which they cannot live. It is thought that members of the simplest group of thallophytes, the bacteria, have descended from forms like the blue-green algæ, and that as they were enabled to live more and more completely as parasites and saprophytes their nutritive structures became more and more simple, until now they are reduced almost to the lowest possible limit. It is generally supposed that different groups of fungi are descended from different groups of algæ.

An important series in increasing complexity of nutritive and reproductive structures is shown in the algæ. In nutritive structures we have first single-celled plants or colonies (*Pleurococcus*); then filamentous plants (*Ulothrix*, *Œdogonium*, *Spirogyra*); then branching filaments (*Vaucheria*, *Cladophora*); and branching filaments with leaf-like expansions (brown algæ). The chloroplasts, at first poorly organized, become definite and often quite complex structures. The lowest algæ are free-floating, but a holdfast develops (*Ulothrix*, *Œdogonium*, brown and red algæ) which gives relative permanence of living-place. Distinct basal and apical ends and the branching habit, with well-organized and well-exposed chloroplasts, provide a favorable organization for manufacture of foods.

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[1] Only part of the types of plants that have been discussed in this text are cited in this summary.

The green algæ offer the best series in evolution of reproductive organs. One-celled plants that reproduce vegetatively (fission) and sometimes by zoöspores are followed by plants which, while still reproducing vegetatively, have vegetative cells which, by division of their contents, produce numerous asexual spores (zoöspores), as in *Cladophora* and *Ulothrix*. From small zoöspore-like bodies the first sex spore (zygospore) is formed, and the origin of gametes and sexuality in plants appears. Then in *Œdogonium* vegetative cells produce special sex organs (oögonia and antheridia) in which differentiated gametes (eggs and sperms) are formed. From these the oöspore is formed. In such cases as this we have an illustration of the differentiation of sex cells into male and female, and the differentiation of sex organs. Finally, in plants such as *Vaucheria* the sex organs are made solely for reproductive work.

304. Bryophytes. This division is subdivided into two classes, liverworts and mosses. The protonema of mosses greatly resembles the green algæ, and some simple liverworts are masses of cells much like some of the higher algæ. Rhizoids and special chlorophyll tissues are developed both in liverworts and in mosses, and in the highest members of each class leaf-like and stem-like structures are formed. In the mosses this leafy plant is erect, the leaves are radially arranged about the stems, and altogether the mosses appear to be good chlorophyll-working plants. While the liverworts have not developed the erect stem and radially arranged leaves, in the leafy liverworts there is an almost equal degree of vegetative differentiation. The chlorophyll tissues of bryophytes present a great advance over those of thallophytes.

In reproduction, bryophytes also offer distinct advances over thallophytes. The sex organs are complex structures. The egg is produced in a many-celled archegonium, instead of the one-celled oögonium of the thallophytes, and the sperms are produced in a many-celled antheridium. These organs may be embedded in the thallus or borne upon the surface. The oöspore produces a distinct phase of the plant, which when mature produces asexual spores. This gives rise to alternation of generations, in which a gametophyte by means of an egg and a sperm produces an oöspore; the oöspore upon germination produces a sporophyte; the sporophyte produces asexual spores, which germinate and produce new gametophytes. In some bryophytes (mosses and *Anthoceros*) the sporophyte bears chlorophyll, but in all it is wholly or largely dependent upon the gametophyte for nourishment. The gametophyte is the chief chlorophyll-working generation. Indeed, the most complex nutritive structures in any gametophyte of the plant kingdom are in the bryophytes.

305. Pteridophytes. In most pteridophytes both generations bear chlorophyll. In the true ferns the gametophyte is smaller and less complex than in most bryophytes. It looks like a simple liverwort. The sporophyte has a heavy woody stem and large leaves. The stem and leaves possess fibrovascular tissues, which aid in giving support and in conducting food material. The introduction of fibrovascular tissue represents an epoch of enormous significance in the plant kingdom. It makes possible the development of large upright plants and giant tree trunks, which can expose chlorophyll tissue high in the air. It must be kept in mind that in so far as bryophytes develop special chlorophyll structures, these are found in the gametophyte and not in the sporophyte.

In the true ferns a gametophyte may bear both sex organs and produce an oöspore. The sporophyte produces many spores, any of which may produce gametophytes. The asexual spores are of one kind (homosporous). In other fern-like plants (*Selaginella*) two kinds of asexual spores (heterosporous) are produced. The small spores produce male gametophytes, which produce the antheridia and sperms, and the large spores produce female gametophytes, which produce archegonia and eggs. The egg is fertilized within the female gametophyte, which has not escaped from the megaspore wall. The oöspore produces an embryo sporophyte, which grows out of the old megaspore wall, and becomes established as a new plant.

A period of dormancy after the embryo is formed would cause the old megaspore and its contents (female gametophyte and embryo) to look much like the seed of spermatophytes.

306. Spermatophytes. The sporophyte of the seed plants is a far better nutritive-working plant than those of any of the preceding divisions. Not only has it better structures for making food, but many structures and habits enable these plants to store surplus food from more active through less active periods, or from year to year.

From an evolutionary point of view the seed marks the most important advance in the spermatophytes. The seed is the megasporangium (ovule) and the remaining part of the female gametophyte and the embryo sporophyte. It can lie dormant through unfavorable periods, often for years, and upon return of favorable conditions proceed to grow. Its stored food nourishes the young plant until it establishes its own food-making structures.

In gymnosperms the megasporangium (ovule) and the seed which is developed from it are borne upon the megasporophyll and not within it, as in angiosperms. In the first case the microspore (pollen grain) alights upon the ovule. A pollen tube carries the male cells or sperms to the egg. In angiosperms the pollen grain alights upon the stigma of the carpel. The pollen tube carries the male cells through the style to the ovule, thence through it to the egg. In the gymnosperms the female gametophyte is developed from the megaspore entirely within the ovule, is composed of many cells compactly arranged, and bears archegonia and eggs. In the angiosperms the female gametophyte is not compact, is reduced to seven cells, and bears an egg without a surrounding archegonium. Furthermore, this angiosperm gametophyte has a second period of growth, which results in production of the endosperm of the seed.

In *spermatophytes* the gametophytes are very nearly lost. They are so inconspicuous that they are hard to understand, but they cannot be wholly lost while plants have sexual reproduction.

CHAPTER XX

SOME LEADING FAMILIES OF FLOWERING PLANTS AND THEIR USES[1]

MONOCOTYLEDONS

307. Introductory. When people speak of flowering plants they usually mean angiosperms, or plants with a closed ovary (Fig. 101), including all the families of monocotyledons and dicotyledons. As shown in Sects. 302–306, these groups occupy the highest place in the plant world.

Monocotyledonous plants usually have *seeds with one cotyledon, flowers with their parts in threes, leaves with parallel veining* (Fig. 268), *and stems with the woody bundles not forming a hollow cylinder about a central pith* (see Fig. 38).[2]

Dicotyledonous plants usually have *flowers with their parts mostly in fives (not in threes), seeds with two cotyledons, leaves with netted veining* (Fig. 270), *and stems with the woody bundles arranged at first in a hollow cylinder about a central pith* (see Fig. 30).[3]

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[1] Teachers' Note. There is included in this chapter a great deal of information about the families presented and their economic value. Generally it will not be found advisable to use the entire chapter as a basis for assigned lessons. Sometimes it should be so used, but more often it will be found valuable for collateral reading and as a source of information regarding many questions that arise in an elementary course. A few figures of plants from families not mentioned in the text have been introduced for the sake of illustrating additional types.

[2] There are occasional exceptions to these statements; for instance, most seeds of the Orchis family have no cotyledon, the pondweeds (*Potamogeton*) have flowers with parts in fours, the leaves of *Trillium*, *Smilax*, jack-in-the pulpit, and plants of the Yam family are netted-veined.

[3] A few dicotyledons, like *Cyclamen*, have seeds with only one cotyledon, and a few others, like Indian pipe (*Monotropa*), have no cotyledons. Some parasites have hardly any stem, but are practically flowers attached to the root or stem of the host by numerous haustoria.

308. Families of monocotyledons. There are about forty families of monocotyledons, variously grouped by botanists into from seven to eleven orders, and embracing over 20,000 species. This chapter will discuss only four of the most important families, — the Grass family (*Gramineæ*), the Palm family (*Palmæ*), the Lily family (*Liliaceæ*), and the Orchis family (*Orchidaceæ*).

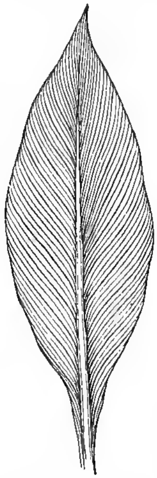

FIG. 268. Parallel-veined leaf of canna, veins running from midrib to margin

309. The Grass family. The grasses number about 3500 species, and are distributed very widely over the earth's surface. Some species, such as the wild rice found in the Middle West and northward, are aquatic, others grow in semi-desert regions; but most grasses inhabit plains, meadows, or open woods. Tree-like species, such as the bamboos of many kinds, may form dense and lofty groves, and our Southern canebrakes are tall and almost impenetrable; on the other hand, the smallest of the grasses are of sparse growth and only a few inches in height. Grasses are generally gregarious; that is, many individuals of a species grow side by side. It is rarely that a single plant occurs without neighbors like itself. The general form and appearance of the ordinary grasses, with their usually hollow and conspicuously jointed stems, are familiar to all. The flowers are rather small, and relatively simple (Figs. 271 and 272); the structure of the fruit and seed is sufficiently shown in Figs. 128 and 129.

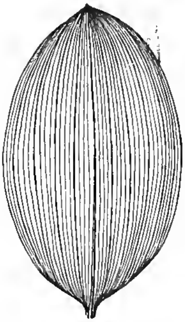

FIG. 269. Parallel-veined leaf of Solomon's seal

After Strasburger

310. Various uses of the grasses. The Grass family is probably more useful to man than any other family of plants. *The bamboo* serves the Asiatic peoples among whom it grows for many of the purposes for which we employ wood, various fibers, earthenware, and metals. It is almost the only material used in house construction and in bridge building; it is used for fences, water pipes, troughs, jars, mats, baskets, and miscellaneous household articles.

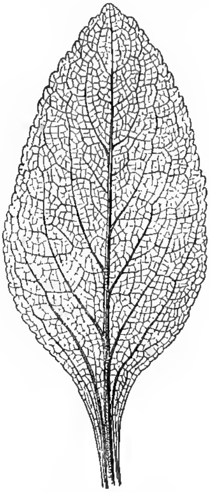

FIG. 270. Pinnately netted-veined leaf of foxglove

Straw of many kinds of grains is braided into mats, baskets, and hats, and is much used in making coarse paper; it is also used as a winter food for domestic animals.

Esparto, a very tough, coarse grass imported from Spain and the North African coast, is extensively used in paper-making and for stuffing mattresses.

Sugar cane, a very large solid-stemmed grass (Fig. 273), is considerably raised in Louisiana and in some Southern states, and more extensively in the West Indies, Hawaii, and Java. Once it was almost the only source of commercial sugar, and it still furnishes about a third of the world's supply. Its growth and commercial use have been an important factor in tropical industrial life.

FIG. 271. Spike-like panicle of vernal grass (*Anthoxanthum*)

a, mature anthers. Slightly enlarged

Meadow and pasture grasses are highly important to man. The best meadows are usually carefully sown with selected seed, but pastures are generally self-sown with grasses of many kinds. Most of the grasses valuable for haymaking or for pasture grow best in northern climates, with moderate summer temperature and abundant rainfall. This fact makes it difficult to grow hay to the best advantage or to maintain good pastures in the South or (without irrigation) in the arid portion of the Great Plains.

The grasses most valuable for hay, like timothy and redtop, are those which grow rather tall and contain much nutriment in the stem and leaves, in the seeds, or in both. The best pasture grasses, like the famous Kentucky blue grass, are those which spread freely by rooting branches (*stolons*) from the base, and which finally mat together to form a compact turf, not easily destroyed by trampling. Their nutritive value must also be high. In poor soil or where lack of moisture or too much shade makes vigorous growth of the best grasses impossible, inferior but more hardy species may serve a useful purpose.[1]

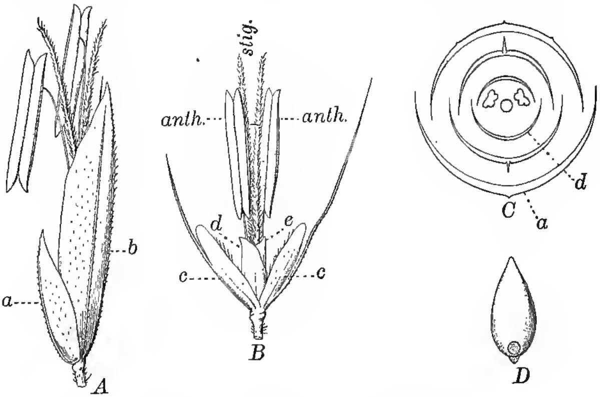

FIG. 272. Vernal grass (*Anthoxanthum*)

A, a one-flowered spikelet: *a*, *b*, the outer empty glumes. *B*, a spikelet with the outer glumes removed: *c*, *c*, the inner empty glumes (neuter flowers), with long, bristle-shaped appendages; *d*, *e*, palets; *anth.*, anthers; *stig.*, stigmas. *C*, diagram of cross section of a spikelet: *a*, glume; *d*, palet, within which are the stamens and pistil. *D*, a fruit. All magnified. After Cosson and De Saint-Pierre

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[1] For other facts about common grasses consult Chapter XXIV. See also Warren, Elements of Agriculture, chap. vii. The Macmillan Company, New York.

311. The cereal grasses. The cereals, or grasses cultivated for their edible grains, furnish the most important part of our vegetable food and much of that consumed by our domestic animals as well. The principal species grown in ordinary soils in temperate climates are wheat, corn, oats, rye, and barley. Various kinds of millet much used as human food in Asia and elsewhere are with us only forage crops. The rice plant is noteworthy among the cereals as being aquatic,—usually cultivated during the earlier months of its growth partially or wholly under water (Fig. 274). Some details in regard to the cereals will be found in Chap. XXIV.

FIG. 273. A field of sugar cane at Vera Cruz

After Freeman and Chandler

FIG. 274. Harrowing flooded ground for a rice field in Java to get rid of the weeds

After Freeman and Chandler

FIG. 275. A group of coco palms

Photograph furnished by United Fruit Company

312. The Palm family. The palms number about 1100 species, principally tropical. Most of the familiar palms have a nearly cylindrical trunk, crowned with a great rosette of pinnately or palmately divided leaves (Fig. 275). Many palms are among the most beautiful plants, and no other kind of tree gives such a tropical air to a landscape in which it is abundant. Some, such as the rattan, are lianas, with supple stems hundreds of feet long. The flowers are not usually very conspicuous and are borne in much-branched

FIG. 276. Flower clusters of the coco palm

The upper cluster is shown at an early stage, with the staminate flowers still clinging to its branches. The lower cluster has lost the staminate flowers and the young coconuts have enlarged considerably. After Freeman and Chandler

FIG. 277. Dragon-root, a plant of the Arum family, a monocotyledon with netted-veined leaves

A, entire plant; *t*, tuber; *B*, the flower cluster surrounded by a hood-like bract. About one eighth natural size inflorescences, each cluster provided with a very large bract (*spathe*), shown above each cluster in Fig. 276. The fruit is often a berry, as in the date, or a drupe, as in the coconut.

313. Uses of palms. In tropical countries use is made of palm wood and the leaves in various kinds of construction, and the fruit of some kinds (royal palm) is used as food for domestic animals. The stems of the rattan palm are largely employed in the manufacture of baskets and light furniture. The fiber of the coco palm is utilized in making coarse matting and heavy cordage.

Palm oil, much used in soap making, is obtained from the fruit of the African oil palm.

The coco palm (Figs. 275–276) is the most important tree of the family. It grows very widely distributed along tropical coasts and will flourish on beaches of coral islands where no other valuable tree can be made to grow. The milk of the unripe nut is a refreshing drink, and the nuts themselves are largely used for food by the natives of coconut-growing regions. The meat (endosperm) of the nut is the only considerable article of export from many islands of the South Pacific. It is sold under the name of copra and is the source of coconut oil. As is well known, the nuts are largely sold in our

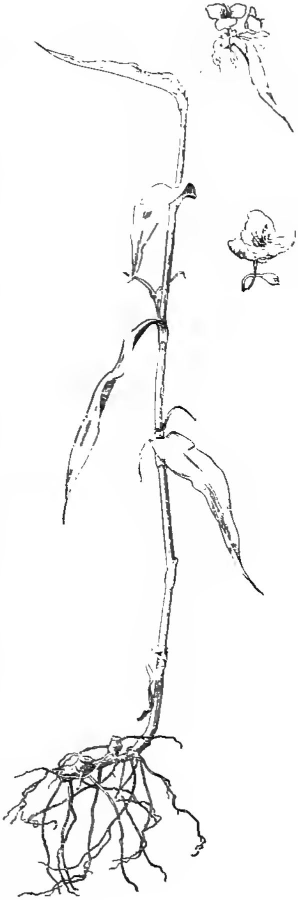

FIG. 278. A monocotyledonous plant, the spider lily, or spiderwort (*Tradescantia virginica*)

One sixth natural size

markets, and shredded and desiccated coconut finds a place in the preparation of candies and various articles for the table.

The date palm furnishes one of the most considerable articles of food for the peoples of northern Africa and western Asia. It has been in cultivation for as much as four thousand years and there are several thousands of named varieties. It is a most productive tree, bearing for a century or more, and when well grown producing from 100 to 600 pounds of fruit a year.

FIG. 279. Trillium

A shade plant of the Lily family, which blossoms before the trees beneath which it grows are in leaf

Vigorous and successful attempts are now under way to introduce date culture into the United States.[1] A very hot, dry climate is required, as the late varieties demand a mean temperature of 90° F. for three months of the year. It is important to secure a moist soil (by irrigation if necessary) for date culture. A large region of central Arizona, the Colorado desert in California, and several other arid or semi-arid areas will probably be found adapted to this industry, and dates have already been successfully grown in some portions of this region.

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[1] See Yearbook of the Department of Agriculture, 1900.

314. The Lily family (*Liliaceæ*). The Lily family numbers about 2600 species. These are scattered over most parts of the world. They are especially abundant in regions with a long dry season, like South Africa, the Mediterranean countries, and parts of California. Most *Liliaceæ* are herbs, though a few are shrubs or small trees. Many species, like the lilies and tulips, have bulbs which survive the winter or a dry season, while the rest of the plant dies to the ground every year. Others, as the lily of the valley and Solomon's seal, spring from the rootstocks (Fig. 60), and still others, as the yucca and asparagus, have mainly fibrous roots. The flowers are hypogynous, often showy, and the parts of the perianth frequently all alike or nearly so. The structure of a typical seed is shown in Fig. 127.

Ornamental plants of the Lily family are among the commonest in cultivation. Familiar examples are the true lilies, the hyacinths, the star of Bethlehem, squill, tulip, crown imperial, day lily,

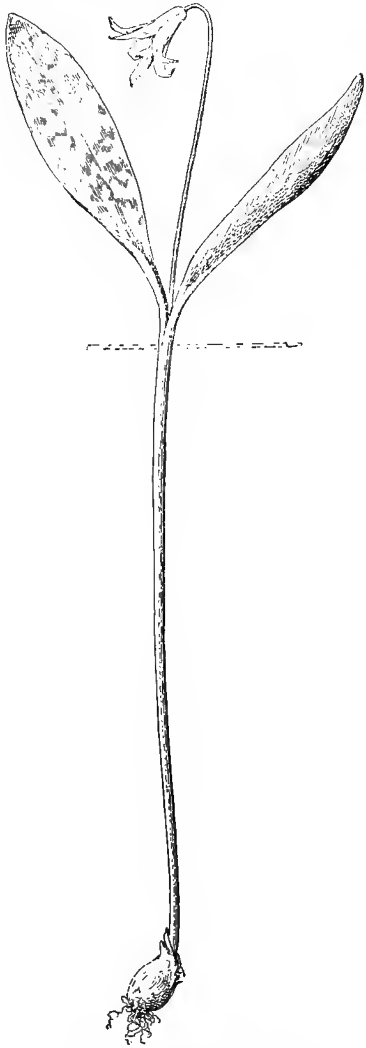

FIG. 280. White dogtooth violet

A common plant of the Lily family, with the stem springing from a deeply buried bulb. The dotted line shows how much of the plant was underground. About half natural size

FIG. 281. The stemless lady's-slipper (*Cypripedium acaule*)

One of the most familiar orchids of the northeastern states and lily of the valley. Showy wild genera are the following: many lilies, the dogtooth violet (Fig. 280), *Trillium* (Fig. 279), *Clintonia*, and several Rocky Mountain and Pacific coast genera, such as *Brodiæa* and *Calochortus*.

Useful plants are not very numerous in the Lily family. Asparagus and onions are common articles of food. *Colchicum*, *Veratrum*, *Aloe*, *Smilax*, and a few other genera yield valuable medicines. The so-called New Zealand flax produces an important fiber.

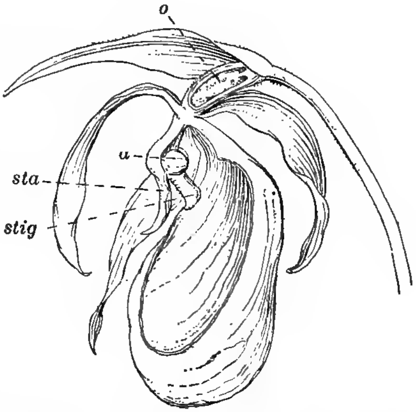

FIG. 282. Lengthwise section of one of the flowers of Fig. 281

stig, stigma; *sta*, imperfect stamen of bract-like appearance; *a*, anthers of perfect stamens; *o*, ovary

315. The Orchis family (*Orchidaceæ*). The orchids number more than 5000 species dispersed throughout tropical, sub-tropical, and temperate climates. Few other plants seem as capricious in their distribution, since a single individual or a small patch of them may constitute the only representation of a species throughout a considerable region. Orchids are all herbs, but vary greatly in habit, from low forms with hardly any stem aboveground, — like the true *Orchis* and the lady's-slipper (*Cypripedium*) (Figs. 281 and 282), — to tall climbers like the vanilla plant and such air plants as Fig. 20. Some genera, like the coralroot, are almost or quite destitute of chlorophyll, and live as root parasites or as saprophytes. Many species have tubers and are able to survive a long dry season. The flowers are of peculiar forms and have developed the most remarkable known structures for insect pollination. Great numbers of orchids are cultivated in greenhouses, and are among the most admired and highly prized of all ornamental plants. The only important useful orchid is the vanilla plant, a native of Mexico and the West Indies, from the unripe pods of which vanilla is obtained.

316. Useful products from other families. Many families of monocotyledons yield single products of much value. A few of the most important of these useful products are as follows:

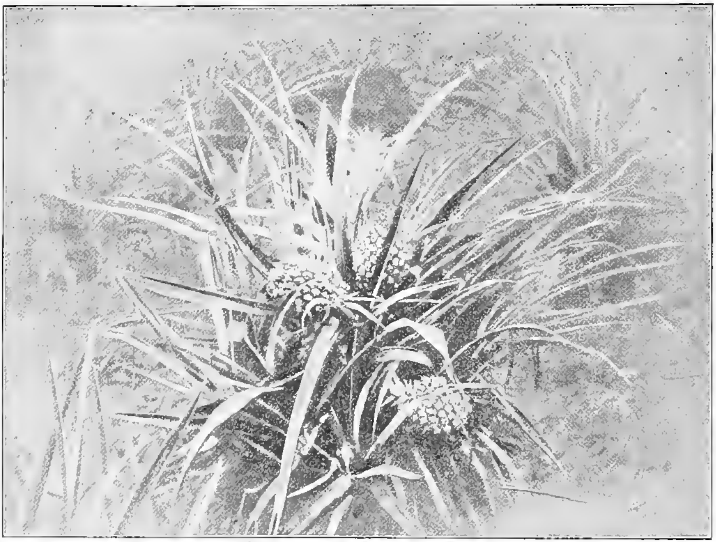

FIG. 283. Fruiting pineapple plants, Natal, South Africa
After Freeman and Chandler

Fibers are secured from the Sedge family (genus *Cyperus*), — used in making East Indian and Chinese mattings, — from the Amaryllis family, and from the Banana family.

Edible roots and rootstocks are derived from the Yam family and the Ginger family.

Fruits of great value are produced by the Pineapple family (Fig. 283) and the Banana family. Of these fruits the banana is so important an article of food that some details may be given in regard to its mode of growth and its place in our markets.

The banana plant (Fig. 284) is herbaceous, though in the most favorable soil and climate it may reach a height of forty feet. The leaves grow to be as much as ten feet long and two feet wide, and are usually, when full-grown, slit into strips by the wind. The fruit (technically a berry) is produced in long spikes, each bearing a hundred or more bananas. As a result of long cultivation the fruit has become seedless, and the plant is propagated by suckers from the base. There are two edible species, running into about 176 varieties, cultivated everywhere in the tropics for their fruit. Another species, grown in the Philippines, is an important fiber plant, yielding "Manila hemp."

FIG. 284. Gathering bananas in Costa Rica
Photograph furnished by United Fruit Company

The annual imports of bananas into the United States now amount to about 40,000,000 bunches, while in 1872 the total importation was only about 500,000 bunches. A few bananas are grown in the Gulf States, but our main supply comes from Jamaica and Central America. Entire trainloads of bananas are shipped daily from New Orleans and Mobile to supply the region west of the Mississippi as far as the extreme northwest, and also some portions of the country east of the Mississippi.

Bananas differ from ordinary fruits in that they possess a much higher nutritive value, so that they constitute a true food which needs little supplementing to support life indefinitely. They contain about three times as much protein and one and a half times as much carbohydrates as do apples; in fact, a banana has about the same food value as a potato, containing two thirds as much protein and a somewhat larger quantity of carbohydrates.

DICOTYLEDONS, CHORIPETALOUS SUB-CLASS

317. Families of dicotyledons. There are about 34 orders of dicotyledons, comprising 200 or more families. Of these orders 26 belong to the choripetalous sub-class and 8 to the sympetalous sub-class. The flowers of the choripetalous sub-class have either no perianth, or one consisting of separate sepals and petals (or sometimes of sepals only). The flowers of the sympetalous sub-class have a sympetalous corolla.

In this book only five of the most important among our families of deciduous trees can be mentioned. Some other facts in regard to them will be found in Chapter XXII. Four of the other principal families will be briefly treated here, — namely, the Rose family (*Rosaceæ*), the Pea family (*Leguminosæ*), the Spurge family (*Euphorbiaceæ*), and the Parsley family (*Umbelliferæ*).

318. Some families of hardwood trees. A large part of our valuable hard wood comes from trees of four families, — that of the willows and poplars, that of the walnuts and hickories, that of the oaks, chestnuts, and beeches, and that of the elms. All of these except the Elm family have unisexual flowers

(Fig. 285), often one or both kinds in catkins. In the Elm family (Fig. 286) the flowers are usually bisexual. A fifth family, that of the mulberries, includes among the economic plants of temperate North America few except the mulberries and the Osage orange, the hemp and the hop. This family also embraces the tropical breadfruits, and the great fig genus of some 600 species, including the edible fig and the rubber tree (*Ficus elastica*).

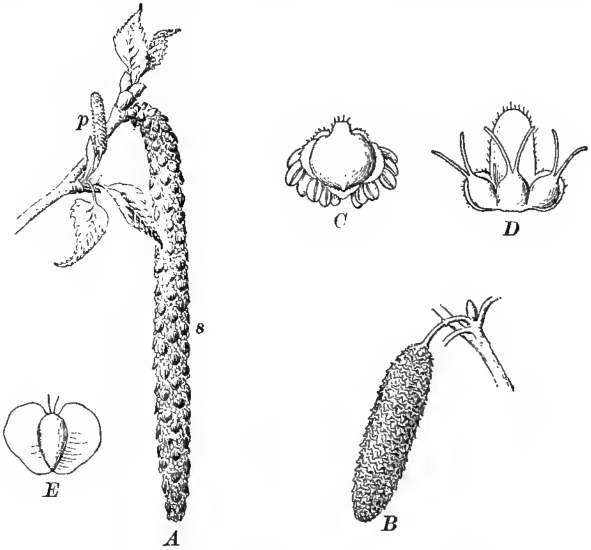

FIG. 285. Gray birch (*Betula populifolia*)

A, catkins, natural size: *s*, staminate; *p*, pistillate. *B*, cluster of ripened fruits; *C*, bract with three staminate flowers; *D*, bract with three pistillate flowers; *E*, fruit. *B*, *C*, *D*, *E*, somewhat magnified

Edible seeds of many kinds are produced by members of the families of catkin-bearing trees. Most familiar are the American and the European walnuts, the hickory nut, and the pecan. Hardly less so are the American and the European chestnuts.

Edible fruits—not however of much importance—are borne by the mulberries. The breadfruit, from a tree of the same family, forms most of the subsistence of many islanders of the South Pacific. Figs, belonging to the Mulberry family, are a highly prized article of food in their native countries. They are among the most valuable of our imported dried fruits, and are coming to be extensively grown in California.

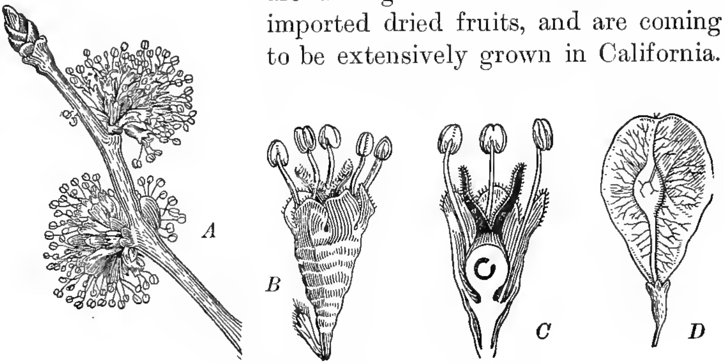

Fig. 286. European elm (*Ulmus campestris*)

A, a flowering twig; *B*, a flower; *C*, longitudinal section of a flower; *D*, a fruit. *A*, *D*, natural size; *B*, *C*, enlarged. After Wossidlo

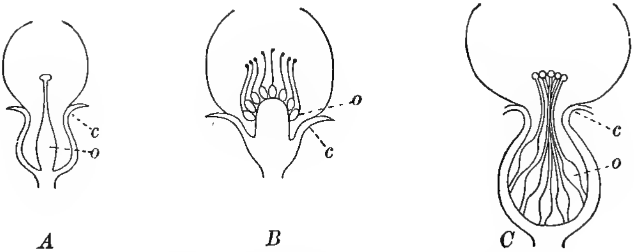

Fig. 287. Pistils in the Rose family

A, *Prunus* type; *B*, *Potentilla* type; *C*, *Rosa* type; *c*, calyx; *o*, ovary. After Prantl

319. The Rose family (*Rosaceæ*). The Rose family numbers about 2000 species of herbs, shrubs, and trees. The flowers are perigynous or epigynous (Fig. 287), with the parts of the perianth usually in fives; stamens generally more numerous than the divisions of the perianth; carpels one to many. The fruit is dry in some genera (Fig. 147) and fleshy in others (Fig. 148). Our genera are grouped into four divisions (based on characters of the flowers and fruit), which are often ranked as separate families.

320. Various uses of rosaceous plants. Aside from their importance as fruit producers (Chapter XXIV), plants of the Rose family are of value in many other ways.

Medicinal products are oil of bitter almonds, blackberry-root bark, wild-cherry bark, and oil of rose (used mainly as a perfume).

Cabinet wood of fine quality is furnished by our wild black cherry, and the wood of the apple, pear, and wild hawthorn is excellent for tool handles and similar uses.

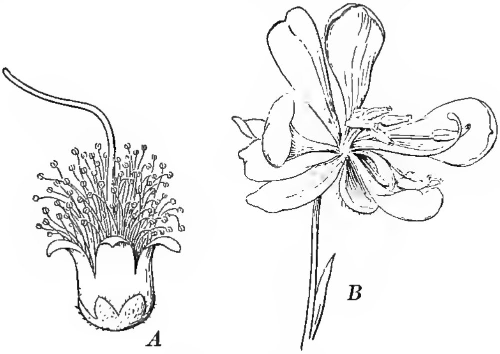

FIG. 288. Pea family

A, actinomorphic corolla (*Acacia cinerascens*); *B*, zygomorphic corolla of wild senna (*Cassia marilandica*). After Schnizlein

In the Rose family *ornamental plants* are so numerous that a mere list of all of them would occupy too much space. Some of the principal ones are roses, hawthorns, various species of spiræa, several kinds of crab apple, the rowan tree or mountain ash, and the Japan quince.

321. The Pea family (*Leguminosæ*).[1] The Pea family comprises about 7000 species of herbs, shrubs, and trees. The flowers are usually hypogynous or somewhat perigynous, often bilaterally symmetrical (Fig. 289), perianth generally in fives, pistil of one carpel, fruit usually a one-celled pod (Fig. 290).

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[1] The characteristic pod of the family is called a legume, and the plants of the most familiar of the sub-families are often spoken of as legumes, but the name does not seem to be botanically desirable.

The *Leguminosæ* constitute the largest family of choripetalous dicotyledons, an extremely important one on account of the numerous useful species. The genera are divided into three sub-families (often ranked as families), of which the acacia, the redbud (also the wild senna), and the sweet pea are respectively well-known types (see Figs. 288 and 289).

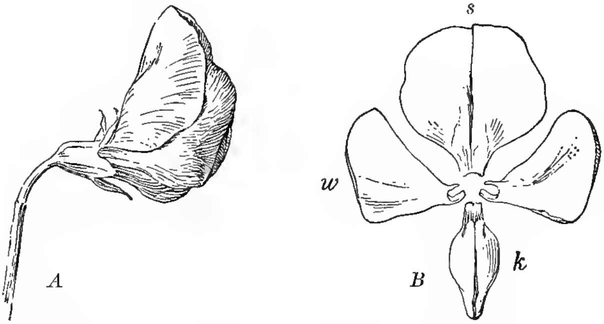

FIG. 289. Pea family. Papilionaceous zygomorphic corolla of sweet pea (*Lathyrus odoratus*)

A, side view. *B*, front view: *s*, standard; *w*, *w*, wings; *k*, keel

322. Edible seeds of the Pea family. Many seeds which form an important part of human food are derived from this family. The ones most generally used in our own country are peas and beans. Peanuts are the seeds of a leguminous plant largely grown in the South Atlantic states and elsewhere, which forces its pods underground to ripen. Our crop of 4,000,000 or more bushels per year is largely consumed at home, but is also considerably exported.

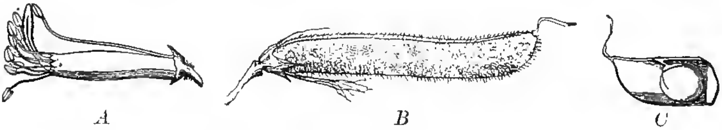

FIG. 290. Pea family. Stamens and pistil; fruit

A, stamens and pistil of sweet pea (magnified); *B*, fruit; *C*, part of fruit, showing one seed

Other leguminous seeds much used as articles of food in Europe, though not much eaten in the United States, are broad beans, chick-peas, and lentils.

323. Other useful products of the Pea family. Medicinal substances, dyestuffs, and varnishes are obtained from several genera of leguminous plants. Among the most familiar of these are gum arabic, licorice, balsam of tolu, senna, catechu, tamarinds, logwood, and copal varnish.

Timber of considerable value for some purposes is obtained from two North American genera, the black locust and the honey locust. Rosewood, blackwood, ironwood (*Afzelia*), coralwood, and some other kinds used in fine cabinet work, are from tropical or sub-tropical leguminous trees.

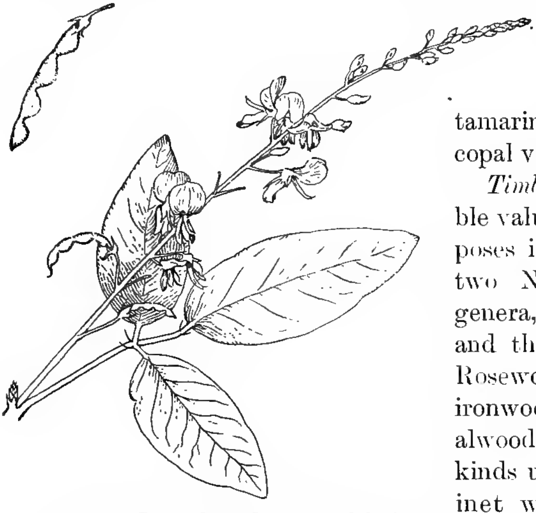

FIG. 291. *Desmodium* flowers and fruit

An herb of the Pea family. Reduced

324. Ornamental leguminous plants. The list of ornamental plants of the *Leguminosæ* is a very long one. Many genera, such as the true acacia, are not hardy in the Northern states, but a large number of our familiar cultivated herbs, shrubs, and trees are leguminous plants. Among the herbaceous ones are lupines, sweet clover, scarlet runner, the sweet pea and a scentless species which much resembles it. Common shrubs are several acacias, the "genista"[1] of the florists, "rose acacia," and wisteria. Commonly planted trees are the black locust, honey locust, yellowwood, and laburnum.

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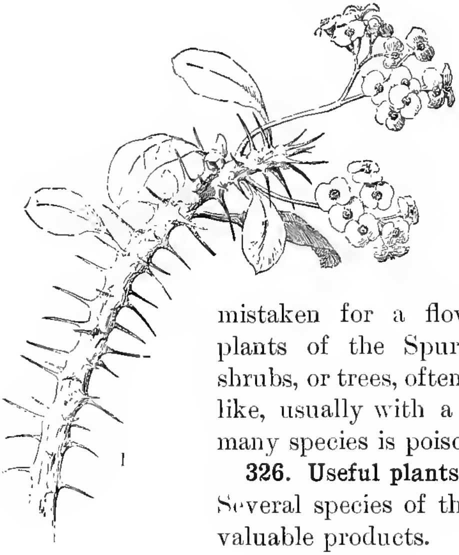
[1] *Cytisus canariensis.*

325. The Spurge family (*Euphorbiaceæ*). The Spurge family comprises about 4000 species, many of them tropical. The flowers (Fig. 292) are hypogynous, mostly unisexual; perianth usually simple or wanting; stamens one to many; ovary of three carpels and three locules, with one or two ovules in each locule. Often the inflorescence is so small and compact as to be easily mistaken for a flower (Fig. 292). The plants of the Spurge family are herbs, shrubs, or trees, often succulent and cactus-like, usually with a milky juice, which in many species is poisonous.



326. Useful plants of the Spurge family. Several species of this family yield highly valuable products.

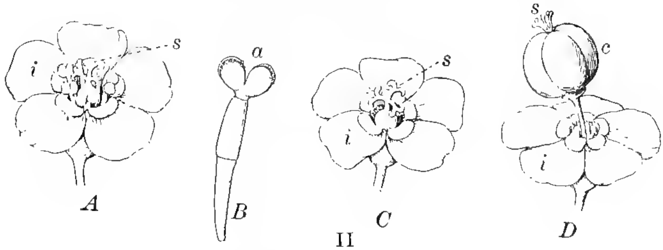


Fig. 292. I, *Euphorbia splendens*; II, *Euphorbia corollata*

A, flower cluster with involucre, the whole appearing like a single flower. *B*, a single staminate flower: *a*, anther. *C*, fertile flower, as seen after the removal of the sterile flowers. *D*, partly matured fruit. *i*, involucre; *s*, stigmas; *c*, capsule

The cassava plant is a native of Brazil but is now cultivated in many of the warmer parts of the world, including our own Gulf States. Tapioca is made from the clustered roots, which from a single plant sometimes weigh as much as thirty pounds. The ground or sliced roots are largely fed to horses, cattle, and hogs. One of the most valuable species has an acrid poisonous juice, which must be removed by heating or drying the ground-up roots before they are fed to animals.

Medicinal substances in considerable number — especially cascarilla bark, castor oil, and croton oil — are obtained from euphorbiaceous plants.

India rubber is largely obtained from two South American species of *Hevea*, a plant of this family (Fig. 293).

Ornamental plants of the Spurge family are several species of *Euphorbia* (Fig. 292, I), one of them commonly known as *Poinsettia*, and the castor bean, which in warm climates grows to be a small tree, but with us is a large annual.

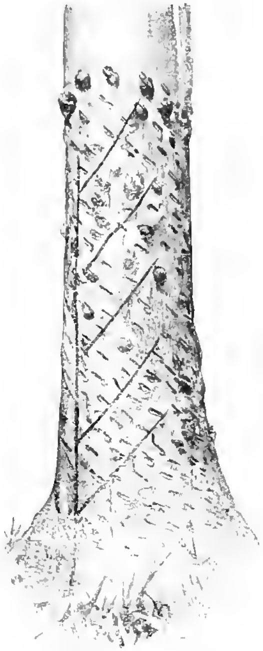


FIG. 293. Hevea tree tapped for india rubber

After Freeman and Chandler

327. The Parsley or Carrot family (*Umbelliferæ*). The Parsley family comprises about 1300 species, — herbs which are mostly natives of temperate regions in the northern hemisphere. The structure of the flowers and fruit can be understood from Fig. 295. As the flowers are usually much alike, the distinctions between species are based upon the form and structure of the fruit. Many species have poisonous qualities; some — as the poison hemlock (*Conium*), asafœtida, anise, and coriander — have medicinal value. The carrot, parsnip, celery, and fennel are of considerable importance as food substances, and parsley leaves and caraway fruits ("seeds") are much used for their flavoring qualities.

FIG. 294. Ginseng (*Panax quinquefolium*), a plant of the Ginseng family, closely related to the Parsley family. It is used in Chinese medicine, and is a valuable article of commerce

A, entire plant; *B*, flower cluster, flower, and fruit

328. Useful products from other families; foods and medicines. Valuable products are obtained from many other families of choripetalous dicotyledons besides those above described, and a few of these may be mentioned in this place.

Edible fruits. From the Saxifrage family we get currants and gooseberries. From the Rue family are obtained the citrous fruits, including ordinary oranges, tangerines, mandarins, lemons, and grapefruit.

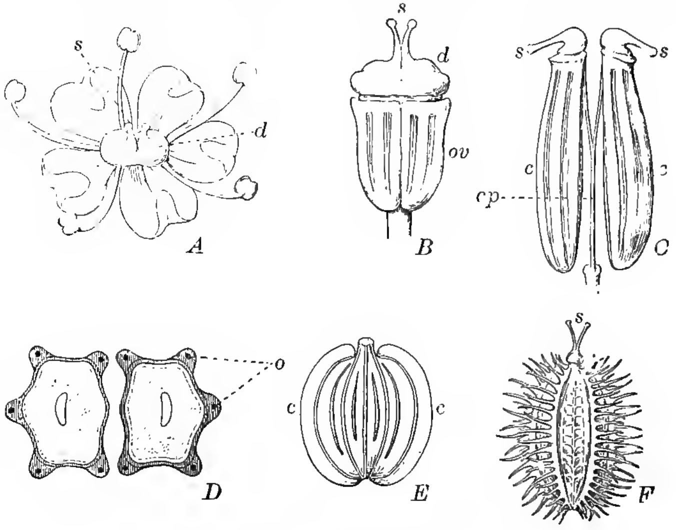


Fig. 295. Flower and fruit of Parsley family (*Umbelliferæ*)

A–D, caraway (*Carum Carvi*): *A*, flower; *B*, partly matured pistil; *C*, mature fruit; *D*, cross section of fruit. *E*, fruit of parsnip; *F*, fruit of carrot. *c*, carpels; *cp*, carpophore, or stalk to which ripe carpels are attached; *d*, disk; *o*, oil tubes; *ov*, ovary; *s*, stigmas. *A–D*, after Schnizlein; *E*, after Bischoff

Of the Grape or Vine family only one genus, the grape, is of economic importance, but it is an old and very important cultivated plant.

Chocolate and tea. Chocolate is manufactured from the seeds of the cacao tree; this tree was originally found in Mexico, but is now cultivated in hot climates in many parts of the world. The flowers spring from the trunk and older branches, and mature into juicy, many-seeded fruits, from which (after a fermenting process) the seeds are extracted, roasted, and ground. The family to which the cacao tree belongs is a tropical one, somewhat related to the familiar Mallow family.

Tea is made from the leaves of a shrub of the Tea family (Fig. 296), which consists of tropical and sub-tropical plants.

FIG. 296. An American-grown tea bush, from Darjiling seed (northern India)

The bush is four or five years old, and has been plucked for the tips of the twigs, for high-grade tea. Photograph furnished by the Bureau of Plant Industry, United States Department of Agriculture

The tea plant is thought to occur in a wild state in Assam, eastern India, and has certainly been cultivated for ages in China and the East Indies. The tea of commerce is made by drying the leaves of the shrub, allowing them during the process to undergo more or less fermentation.

Medicinal and other products. Opium and morphia (which is derived from opium) are obtained from capsules of the opium poppy. Cocaine is made from the leaves of a Peruvian shrub, a member of a small family allied to the geraniums. Cinnamon and camphor are obtained from trees of the Laurel family.

329. Products useful in textile and other manufactures.

Sumach products. From shrubs and small trees of the Sumach family, growing in the United States and in Sicily, are obtained leaves and young twigs much used for tanning the finer kinds of leather.

A Japanese species of sumach, with very poisonous sap, yields the famous Japanese lacquer so much used for varnishing articles of wood and other materials.

Fiber plants. The flax plant, which belongs to a family allied to the geraniums, produces from its tough bark the very fine and strong fibers from which linen goods and thread are made. It is grown in many parts of Europe, especially in Russia, and somewhat in the United States, both for the oil obtained from its seeds and for the fiber.

Valuable fibers or hair-like materials are yielded by plants of three closely related groups, the Linden family, the Mallow family, and the Silk-cotton family.

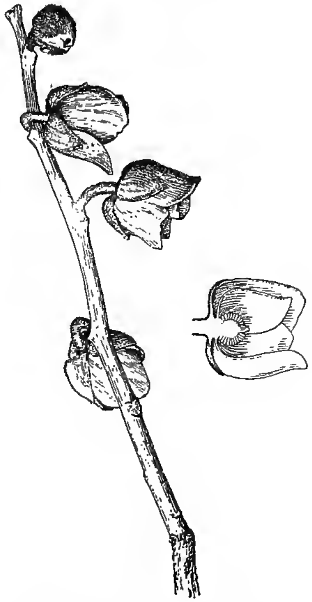


FIG. 297. Flowers of papaw (*Asimina triloba*)

The only North American representative of the tropical Custard-Apple family, noted for its delicious fruits

Russian bast and jute are products of the Linden family.

Cotton, the most important fiber plant, is discussed at some length in Chapter XXIV.

The silky fiber sold under various names as a material for stuffing pillows, cushions, and for other purposes, is obtained from the hairs which clothe the seeds of trees of the Silk-cotton family (*Bombacaceæ*), a small family of tropical plants.

330. Ornamental plants. Only a very few of the best-known ornamental plants of the choripetalous dicotyledons not already referred to can here be mentioned. Among them are pinks, water lilies, lotuses, magnolias, poppies, "geraniums," "nasturtiums" (*Tropæolum*), balsams, violets, mallows, begonias, and cacti. Here belong a large proportion of the annuals in our gardens and many of the familiar early wild flowers of the woods and fields, such as fire pink, buttercup, Dutchman's-breeches, hepatica, anemone, catchfly, and bloodroot. Here, too, are classed the numerous showy species of the Mustard family. Many favorite shade trees, such as the oaks, birches, elms, and maples, and many ornamental shrubs, such as barberries, hollies, hibiscus, and others, belong to the choripetalous sub-class.[1]

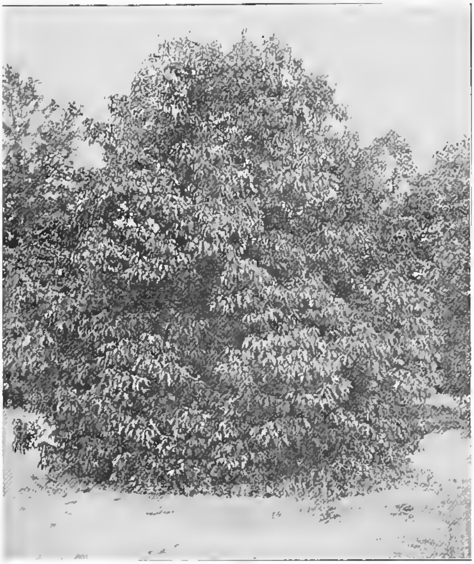


FIG. 298. An American-grown camphor tree

The tree is six or eight years old and eighteen feet high; it is grown on the Florida "high pine land," of almost pure white sand. Camphor-growing is now carried on extensively in this region, and by the improved method of distilling camphor from twigs clipped with their leaves from the live tree the latter is little injured, and the industry can be carried on for many years without replanting. Photograph furnished by the Bureau of Plant Industry, United States Department of Agriculture

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[1] Considerable matter relating to various species of hard-wood trees (most of which are choripetalous dicotyledons) will be found in the summary of facts concerning timber in Chapter XXII, and a short account of the citrous fruits and the grapes in Chapter XXIII.

DICOTYLEDONS; SYMPETALOUS SUB-CLASS

331. Families discussed. Five sympetalous families will here be treated: the Heath family, the Mint family, the Nightshade family, the Madder family, and the Composite family. Not all of these families are of great economic importance (though two of them are so), but they are among the best representatives of sympetalous plants, — the highest group of the vegetable kingdom.

332. The Heath family (*Ericaceæ*). This family numbers over 1300 species, mostly of shrubs or undershrubs, widely distributed from the polar regions to the tropical forests. The flowers are hypogynous (Fig. 90) or else perigynous (not always sympetalous); the anthers open by pores or short slits. The fruit is a capsule, a berry (often edible), or a drupe with very small seeds. The leaves are generally leathery and evergreen, often small.

FIG. 299. The common cranberry, not quite half natural size

333. Important plants of the Heath family. Cranberries, blueberries, and huckleberries are highly valued fruits of this family. Cranberries are borne by a delicate, trailing, woody plant. The upland species is little used, but the ordinary large cranberry (Fig. 299), found in peat bogs all the way from North Carolina to Minnesota and throughout a large part of Canada, is much valued. The yield from uncultivated bogs is considerable; in Massachusetts, New Jersey, and Wisconsin cranberries are extensively cultivated.

Blueberries and huckleberries belong to two different genera but resemble each other superficially. The former berry, borne on bushes of several species, from six inches to ten feet in height, is the more valuable, and is gathered over wide areas of the northern United States and Canada. The "heaths," or "blueberry barrens," on which the bushes grow in great abundance, are often carefully reserved, to be picked for the market.

Ornamental shrubs of the Heath family are numerous and highly prized. Best known among them are the rhododendrons (Fig. 56) (including many species commonly called azaleas) and the heathers. The so-called mountain laurel (*Kalmia*) is somewhat cultivated, and is a characteristic feature of many wooded hill and mountain sides in the northeastern states. The "trailing arbutus" (*Epigæa*), which is not, properly speaking, an arbutus at all, is perhaps the favorite spring wild flower of those regions where it occurs. The madroño (*Arbutus*) of the Pacific coast is one of the most beautiful trees of that region.

334. Mint family (*Labiatæ*). This family comprises about 2600 species, mostly natives of warm or temperate regions. The flowers are hypogynous; stamens usually two or four; ovary four-lobed, with a single style; corolla bilaterally symmetrical. Most labiates are small shrubs or herbs, with square stems and opposite leaves; the whole plant is usually aromatic and often glandular-hairy.

For so large a family, the *Labiatæ* ranks low in economic importance. Many species, however, afford volatile oils, which are of use in medicine, in cookery, or for perfumes. Some beautiful garden plants belong to this family, one of the most familiar being the scarlet salvia.

335. The Nightshade family (*Solanaceæ*). This important family numbers about 1300 species common in warm and temperate regions. The flowers are hypogynous; stamens five; ovary two-loculed, usually many-ovuled; fruit a capsule (Fig. 300) or sometimes a berry. Most plants of the family are herbs, but some shrubs and small trees occur, especially in the tropics.

Many of the genera are actively poisonous, and even in the case of edible species, like the potato, the foliage and other green parts often have an offensive smell and may be poisonous.

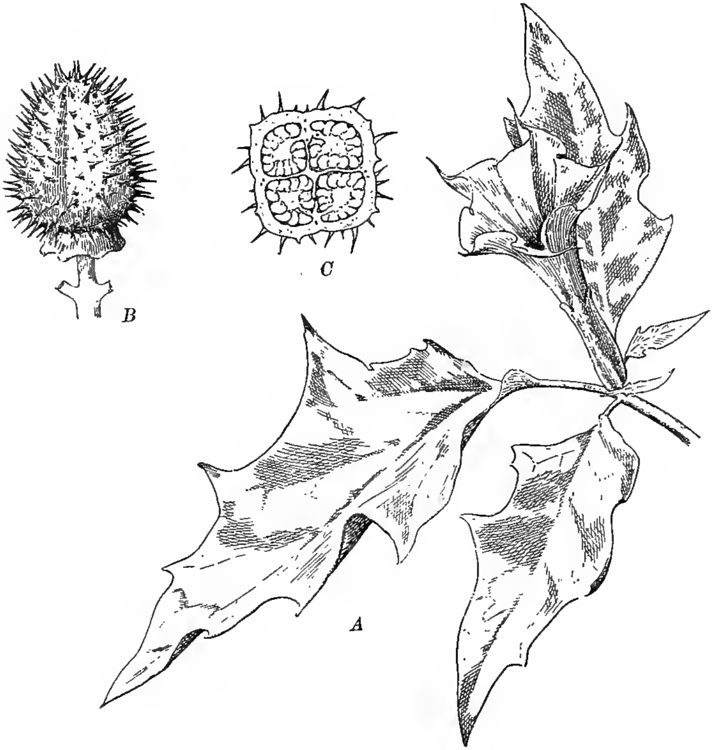

Fig. 300. Jimson weed (*Datura*)

A highly poisonous, ill-scented weed of the Nightshade family, common in barnyards and other waste ground. *A*, part of a flowering shoot; *B*, pod; *C*, cross section of pod. One half natural size

336. Three important plants of the Nightshade family. Three solanaceous plants of much commercial importance are the potato, the tomato, and tobacco. *The potato* (*Solanum tuberosum*) was probably introduced into cultivation from Peru. Its tubers have long formed a considerable part of the subsistence of mankind, especially in the cooler parts of Europe. Potatoes are particularly adapted for cultivation as a food crop in regions where the summer is so short and cool that wheat or Indian corn may not mature or produce profitable crops. Many varieties have been produced by selection of the most promising plants raised from the seed (collected from the berries or "potato balls"). Under the influence of long cultivation the size of the tubers has greatly increased (Fig. 331) and the tendency to bear seed has diminished.

Our annual potato crop is usually over 200,000,000 bushels. New York is the principal potato-growing state, producing nearly twice as many bushels as any other one of the chief potato-producing states, Pennsylvania, Michigan, or Wisconsin.

The tomato (*Lycopersicum esculentum*) was introduced into cultivation from tropical America, at first as a curious ornamental plant for the garden, whose fruit was supposed to be poisonous. Its fruit was originally small, two-celled, and watery, but by cultivation and selection has become large, fleshy, and several-celled. It is extensively grown for the market, and in several states large canning establishments handle the product of many special tomato farms.

Tobacco (*Nicotiana Tabacum*) was introduced into Europe from America during the latter half of the sixteenth century. The parent form of the cultivated species is said to be found in the wild state in Peru and Ecuador. Tobacco is an extremely profitable though somewhat uncertain crop. It impoverishes the soil more than any other field crop, since the plant withdraws from it great quantities of nitrates. The annual product of the United States and Porto Rico amounts to over 800,000,000 pounds, the leading tobacco-producing states being Kentucky, North Carolina, and Virginia.

337. Other important genera. No other plants of the Nightshade family are of great value as food plants, though another species of *Solanum*, the eggplant, is considerably cultivated. Red peppers (*Capsicum*), ground or whole, are much used as a condiment.

Medicinal substances are derived from belladonna, *Capsicum*, *Hyoscyamus*, and other solanaceous plants.

Ornamental plants of this family are rather numerous. The most familiar ones are species of *Datura*, tobaccos with showy flowers, matrimony vine, and various species of *Nierembergia*, *Petunia*, and *Salpiglossis*.

338. The Madder family (*Rubiaceæ*). This is one of the largest and most diverse families of dicotyledons, comprising about 4500 species of herbs, shrubs, and trees. Its representatives occur in all climates, though the majority are tropical. The flowers are epigynous; calyx minute; corolla lobes and stamens as many as the lobes of the calyx; ovary with two locules; fruit dry or fleshy. The outline and arrangement of the leaves, — which are almost always entire and opposite, — and the presence of leafy or scale-like stipules, are especially characteristic of the family. Our commonest wild genera are three herbs (bluets, cleavers, and partridge berry), and also one shrub, common by ponds and river banks, — the buttonbush.

FIG. 301. A coffee twig with berries

After Sadebeck

Coffee is made from the parched seeds of a small, slender, evergreen tree, a native of the mountainous portions of eastern Africa. It is cultivated in many warm countries, the largest amount coming from Brazil, but the finest quality from southwestern Arabia and from Java. The abundant white flowers, borne in axillary clusters, produce red, cherry-like drupes (Figs. 301 and 302), within each of which are two seeds, the familiar raw coffee of commerce, valued for the caffeine which they contain and the aromatic oil evident after roasting.

Cinchona trees of several species, growing wild in the Andes and cultivated in India and elsewhere, furnish cinchona bark. From this quinia (quinine), one of the most valuable of all remedies, is extracted.

Ornamental plants of two genera of the Madder family — *Bouvardia* and *Gardenia* — are rather commonly cultivated in greenhouses.

339. The Composite family (*Compositæ*). This immense family comprises about 11,000 species, those of temperate climates mostly herbs; some species of the tropics are shrubs, lianas, and even trees. The flowers are epigynous (Fig. 303, *D*); calyx rudimentary; corolla tubular and five-lobed, or strap-shaped, or bilaterally symmetrical; stamens five, with anthers united into a ring; stigma two-lobed; fruit an akene (Fig. 304). The most obvious characteristic of the *Compositæ* is the grouping of the flowers into a head. This sometimes (as in the thistles) consists wholly of tubular flowers, sometimes (as in the sunflowers and the yarrow, Fig. 303) of tubular disk flowers surrounded by strap-shaped ray flowers, and sometimes (as in the dandelion) of strap-shaped flowers only.

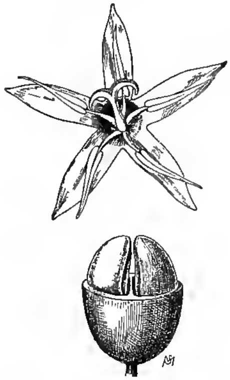

FIG. 302. Flower of coffee and a fruit partially dissected to show the seeds

After Karsten

The *Compositæ* are ranked as the highest seed plants. They probably owe their great numbers and wide distribution over the earth largely to their very perfect arrangements for securing pollination and fertilization.[1] Part of their success is no doubt also due to their means of dispersing seeds by the wind, as in the thistle, dandelion, and other genera (Figs. 136 and 141); or by animal agency, as in the burdock, Spanish needle, and the cocklebur (Figs. 135 and 352). *Compositæ* are very fully

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[1] See Knuth-Davis, Handbook of Flower Pollination. Clarendon Press, Oxford.

represented in the United States, and some genera, such as the ironweed, the golden-rod and aster, the rosinweed, the sunflower, coreopsis, and *Helenium*, are either exclusively American or at any rate very characteristic of our flora. The prairies and the Great Plains especially abound in composites.

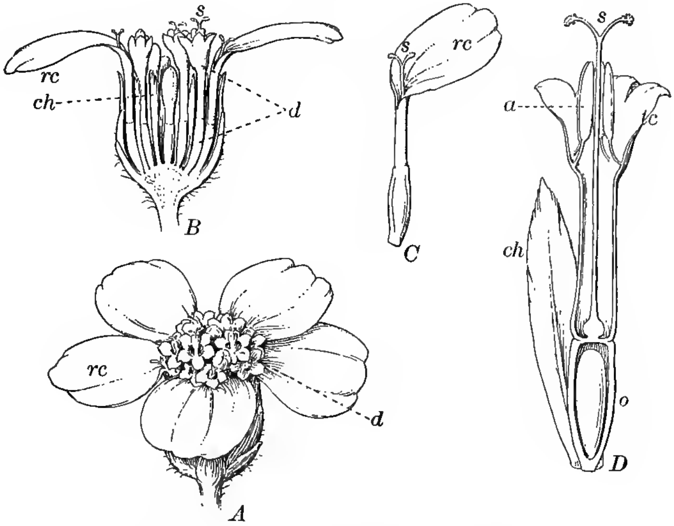

Fig. 303. Flower cluster and flowers of yarrow

A, flower cluster; *B*, section of flower cluster; *C*, a ray flower; *D*, a disk flower. *a*, anthers; *ch*, chaff of disk; *d*, disk flowers; *o*, ovary; *rc*, corollas of ray flowers; *s*, stigmas; *tc*, corolla of tubular flower. *A*, *B*, *C*, seven times natural size; *D*, eighteen times natural size

Food plants are rather rare among *Compositæ*. Lettuce is the most generally cultivated, but chicory and endive, dandelion, oyster plant, the globe artichoke, and the Jerusalem artichoke are of some value as food.

Medicinal Compositæ are not uncommon. A few of the most familiar are arnica, boneset, camomile, coltsfoot, dandelion, tansy, and wormwood.

Ornamental plants of this family are so numerous that only a small proportion of them can here be mentioned. Among these are bachelor's-button, China aster, chrysanthemum (including feverfew and marguerite), coreopsis, cosmos, dahlia, English daisy, everlastings, marigold, sunflower, zinnia.

340. Useful plants of other families. Several plants belonging to families of sympetalous dicotyledons not already described are important enough to be briefly mentioned.

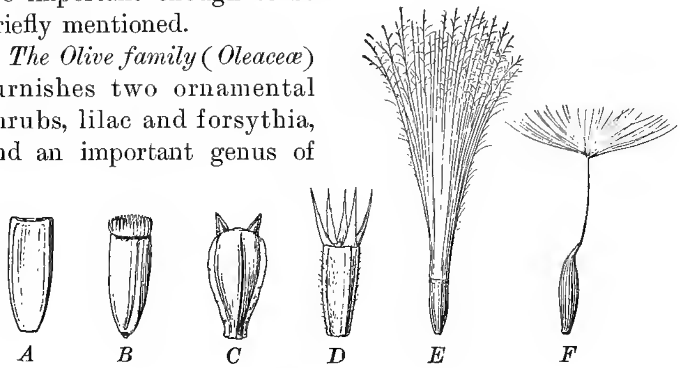

FIG. 304. Akenes with various types of pappus

A, *Rudbeckia*, pappus wanting; *B*, *Cichorium*, pappus a crown of fine scales; *C*, *Coreopsis*, pappus of two small scales; *D*, *Helenium*, pappus a crown of conspicuous scales; *E*, *Cirsium*, pappus a tuft of plumose hairs; *F*, *Lactuca*, pappus borne on a long beak

The Olive family (*Oleaceæ*) furnishes two ornamental shrubs, lilac and forsythia, and an important genus of timber trees, the ash genus. The olive itself is probably a native of the eastern Mediterranean region. It is now considerably grown in California.

The Gourd family (*Cucurbitaceæ*) furnishes many edible fruits. Of these the pumpkin and the summer squashes are varieties of the same species and the large winter squashes belong to another species of the same genus (*Cucurbita*), probably of American origin. The watermelon belongs to a genus (*Citrullus*) of Asiatic origin. The muskmelons, cantaloupes, nutmeg melons, and the cucumber belong to a third genus (*Cucumis*) and are modified forms of two southern Asiatic species.

The Morning-glory family (*Convolvulaceæ*) contains one highly useful food plant, the sweet potato, which belongs to the same genus (*Ipomœa*) with some of the morning-glories.

CHAPTER XXI

FURTHER DISCUSSION OF DEPENDENT PLANTS

341. Nutrition, the leading problem. "Getting a living is the first business of life, and food is the basis of a living; for the body derives both its substance and its energy from its food" (Needham). This statement is equally true of plants and of animals, and the greatest problem of living things is how they are to obtain an adequate supply of proper food. Much of what has already been said about plants has to do in one way or another with their nutrition. A good deal has also been said about the dependence of plants upon one another and upon animals, both in relation to food and to reproduction. The discussion of the bacteria and other fungi (Chapters XI, XIV, and XV), though it deals with structures and reproduction, constantly presents the relationships of these organisms to their food material. There are, however, some further aspects of interdependence which we shall consider.

342. Kinds of dependence for nutrition. Plants such as forest trees, ordinary grasses, cereals, and many others familiar in the farm and garden, which possess chlorophyll, can manufacture their own food (Chapter II). Since these green plants are dependent for materials from which to make food rather than for organized food, it is common to consider them as *independents*. This does not mean that they can live independent of anything outside themselves, but that if carbon dioxide, water, certain mineral salts containing nitrogen, potassium, etc., proper light and temperature, are available to them, they can use these things in constructing nourishing foods. These primary foods which are made by green plants are directly or indirectly the basis of the foods of all plants which are not green, and of all the food of animals, which in this wide sense are *dependents.* Usually the expression *dependent organisms* refers to an intimate life association between two or more organisms. All such life associations are included under the term *symbiosis.*

A good illustration of the different kinds of symbiosis is sometimes seen in the common Indian-corn plant and other plants and animals that live upon and within it. Upon the growing cornstalk, ear, or tassel, the dependent corn smut often appears (Fig. 197). Most of this fungus grows within the tissues of the living corn plant, from which it secures its food. This particular kind of symbiosis is known as *parasitism*, and the dependent plant is known as a *parasite.* Later the corn plant may die and fall upon the moist ground, when molds and bacteria may grow upon it. These take their nourishment from the dead corn plant, and as they do so they assist in bringing about its decay. Such a relation is known as *saprophytism*, and the plants or animals which live upon dead plants or animals are known as *saprophytes.*

Still another phase of dependency is often shown by small insects known as aphids, or plant lice, one kind of which thrives upon the roots of corn. Their nourishment consists of the juices which they suck from the tender roots. They also excrete a sweetish substance called honeydew, which is used as food by ants and sometimes by other kinds of insects. The aphids may begin to live upon corn when the seedling is germinating, and continue upon the growing plant until it is mature. Evidently these aphid insects are parasites. It is to be further noted that they are sluggish insects, and although they reproduce rapidly when food is abundant, they are not readily able to pass through the soil or over its surface to the roots of new plants.

There is a common black field ant which devours the honeydew apparently with great relish. Often about the bases of corn plants the burrows of these ants may be seen. They dig tunnels to the roots of the corn, then carry down some of the aphids and place them upon the roots. There the aphids are cared for by the ants, and the latter secure the honeydew as food. Throughout the summer and autumn the ants constantly care for the aphids and their young. Aphid eggs are carried to places most favorable for their hatching, and when the young are hatched they are transplanted upon tender young roots. When disturbances of the soil threaten destruction to the eggs, the ants seize them as they would their own eggs and carry them away. At the beginning of the winter aphid eggs are carried by the ants into the deepest parts of the ant nests. At the return of favorable weather the eggs are brought forth again to suitable places for hatching. In this case the aphids which are parasitic upon the corn roots are themselves in slavery (*helotism*) to the ants, and this interrelation obviously reaches a high degree of development.

In connection with the corn plant, therefore, we have an illustration of six kinds of food relations: (1) the corn is a so-called independent plant, since it is able to manufacture carbohydrate food from water and carbon dioxide; (2) men and domesticated animals are more or less dependent upon the surplus food that is made by the corn plant and stored in its seeds or in its stalk; (3) living upon corn there is often found the plant parasite known as corn smut; (4) aphids are placed upon corn roots by ants, the aphids being parasites upon the corn; (5) the aphids are themselves in a condition of slavery to the ants; (6) after death the corn plant may be attacked by bacteria and molds, which as saprophytes assist in bringing about its decay.

There are other destructive plants and animals which may attack the corn plant, but these will not now be discussed. Indeed, almost every kind of plant may be attacked by several kinds of dependent organisms. One kind of dependency may grade into another, as when a tree-destroying fungus takes its food from a living tree, and after the tree's death continues to live upon the dead body, thus changing from parasitism to saprophytism.

343. Dependent relations of soil bacteria. Most bacteria are saprophytic. Upon and within the soil are many kinds which get their nourishment chiefly from the organic products of plants and animals. Saprophytic bacteria, as they grow upon these substances, decompose them until they finally no longer appear as organic materials (Sect. 154, Relation of bacteria to decay). Many kinds of saprophytic bacteria, and some of the parasitic ones, are able to live for a long time in soils which contain only a very small amount of organic matter. The dependent habit of these saprophytic forms is important, since they reduce much organic matter to a condition in which it is usable in the growth of other plants. Conspicuous among these important products of decay are the nitrogen compounds which are essential to growth of green plants.

There are four groups of soil bacteria of particular interest in this connection. First, there are saprophytic forms which in their processes of nutrition make certain compounds of nitrogen and hydrogen which are known as ammonia. This bacterial action is known as ammonification, which means ammonia-making. The bacteria which are responsible for the action are called the "ammonification bacteria." Secondly, there are the so-called nitrite bacteria, which in their processes of nutrition change ammonia into compounds in which there is one part of nitrogen to each two of oxygen. Such compounds are known as nitrites. Thirdly, there are the nitrate bacteria, which change nitrites into compounds in which there is one part of nitrogen to each three of oxygen. Such compounds are known as nitrates. These last two processes are spoken of as nitrification. And fourthly, there are still different bacteria (Sect. 37, Chapter III) which at times enter the roots of certain kinds of plants, as clover, soy beans, peas, and alfalfa. When some of these bacteria have entered the roots they are surrounded by tissue so as to form nodules or tubercles (Fig. 305). Within these tubercles the bacteria are able to take uncombined nitrogen from the air and to combine it with oxygen in such a way as to form nitrates. These tubercle bacteria are known as the nitrogen-fixing bacteria, since they fix free nitrogen from the air. Since the ordinary grain-producing plants of the fields must have nitrogen in order to grow, and since they can use it only in the nitrate form, the significance to agricultural plants of the work of these root-tubercle or nitrogen-fixing bacteria is evident. An experiment may readily be performed (Fig. 306) to determine the relative influence of these organisms upon the rate and amount of plant growth. At the death of the clovers, peas, beans, etc., upon which the tubercles have grown, those surplus nitrates left in the soil furnish a most important part of the food of other agricultural plants.

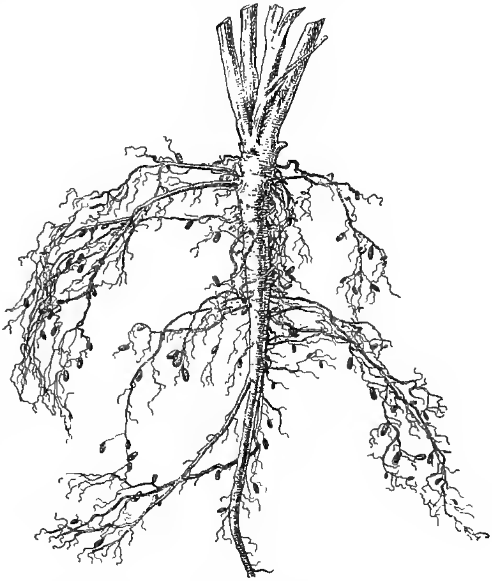

Fig. 305. Roots of red clover, with tubercles in which are the bacteria that collect nitrogen from the air

One half natural size

We have, therefore, at least four kinds of dependent soil bacteria, each of which in its processes of nutrition transforms nitrogen compounds in such a way that those compounds are eventually available as food for higher plants. The importance of this is further indicated in Sect. 37 (Partnership of roots and bacteria) and in Chapter XXIV. There are yet other kinds of bacteria which break up organic compounds so as to release nitrogen into the air, the process being known as

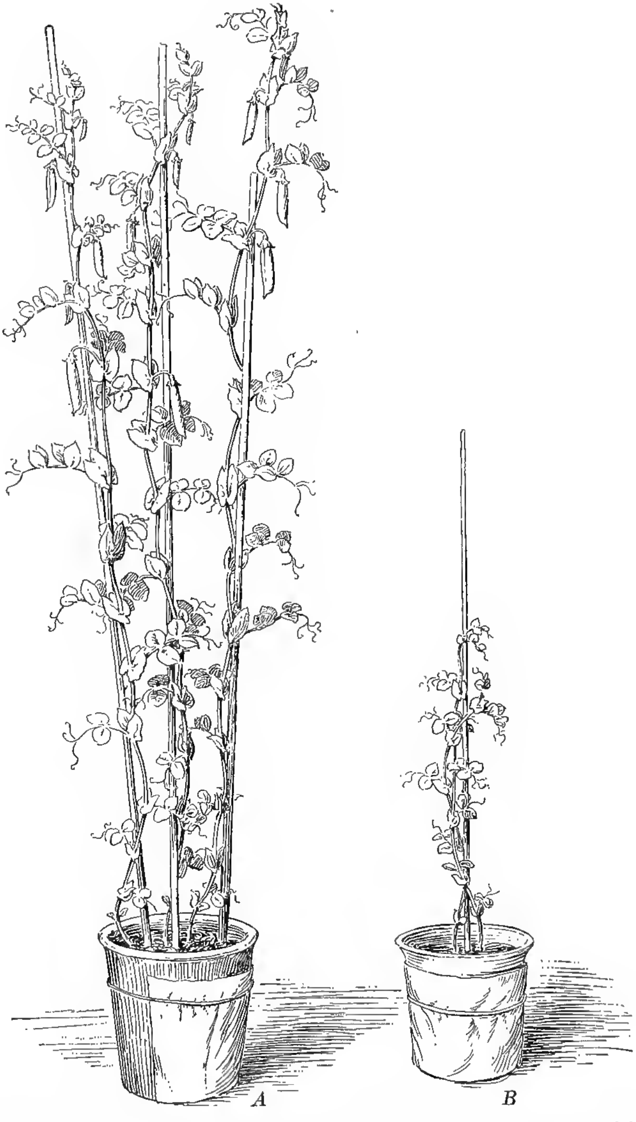

FIG. 306. Cultures of peas of same age and same kind of seed, one with and one without root-tubercle bacteria. After Frank

denitrification. In discussing the dependent relations of these bacteria we may mention another dependent organism which has recently been described.[1] In the soil a very small animal, closely resembling the amœba, is said to devour the bacteria of nitrification. This, if true, adds a new feature to what we have known of the interdependency of life in the soil. If these amœba-like animals become very abundant, they may destroy so many of the nitrifying bacteria that comparatively little nitrification will occur. Hence a smaller amount of nitrites and nitrates will be produced, and hence less nitrogen food from this source will be available for higher plants. But it is asserted that there tends to be a "balance of life," since, if the nitrifying bacteria of any locality are nearly exhausted, the food supply of the animal that lives upon them is thereby so reduced that for a time it does not thrive so well. Meantime the accumulating compounds offer greater food supply to nitrifying bacteria, and then for a time they may flourish, until when again they are abundant they offer increased food for the organisms that prey upon them. In this way a very long predominance of any kind of organism is usually prevented by the fact that its abundance offers new opportunities for the development of organisms that can use it as food.

A significant artificial method of regulating the growth of this amœba-like organism was almost accidentally discovered. Upon the roots of the grapevine there sometimes lives an insect parasite known as phylloxera. It was found in France that a treatment of the soil in the vineyards with carbon disulphide, though an expensive process, would prevent the growth of phylloxera. The fact that after such treatment the soil contained more nitrates and nitrites than before led investigators at Harpenden, England, to studies from which they state that the carbon disulphide not only kills phylloxera, but also kills most or all of the amœba-like animals which live upon nitrifying bacteria. It does not seriously interfere with the activities of the bacteria that break up the ammonia compounds.

[1] Hall, A. D., *Science*, Vol. XXXII, pp. 363–371, 1910.

Therefore treatment with carbon disulphide is said not only to prevent phylloxera from living upon the roots of the grape, but, by killing the amœba-like animals, to make it possible for the bacteria of nitrification to produce more ammonia compounds within the soil than would be produced if the bacteria were themselves being preyed upon by their enemies.

The student must clearly understand that there are many kinds of soil bacteria. The above statement includes a few facts from a very intricate and as yet incompletely understood subject.

344. Dependent relations of parasitic bacteria. In addition to what was said in the chapter on bacteria, but a brief statement need here be made regarding the dependent habit of parasitic bacteria. Many kinds of bacteria may take their food directly from other living things, and are wholly or partially dependent upon living hosts for their food.

The bacteria which cause "pear blight" may be taken as an illustration of the nature and degree of dependence that may exist. This is a disease which often seriously affects the leaves, young twigs, and fruit of the pear and apple. The bacteria cannot live under long exposure to direct sunlight or to drying, but can endure low temperatures. During the winter they live in the diseased twigs. In the early growing season the leaves and young growth of the twigs become blackened and soon wilt as a result of the internal growth of the parasite. The bacteria secure nourishment from the cells of the host. They may also serve partially or wholly to stop the cellular passages of the host, and possibly are injurious in other ways.

The question of how these bacteria are distributed to new hosts is important. Even if they should be carried through the air, and should withstand the consequent drying and sunshine, and fall upon the surfaces of twigs, leaves, or fruit of the proper host, it is said that they could not make their way into the tissue. It is believed that the common means of infection is through biting or stinging insects, or nectar-hunting insects that visit the flowers and fruit. When a few bacteria are inserted into a new twig, leaf, or floral structure, the infection may spread several inches and soon the blighting begins. When one flower is infected, insects may carry the bacteria to practically every flower upon the tree or upon other trees within the vicinity. Moreover, when the disease has developed far enough for the characteristic gummy exudations to appear, insects that bite into them may become loaded with the bacteria and may insert some of them into a new host. In pruning both diseased and healthy twigs, the knife may be the means of transferring bacteria. If all infected parts are removed and burned, and if the knife used in pruning diseased twigs is sterilized before being used in pruning healthy plants, the continued spread of the disease is made unlikely.

The "pear-blight" bacteria, therefore, are dependent upon such plants as the apple and pear for nutrition, dependent upon their twigs for protection through the winter, and dependent chiefly upon insects for distribution to new hosts. This is but one of many illustrations that might be cited to show the degree of dependence to which parasitic bacteria have come.

345. Other saprophytic fungi. One has but to observe carefully in any deeply shaded, moist, and warm undergrowth to see abundant illustrations of molds, mushrooms, and toadstools which are dependent upon decaying organic matter. Usually the major portion of such a saprophytic plant lives within the supporting substance and gathers nourishment from it. In this way the saprophyte may live for months or years with no external appearance of its growth. Upon breaking open an old log or stump, or upturning the soil, one often finds the extensively interwoven network of a saprophytic fungus. After a period of growth by the mycelium of the saprophyte, its superficial reproductive structure develops under favorable conditions as a sort of final and outward expression of its previous more or less prolonged period of nutrition. Spores thus produced may be carried by agencies such as the wind, insects, or other animals. When they fall in favorable locations they germinate, penetrate nutrient substances, and continue the life round. In the chapters on fungi there were given detailed accounts of the processes and structures that have to do with the nutrition of several kinds of saprophytic as well as parasitic fungi.

346. Other parasitic fungi. Usually parasitic fungi are extremely dependent, since most of them can live on but one or at most a few kinds of hosts. If for any reason these hosts are lacking, or if the parasite is not properly placed upon or within the host, the parasite fails. Wheat and oat rust may thrive upon wheat and oats and produce their summer and winter spores in great quantities (Sect. 232). But in entire absence of wheat and oats the parasite would probably soon disappear. It is apparently well adjusted to life upon these hosts, but, correspondingly, thoroughly dependent upon them for nourishment. Such is the case with many parasitic fungi. Their close adjustment to life upon one type of host is accompanied by complete dependence upon that host. It may be easier for the dependent plant to secure food when it is well located, but it encounters serious dangers when not well located.

347. Degrees of dependence among flowering plants. Some dependent flowering plants, like the woodbine or Virginia creeper, are almost independent. A woodbine may grow in the open and attain its full size; but in dense woodlands woodbines, grapevines, and many other climbers can only make a normal growth by raising themselves into the light by climbing up the trunks of trees. Similar degrees of dependence are found among the members of most of the other groups of plants described in the succeeding sections of this chapter.

348. Kinds of dependent flowering plants. The principal groups into which dependent flowering plants are divided are as follows:

(1) Lianas, or climbers.

(2) Epiphytes, or plants which live perched upon other plants.

(3) Saprophytes, or plants which live on the products of the decay of organic matter.

(4) Parasites, or plants which live upon other plants (known as host plants) while the latter are still alive.[1]

(5) Carnivorous plants, or those which capture small animals (such as insects) and live at least in part upon them.

Types of lianas were mentioned in the preceding section. They can get their living without the aid of other plants. The other groups (2–5) are discussed in the following sections.[2]

349. Epiphytes. Unfortunately for the student in temperate climates, flowering epiphytes are mainly confined to the tropics. The Spanish moss (Figs. 367 and 368) is one of the few exceptions. A visit to any large greenhouse in which orchids are kept will, however, suffice to give a fair idea of the appearance of some of the most characteristic plants which live perched upon the trunks or branches of trees. Since these plants usually have little or no permanent water supply abont their roots, they must be provided with means of absorbing water rapidly during rains, and for resisting drying between one rainfall and the next. The Spanish moss (which is rootless) takes up water

FIG. 307. Indian pipe (*Monotropa uniflora*), a symbiotic saprophyte

The plants are white from lack of chlorophyll

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[1] Cases of parasitism of plants upon living animals, although only too common among the lower plants (Sects. 157–160), are unknown among the higher ones.

[2] See Warming, Œcology of Plants, chap. xxv.

along the surface of the stems by the aid of special absorbent hairs which grow from the epidermis. This plant can become almost dried up without permanent injury. Orchids like *Cattleya* (Fig. 20) frequently have long, dangling roots, covered with an absorbent layer of tissue which acts much like blotting paper, taking up water very promptly, and gradually releasing it for the use of the plant. Many epiphytes of this type have thickened, fleshy stems, or leaves, or both, and a thick epidermis, through which little water escapes.

350. Saprophytes. In general, the seed plants which are saprophytes occur only in the forest or under shrubs. It is in such situations that plants find a most abundant supply of *humus*, or decaying organic matter. *Complete saprophytes* — that is, those which cannot exist without an abundant supply of soluble organic matter in the soil or substratum — are always pale, or even white, from partial or complete absence of chlorophyll (Figs. 307, 308). Their leaves are small and scale-like. Their roots are usually short, little branched, and furnished with a mycorrhiza, which freely absorbs plant food from the substratum.

Partial saprophytes, among flowering plants, are not easily recognized by their form and color, but may be known by their inability to flourish without considerable humus in the soil. Their requirements in this respect differ greatly.

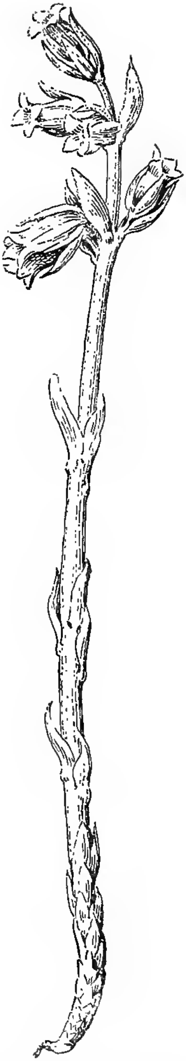

Fig. 308. Pinesap (*Monotropa Hypopitys*), a yellowish symbiotic saprophyte, dependent on mycorrhiza

351. Parasites. The dodders are the most familiar flowering parasites. One of the commonest species is abundant in the central and northeastern states, its thread-like, golden-yellow stems forming great tangled masses on many kinds of plants, from goldenrods to willows, growing in damp places. The dodders and some root parasites, such as the beechdrops, squawroot, and cancer-root (*Orobanche*, Fig. 309), are *complete parasites*, and have no green foliage. Other plants, such as the mistletoe, have green leaves and do photosynthetic work, but depend on the host for water and the mineral substances dissolved in it. Such plants are called *partial parasites.*

FIG. 309. Two plants of cancer-root (*Orobanche*) at left and middle of figure, parasitic on the roots of a wormwood at the right

352. Development of parasite seedlings. The embryo of the dodder is a thread-like object, which lies coiled in a spiral in the endosperm of the seed. The seed germinates late in the spring, and the seedling at first appears as a very slender, naked stem, with a club-shaped lower extremity which is soon pushed underground. The upper portion of the stem, if it encounters a twig or small plant, quickly winds about it and sends sucking roots or haustoria into the tissues of the host. By means of these it draws from the host enough plant food to develop the dodder plant until it flowers and seeds. If it encounters no suitable host plant in the course of four or five weeks, the seedling dies.

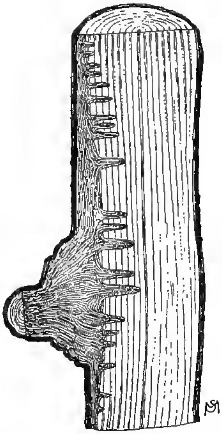

FIG. 310. A piece of fir wood penetrated by the roots of the European mistletoe

After Kerner

Some extraordinary flowering parasites develop scarcely any stem, but consist mainly of haustoria and an immense flower. *Rafflesia*, the most remarkable of these, grows upon the roots of vines which run along the surface of the ground. The buds of the largest species of *Rafflesia* on emerging from the bark of the host are about as large as walnuts. They finally increase in size until they become very large and cabbage-like, after which each bud opens into a fleshy, ill-smelling flower forty inches in diameter, closely attached by its haustoria to the root of the host, which looks as if it bore flowers of its own.

353. Damage inflicted by parasites. So much water and plant food is taken from the host by many parasites that they may cause serious injury to cultivated plants and to forest trees. The flax dodder and the clover dodder often do great damage to crops in this country and in Europe, and another species[1] is sometimes troublesome in fields of alfalfa. The American mistletoe is so injurious to dicotyledonous trees in the Southwestern States that it often has to be cut off from the trees to enable them to thrive. The European mistletoe causes much damage to apple trees in northern France and in the Tyrol.

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[1] *Cuscuta arvensis.*

354. Carnivorous plants. There are many kinds of plants[1] which capture insects and other small animals. In some cases, at least, they may use the captured animals as a part of their food supply. These plants may be roughly classified into (1) plants which capture their prey by means of sticky secretions; (2) plants which capture their prey by means of hollow, trap-like, motionless leaves; (3) plants which capture their prey by means of moderately quick movements of a sensitive hinged leaf.

It would take too much space to discuss these classes of carnivorous plants in detail, so a brief account of one representative of each class must suffice.

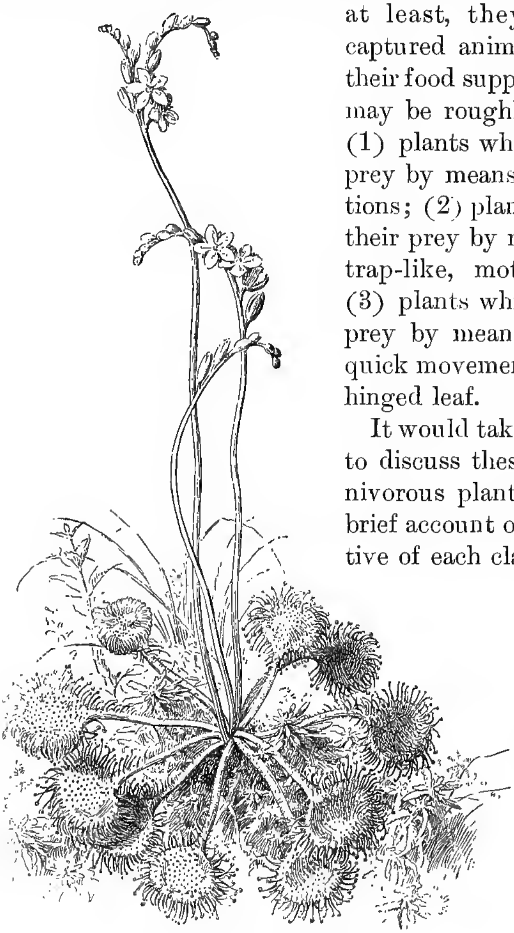

Fig. 311. Sundew (*Drosera rotundifolia*)

355. The sundews. These are low marsh plants, having hairy leaves and slender flower-stalks on which are borne small white flowers (Fig. 311). In one of the commonest species the leaf consists of a roundish blade borne on a moderately long leaf-stalk. On the inner surface and round the margin of the blade

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[1] Probably more than four hundred species.

(Fig. 312) are borne a number of short bristles, each terminating in a knob which is covered with a clear, sticky liquid. When a small insect touches one of the sticky knobs it may be held fast, and in that case the hairs at once begin to close over it, as shown in Fig. 313. The insect soon dies and then usually remains for many days, while the leaf pours out a juice by which the soluble parts of the insect are digested. The liquid containing the digested portions is absorbed by the leaf, and contributes an important part of the nourishment of the plant, while the undigested fragments, such as legs and wing cases, remain on the surface of the leaf or may drop off after the hairs let go their hold on the captive insect.

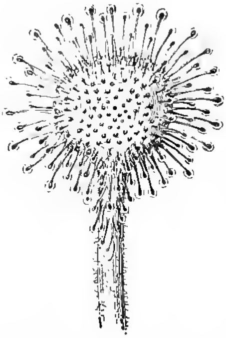

FIG. 312. Blade of leaf of sundew without prey

Somewhat magnified

356. Pitcher plants. In the ordinary pitcher plants (Fig. 314) the leaf appears in the shape of a more or less hooded pitcher. These pitchers are usually partly filled with water, and in this water many drowned and decaying insects are commonly to be found. The insects have flown or crawled into the pitcher, and, once inside, have been unable to escape on account of the dense growth of bristly hairs about the mouth, all pointing inward and downward. The common American pitcher plants may not depend much on animal food, but it is certain that some tropical species require it.

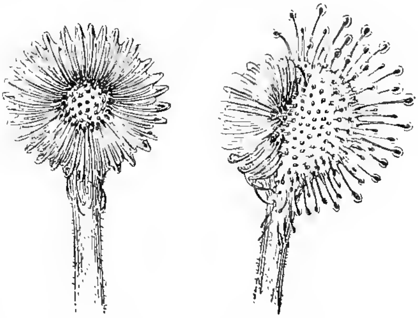

FIG. 313. Leaves of sundew during digestion of captured prey

The one at the left has all its tentacles closed; the one at the right has half of them closed over captured prey. Somewhat magnified

357. The Venus's-flytrap. In the Venus's-flytrap, which grows in the sandy regions of eastern North Carolina, the mechanism for catching insects is still more remarkable. The leaves, as shown in Fig. 315, terminate in a hinged portion which is surrounded by a fringe of stiff bristles. On the inside of each half of the trap grow three short hairs. The trap is so sensitive that when these hairs are touched it closes rather rapidly, and very generally succeeds in capturing the fly or other insect which has sprung it. The imprisoned insect then dies and is digested, — somewhat as in the case of those caught by the sundew, — after which the trap reopens, and is ready for fresh captures.

FIG. 314. Common pitcher plant (*Sarracenia purpurea*)

At the right one of the pitcher-like leaves is shown in cross section

358. Advantages of animal food. It has been claimed that there is an advantage that comes to a good many kinds of plants which catch insects and absorb the digested products. Carnivorous plants belong usually to one of two classes as regards their place of growth; they are bog plants or air plants. In either case their roots find it difficult to secure much nitrogen-containing food, — that is, much food out of which protein material can be built up. Animal food, being itself largely protein, is admirably adapted to nourish the growing parts of plants, and those which have insect-catching powers stand a far better chance to exist as air plants, or in the thin, watery soil of bogs than ordinary plants which have no such habits.

359. Irritability in plants.[1] The popular notion of what plants can do does not credit them with any power to execute movements. It is true most people have heard of sensitive plants, which fold up their leaflets when touched. Every one who is very observant must have noticed such movements as those of bean, clover, and other leaves in taking the nocturnal position (Figs. 52–54).

Fig. 315. Venus's-flytrap

Even people who are not botanists are usually much impressed when they see for the first time such prompt and apparently purposeful movements as those by which the stamens of the barberry flower spring up upon being touched, or those by which the Venus's-flytrap catches insects. But in general the movements of plants are executed so slowly that the change of position of the plant as a whole, or of its parts, can only be discerned by magnifying the motion in some way or by noting the successive positions occupied at considerable intervals of time. And yet plants do move so generally that in comparing them with animals we can only say that "most animals are more active than most plants."

All of the actions of plants are due to the *irritability* of their protoplasts. By this is meant simply their power of

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[1] See Coulter, Barnes, and Cowles, Textbook of Botany, Vol. I, chap. v.

responding in any way to some application of energy which serves as a *stimulus*. Professor W. Pfeffer thus illustrates the chain of events that occurs: An alarm clock which is wound up, but not going, receives a shake (stimulus) which starts its wheels, so that after a time (latent period) the clock sounds its alarm (result). The sensitiveness of the clock to the jar which starts it, corresponds to the irritability of the protoplasm. Among the stimuli which call forth responses from protoplasm are heat, light, electricity, gravity, pressure of external objects, and contact with substances which produce chemical effects on the protoplasm.

360. Examples of responses to stimulation. The earlier chapters of this book are full of instances of irritability called into action by appropriate stimuli. Indeed, the whole life history of a plant is a series of responses to stimuli; every newly sown wheat field in which the grain lies comparatively inactive during a succession of cold days, and then, when warmer weather comes, suddenly begins to sprout, is an excellent illustration of the response of protoplasm in the seed to heat.

Responses to light are very common, one of the most evident being the prompt excretion of oxygen noted when a green aquatic plant arranged as shown in Fig. 12 is brought from darkness into sunlight.

The response to gravity is shown by the downward growth of the roots and upward growth of the stem in very young seedlings.

The response to pressure is most evident in the coiling of a tendril about any slender support, which begins almost as soon as the tendril touches the foreign object.

Responses to chemical stimuli are extremely common and of great importance in the life of the plant. One familiar instance is the manner in which roots grow toward masses of fertilizer or rich soil (Fig. 348). Another case is the huddling of swarms of bacteria about a filament of any green alga which is giving off oxygen during photosynthesis.

CHAPTER XXII

TIMBER: FORESTRY

361. Coniferous woods. Our native woods[1] are best classified into the two principal groups of soft (or coniferous) and hard woods.[2] The needle-leaved or coniferous trees of the country furnish more than three quarters of our timber supply.

The structure of coniferous wood, as seen for example on the end of a beam cut off squarely, or on a new lead pencil, is in one respect less complex than that of most hard woods: the wood is chiefly composed of *tracheids*, long tubular cells with tapering ends, and contains no continuous ducts (it may contain resin passages). The rings plainly seen on the cross section of some kinds are due to the difference in diameter of the tracheids formed in early spring and later (Fig. 316).

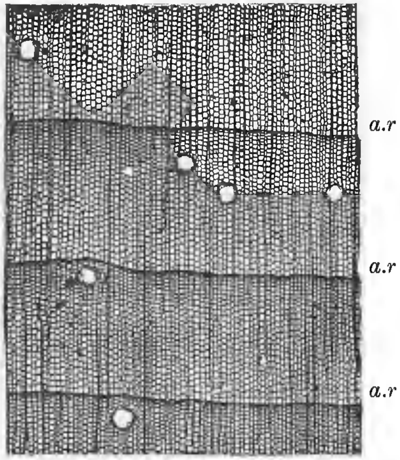

FIG. 316. Cross section of typical coniferous wood of white pine

a.r, boundaries between one year's growth, or "annual ring," and the next; the large, roundish white spots are cut-off resin passages. Magnified fifteen diameters. Photomicrograph by R. B. Hough[3]

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[1] "Timber," *Bulletin 10*, Division of Forestry, U.S. Dept. Agr., 1895.

[2] Some of the needle-leaved or coniferous trees, such as the larch and the yew, have rather hard wood; and some broad-leaved trees, such as willows, poplars, tulip trees, and buckeyes, have soft wood; but people who deal in timber usually speak of the two general classes as explained above.

[3] From Handbook of the Trees of the Northern States and Canada, written and published by Romeyn B. Hough, Lowville, New York.

362. Hard woods. North America furnishes more species of trees valuable for hard-wood timber than any other region of similar area with a temperate climate. About eighty kinds are of economic importance, and of these, six or eight are oaks, classed for commercial purposes as white and red or black oaks. White oak is stronger than the red kinds, but has not so coarse a grain, so that for cabinetmaking the red oaks are more ornamental, and often in "quartered" cut lumber (sawed radially) are very showy. More than half of our supply of hard-wood timber is furnished by the oaks (of about nineteen species).

Among the woods of broad-leaved trees, tulip-wood, from the tulip tree (*Liriodendron*), is next in importance to the various kinds of oak. It is variously known as yellow poplar, and whitewood, and grows in abundance in the Ohio basin and southward, but does not, like oak, form separate forests. The wood is very soft and workable, and has largely taken the place of white pine for the inside finish of houses and in the manufacture of woodenware.

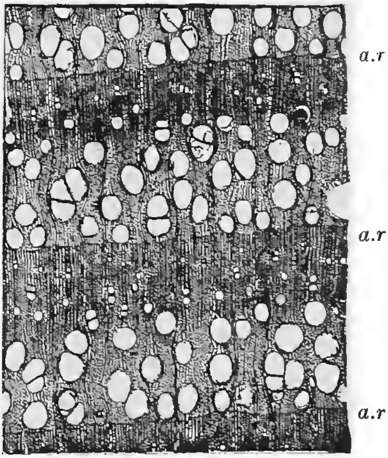

FIG. 317. Cross section of ring-porous wood of sassafras

a.r, boundaries of the "annual rings"; the wood is ring-porous because the ducts (here shown as oval or roundish spots) are most abundant in the spring wood, almost lacking in autumn wood. Magnified fifteen diameters. Photomicrograph by R. B. Hough

Ash, beech, birch, chestnut, elm, maple, red gum, and sycamore are some of the most important hard woods for general purposes besides those already mentioned. For especial purposes certain woods not of the greatest value for all-round construction are highly prized; as hickory for ax and other tool handles, and for carriage spokes; beech for shoemakers' lasts, saw handles, and carpenters' planes; persimmon for wood turning and shoe lasts; black locust for posts and railroad ties (on account of its durability in the ground).

For cabinetwork the most valued of our hard woods are black walnut, cherry, birch, and a good many species of oak and of ash. White walnut, red or sweet gum (*Liquidambar*), sycamore, and holly are also used, although not so largely.

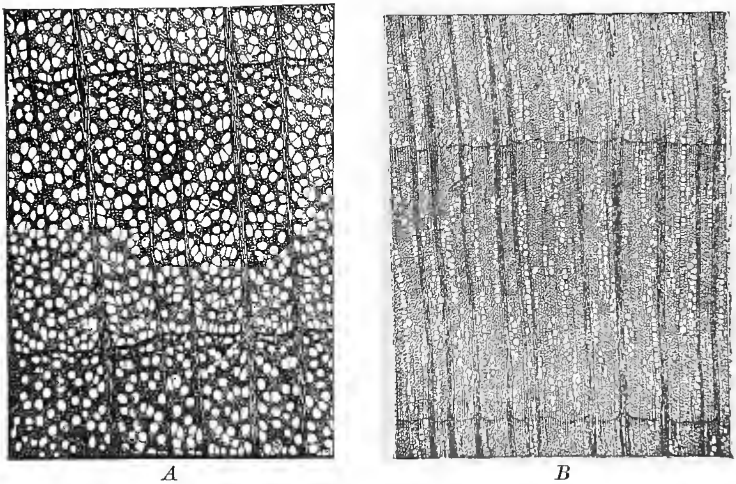

FIG. 318. Cross section of diffuse-porous woods

A, coarse-grained wood of sycamore; *B*, fine-grained wood of holly. The wood is diffuse-porous because the ducts are formed somewhat equally throughout the season's growth; the dark streaks running nearly vertically on the page, as the sections are here placed, are medullary rays (shown more clearly in Fig. 35). Magnified fifteen diameters. Photomicrograph by R. B. Hough

In structure the broad-leaved woods may be classed into two groups, — the *ring-porous* and the *diffuse-porous* kinds. In the former group (Fig. 317) most of the conspicuous ducts (the cut-off ends of which appear as pores in the cross section) are found in the spring wood. In the latter the ducts are scattered somewhat generally throughout the wood of the spring and summer growth (Fig. 318). Among the commonest and most typical of the ring-porous woods are ash and oak, and of the diffuse-porous ones, birch and maple.

In Figs. 316 and 317 the lower part of each section as it stands on the page is the portion nearest the pith of the trunk from which it came. How could this be known in the case of Fig. 317? Assuming that close texture (shown by the darker shade of the sections) accompanies slow growth, is the rate of growth the same throughout the season? If not, in which wood is it most nearly the same, and in which is it most unequal? If the pine wood shown in Fig. 316 is (except the resin passages) mostly made up of tracheids, when are the largest tracheids formed?

363. Some physical properties of wood. All wood contains moisture, the sapwood or outer portion more than the heartwood or inner portion. Not all of this water can be driven off, but much of it is removed by seasoning in the open air, and still more is expelled by drying lumber in kilns at a temperature of from 158° to 180° F. Coniferous woods may be placed in the kiln as soon as sawed, but the hard woods are usually first seasoned in the air for from three to six months. The loss of water from heartwood during kiln-drying amounts to from 16 to 60 per cent of the weight of the green lumber, the amount depending on the kind of wood treated.

When kiln-dried the heaviest woods, such as hickory, oak, and the closest-grained ash, weigh from 42 to 48 pounds per cubic foot. Those of medium weight, such as southern pine, sycamore, and soft maple, weigh from 30 to 36 pounds per cubic foot. The very lightest, such as white pine, spruce, and poplar, weigh from 18 to 24 pounds per cubic foot. Since water weighs about $62\frac{1}{2}$ pounds per cubic foot, all of our native woods float when dry, though some of them sink when green.

Wood is a very strong material in proportion to its weight. A piece of hickory, good oak, or long-leaf pine, 1 × 1 inch and 12 inches long (loaded in the middle and supported at both ends) requires a weight of about 720 pounds to break it.

A stick of hickory 1 × 1 inch is pulled apart lengthwise by a load of 32,000 pounds, and crushed by a weight of 8500 pounds. The corresponding values for long-leaf pine are 17,300 pounds and 7400 pounds.

364. Advantages of wood over other structural materials.[1] Certain disadvantages of wood for construction purposes, such as its combustibility, and liability to decay, are readily evident. Some of its advantages are as follows:

(1) Wood is far cheaper than metals; bulk for bulk, it does not on the average cost more than one thirtieth the price of iron or steel.

(2) Wood is much more easily worked than metals.

(3) Weight for weight, some wood is stronger than iron or steel. A bar of hickory will stand a stronger pull lengthwise than one of wrought iron of equal length and weight. A block of the best hickory or long-leaf pine will bear without crushing a greater load than a block of wrought iron of the same height and weight.

(4) Wood is light, and therefore much more convenient than metals for many purposes of construction, from building vehicles to making packing cases, and for tool handles and so on.

(5) Wood is a poor conductor of heat, and on this account is valuable in the construction of houses, railway cars, refrigerators, and other things. Even in buildings or sailing craft composed largely of steel it is therefore found highly desirable to make the floors, decks, and much of the interior construction of wood.

(6) Wood is a poor conductor of electricity. This makes it far easier to manage electric wiring in houses or other buildings in which the floor joists and most of the interior finish consists of wood, than in metal structures.

(7) Wood usually, when properly finished, has a highly ornamental surface. This makes it possible to give a decorative

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[1] See Roth, A First Book of Forestry, pp. 232–238. Ginn and Company, Boston.

effect to the interiors of rooms, railway cars, and so on, finished with wood, which could be obtained with other materials only with much difficulty and expense. It is difficult to imagine how beautiful furniture of moderate price, such as is made from our ornamental woods, could be made from any metal.

365. Wood as fuel. Although coal is the fuel of the world's great industries, yet there are large areas throughout which wood is still the principal fuel. All kinds of wood can be burned, but for certain purposes those kinds are preferred which make an abundant flame, or which leave solid beds of glowing coals. In general the heating effect of well-dried wood when burned is nearly (though by no means exactly) proportional to its weight per cubic foot. The fuel value per cord is therefore somewhat dependent on the weight per cord, and the heaviest woods, such as hickory, sugar maple, most of the oaks, hackberry, and some kinds of ash, are the best for burning. For certain purposes where a concentrated smokeless fuel which lights easily and does not readily go out is required, charcoal is employed. Generally the heaviest woods make a dense charcoal of great heating power.

366. Forestry. Forestry is the art of forest management. It should be based on the scientific study of woodlands. This study may cover all such topics as the distribution of forests over the earth's surface, their dependence on soil and climate, and their own influence upon these. It also discusses their composition as plant communities,[1] their progress from infancy, through youth and maturity, to old age, and their relations to the animal world. The utility of forests as sources of timber is a forestry topic which stands foremost in the estimation of the public.

It is evident that forestry is so extensive a subject that in a portion of a chapter like the present one only a few of its most important subdivisions can be briefly discussed. Every well-informed person should at least know in a general way what forestry is, since the maintenance of some of our best

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[1] See Sect. 447.

wooded areas and the creation of tracts of woodland in portions of the naturally treeless regions have become matters of national importance.

367. Our timber supply in early times. At the time of the discovery of America, and until long after the Revolution, much of the territory now included in the United States was among the most densely wooded portions of the north temperate zone. No other temperate region of equal extent possesses so great a diversity of dicotyledonous trees, and gymnospermous trees are also very abundant. Along almost the entire Atlantic coast, and inland to what are now the states of Illinois and Minnesota, timber for every kind of construction was once to be had at an extremely low price. The prevalence in early times of log houses, the enormous beams of which old houses in the northeastern states are framed, the panels of white pine, often of single boards three or more feet wide, without a knot, and occasionally in the Middle West the fence made of split rails of black walnut, — all testify to the superabundance of timber in early days.

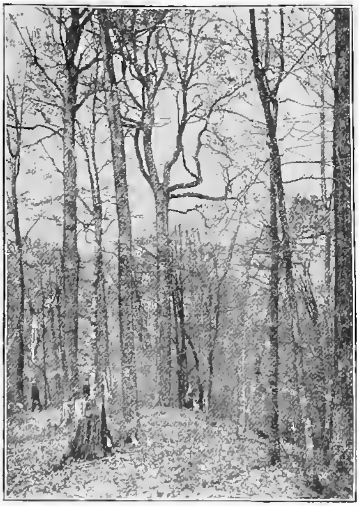

FIG. 319. Primeval deciduous mixed forest, — maple and beech

368. Decrease in the supply. In the days of the pioneers the extensive forests were serious hindrances to the settlement of the country. They harbored wild beasts and Indians, they made road-building difficult and farming at first almost impossible, and they sheltered great malaria-breeding swamps. Naturally the first step in rendering the new country habitable was to make clearings. Trees were girdled by thousands, and as the roots soon died of starvation (Sect. 73), they decayed, and the trees fell and were burned. In this way the farms continually encroached upon the woodlands, until areas of primeval forest (Figs. 319 and 320) became so rare that few of us have ever seen one. Lumbering operations which at first dealt only with full-grown trees, often centuries old, came to deal with "second-growth" woods, in which many of the trees were hardly more than saplings. In some cases the states in which lumbering was once an extensive industry now import most of their good lumber, part of it from the Pacific coast. In the future far more care must be taken to maintain our existing timber lands and to plant new areas. Lumber must hereafter be partially replaced in construction work by other materials. That which is used in situations where it is subject to rapid decay, as in fence posts and railroad ties, must be treated with chemicals which will protect it from the attacks of the saprophytic fungi which cause wood to rot.

FIG. 320. Undrained deciduous swamp forest, — ash, elm, and gum

FIG. 321. Self-pruning in pure growth of white pines

All the lower limbs are dead and will fall, so that the places from which they grew will become covered with new wood. Photograph furnished by Connecticut Agricultural Experiment Station

369. Composition of the forest.[1] Forests, whether of coniferous or of dicotyledonous trees, may be either pure or mixed. *A pure forest is one which consists almost entirely of a single kind of tree; a mixed forest, one which contains two or more kinds.* Nearly pure forests of white pine (Fig. 321) and of long-leaf pine (Fig. 260) are not uncommon. Few kinds of North American hard woods grow unmixed with other species of trees, but some of our birches, oaks, and maples occasionally do so.

Mixed forests, however, are the rule, and these may consist of only two or three kinds of trees, as beeches and maples; oaks and hickories; oaks, elms, and ashes. Often many species of several genera grow side by side, as sycamores, oaks, ashes, black walnuts, elms, and hackberries, which occur in some rich bottom lands of the Middle West.

Beneath the crowns of the trees many kinds of shrubs and undershrubs often flourish, and under these grow herbaceous plants in greater or less abundance. Their numbers depend on several factors, such as the light supply, the moisture supply, and the fertility of the soil. In the eyes of the forester many of these plants which grow beneath the trees are weeds, which more or less effectually hinder the growth of seedling trees.

370. Tolerant and intolerant trees. A tree which can endure a good deal of shade is said to be *tolerant.* Examples are, among conifers, the hemlock and the red spruce; among hard woods, beech and maple. Trees which require much light are said to be *intolerant.* Examples are, among conifers, the white pine and the larch; among hard woods, oaks, hickories, and chestnuts. As a rule, seedlings require far less light to begin life than is needed to enable the mature tree to reach its maximum size. So it often happens that seedling trees may struggle on for years on the forest floor, making but little growth until the decay and fall of overshadowing trees, their destruction

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[1] This section applies especially to forests of temperate zones, those of tropical climates being often very complex in their make-up.

by wind, or their being felled by the lumberman, enables the seedling to grow up rapidly into a large tree. Properly to show this change in rate of growth would require a series of photographs taken at intervals of several years, with increasing amounts of light supplied to the young tree; but there is often a most interesting record of changed rates of growth in the wood of the trunk itself (Fig. 322).

The behavior of trees as regards tolerance of shade has to be carefully considered by the forester, since he must not try to start seedlings in places where they cannot continue to grow. White pines would not succeed under the shade of hemlocks, but the hemlocks can grow under pines and may thus succeed them in a wood lot.[1]

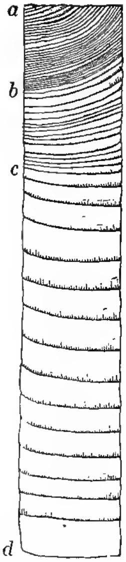

FIG. 322. Effect of thinning out on forest growth

Part of the cross section of a fir tree, about half natural size; the early growth from *a* to *b* was very slow, as the young tree was shaded by spruces; from *b* to *c* the growth was more rapid, as part of the spruces were blown down by a storm in 1871; from *c* to *d* the growth was still more rapid, as the remaining spruces were destroyed by a storm in 1885–1886. After Hopkins, Division of Entomology, U.S. Dept. Agr.

371. Problems of forestry. Forestry has to do chiefly with tree planting on unforested areas, and with the maintenance of existing forests in the most productive condition. Successful management requires much attention to the choice of desirable kinds of trees for planting, adapted to the region where they are to grow. Single trees or portions of the forest should be selected when in suitable condition to be felled. Standing timber must be protected from all kinds of destructive agencies, such as forest fires and animal or plant parasites. Felled trees must be protected from decay and from attacks of boring insects, and the most economical methods must be chosen for felling, transporting, and working up the various kinds of timber.

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[1] See Pinchot, "A Primer of Forestry," Part I, *Bulletin 24*, Division of Forestry, U. S. Dept. Agr.

FIG. 323. Young pines starting in partial shade of hard-wood trees

Photograph furnished by Connecticut Agricultural Experiment Station

FIG. 324. Conifers self-sown after heavy timber has been felled; San Bernardino Mountains, California

Photograph furnished by Division of Forestry, United States Department of Agriculture

372. Propagation of forest trees. In wooded regions, where labor is expensive, it does not usually pay to plant large areas with seeds of trees, or to set out many young seedlings. Self-sown trees will usually spring up in natural or artificial openings in the woods (Figs. 323 and 324). The seeds of conifers are blown considerable distances by the wind, and those of some deciduous trees, such as birches, elms, ashes, and maples, are carried in the same way. Nuts and acorns, on level ground, must depend largely on birds and squirrels as carriers (Fig. 325).

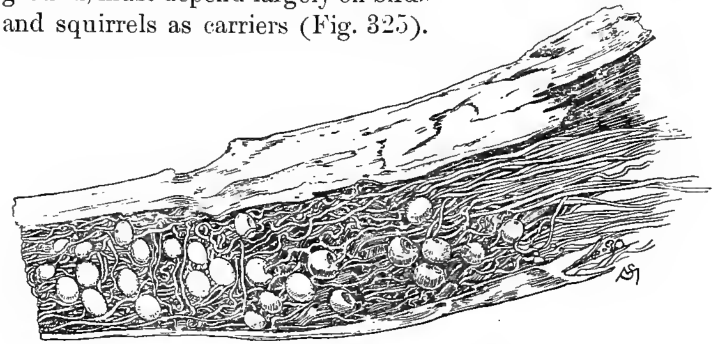

FIG. 325. Tree planting by animals

The figure represents acorns hoarded by a chipmunk in a prostrate hollow limb of a tree. The acorns have begun to grow, and one or more of them, if left undisturbed, would doubtless have grown into trees. From photograph by R. E. Webster

Many trees, as oaks, chestnuts (Fig. 326), and birches, sprout freely from the stump and thus renew woodlands, after cutting, much more quickly than growth of young trees from the seed could accomplish it. Often it is found most profitable to allow the sprouts to grow only twenty or thirty years, forming a *coppice woodland*, which is then cut and used for making telegraph poles, fence posts, railroad ties, and so on.

373. Tree planting. In such treeless regions as the prairies and the Great Plains it is often desirable to establish belts of timber or considerable tracts of woodland. This is done partly for shelter from winds and partly for the timber produced for local uses. The seeds may be planted where the

FIG. 326. Chestnut sprouts springing from the parent stump

Photograph furnished by Connecticut Agricultural Experiment Station trees are finally to stand, or young seedlings may be procured from a forest nursery. The latter plan is the better, and it is well to have the young seedlings transplanted once or twice before their final planting, to avoid formation of long roots, cutting of which would check the growth of the tree. Both coniferous and dicotyledonous trees are much planted. Some of the most generally available conifers are several kinds of spruce, the white pine, the Scotch pine, and the Austrian pine. Among the desirable dicotyledons are cottonwood, silver or white maple, green ash, honey locust, hardy catalpa (Fig. 327), red oak, and (in the warmer parts of the country) eucalyptus. In climates such as that of the lowlands of California, *Eucalyptus globulus* is the most rapid growing of hard woods, reaching a diameter of one foot and a height of 125 feet in ten years. To reach this diameter the white oak would take a hundred years.

FIG. 327. A four-year-old plantation of hardy catalpa

At the left are Russian mulberry trees of the same age. Note the dense shade, sufficient to protect the forest floor from weeds. These trees were cultivated for three years, but now need no further care except pruning

374. Influence of forests on climate and water supply. The temperature and rainfall in and near forests are thought to have slightly different values from those obtained in treeless areas, but the amount of the differences is not fully settled. The effect of woods, or even belts of trees, as windbreaks is familiar enough to every one who has traveled along a road through land partly wooded and partly open on a windy winter day. Evergreen conifers are, of course, much more serviceable than deciduous trees as a protection against winter storms, and they are much planted for this purpose in belts in the more northerly plains and prairie states.

The greatest service, however, which is rendered by woodlands, next perhaps to their use as sources of timber, is in preventing the water which falls as rain or snow from running off at once into streams, thus causing floods which are followed by long periods of low water. The run-off, even in a grassy prairie country, during and after rains is very rapid, so that streams may be overflowing their banks in a few hours after the beginning of a heavy rain. In a region where the land is mostly tilled, with little woodland, the run-off is still more rapid, so that a great deal of the water precipitated on a hundred-acre field may have found its way into ditches or watercourses outside of its limits within much less than an hour after it fell. In treeless regions, as every prairie boy knows, many stream beds in summer become merely a succession of pools or are dry throughout their length. On the other hand, the forest floor is often moss-carpeted, strewn with leaves and covered with underbrush, and overlies a rich black soil containing much partially decayed animal and vegetable matter known as *humus*, which is penetrated to a depth of many feet by an intricate network of rootlets. This soil retains the water from melting snows, often for weeks, and holds the heaviest rains for long periods. The water gradually drains off along the surface or travels slowly through the deep, porous soil, gradually finding its way into the streams. It is therefore of the highest importance that such regions as the White Mountains, the Adirondacks, the central and southern Appalachians, and western mountain ranges which are used as sources of water for irrigation should be forested.[1]

375. Forest growth prevents erosion. Along with the value of the forest in regulating the flow of streams, account must be taken of its importance in preventing the washing away or *erosion* of the earth's surface. Not only mountain and hillsides but cultivated slopes everywhere are subject to great losses by washing during thaws after snows and during rainstorms. How much earth is thus annually carried to the Gulf by the Mississippi alone has already been stated (Sect. 29). Fig. 345 represents a newly cleared slope under cultivation, and Fig. 346 an early stage in the formation of gullies on a steeper slope after clearing. The land in the latter case is already past the stage in which it can be cultivated in the ordinary way. Left to itself the tendency is for the washing to continue until the hillside becomes a series of miniature ravines, strewn with bowlders and separated by bare ridges. Thousands of acres in the southern United States and hundreds

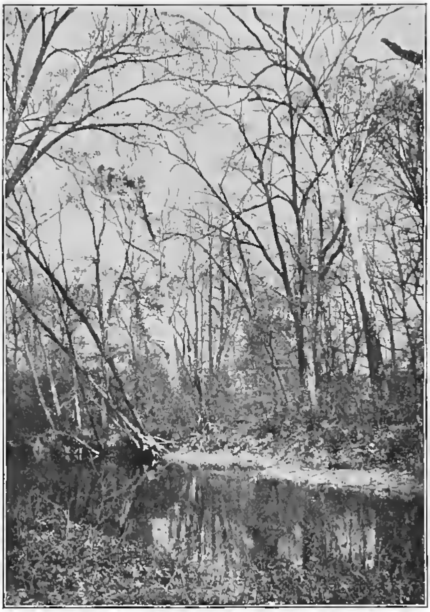

FIG. 328. How the forest holds the soil

The river in the foreground often overflows its banks, but little erosion occurs

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[1] See Fernow, "Forest Influences," *Bulletin 7*, Division of Forestry, U. S. Dept. Agr.

of thousands in some of what were once the most fertile parts of southern Europe have been ruined in this way. Such destruction may be prevented by retaining hillsides in a wooded condition, or at least leaving belts of trees at intervals, running at right angles to the lines of slope. The early stages of erosion may be checked by damming the principal gullies with logs, stones, and brushwood, and then replanting with suitable trees and bushes. Contour plowing, — that is, plowing around the hill instead of up and down it, — terracing, ditching at right angles to the lines of slope, and underdraining all help to prevent erosion.

376. Rules for forest management. For a detailed account of the mode of keeping up the productiveness of woodlands and of handling timber one must go to special treatises on forestry.[1] In this place there is room only to name a very few of the things to which the forester or manager of timberlands must attend:

(1) *A timber forest*, or woodland, consisting in considerable part of full-grown trees, should be cut over on a selective plan; that is to say, only those trees should be felled which are nearly or quite full-grown, or which are too much crowded or in some way imperfect or diseased. This kind of selection may not be possible in case the location of the forest is rather inaccessible, so that large gangs of men must be taken into the woods and the cutting all done within a limited season. As far as possible the felling must be so managed that promising young trees are not barked or otherwise injured by the falling trunks of the trees which are cut.

(2) In managing coppice woods the trees must be cut as soon as they reach a merchantable size, usually in from twenty to forty years.

(3) During the period of most active growth all woodlands should be kept covered with a reasonably close stand, so as to secure self-pruning and not encourage the growth of

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[1] For elementary principles, see Roth, First Book of Forestry. Ginn and Company, Boston.

much-branched trees like those shown in Figs. 329 and 330, which, when cut up into lumber, will be very full of knots.

(4) Forest fires must be prevented, especially in woods of coniferous trees. No fires for any purpose should ever be kindled during dry weather in the heart of such woodlands, except in moderately large clearings free from brush. Cutting up large tracts of forest into smaller portions by means of roads helps to keep small fires from spreading. But in warm, dry weather a coniferous-forest fire under full headway is seldom stopped until it reaches extensive clearings, or rivers or other large bodies of water.

Fig. 329. An Austrian pine with limbs broken by clinging snow

This shows the branching habit of pines grown in the open, worthless for timber

(5) Parasitic fungi and the saprophytic kinds which cause the decay of fallen trunks and branches or felled trees (Figs. 208 and 209) should be burned when to do so is not too expensive, if this can be managed without danger of starting forest fires.

(6) Wood-boring and leaf-eating insects should be killed, if the expense of the process is not too great. It is suggested, for example, that the great damage caused by the spruce-destroying beetle, which kills mature trees by mining the bark of the trunk, may be much lessened. This can be accomplished by cutting and removing most of the infested trees, or by girdling trees early in June to expose them to the attacks of the beetles, then felling and either peeling them or immersing

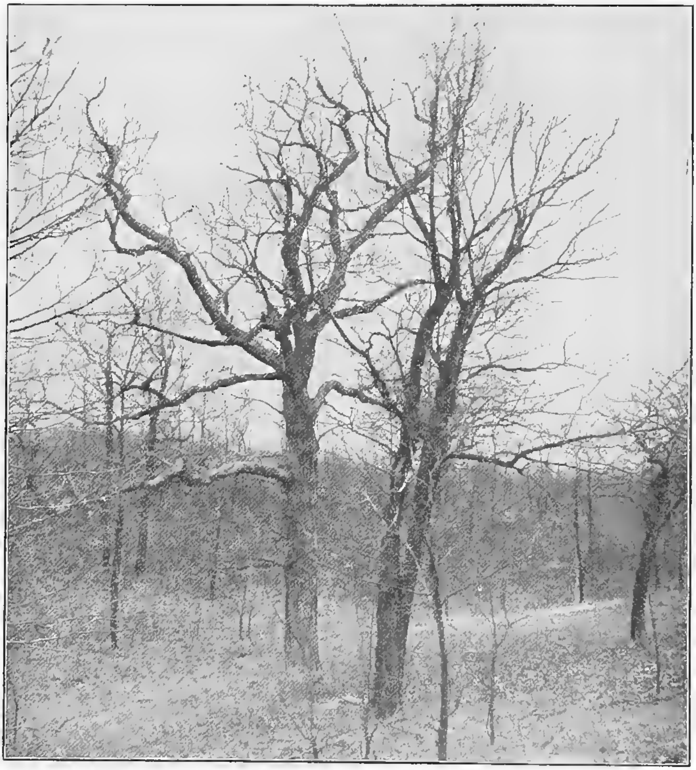

FIG. 330. Oak trees growing in the open

A white oak at the left and red oak at the right them in water to destroy the insects before the new crop of beetles emerges from under the bark the following June.[1]

One of the most effectual means of destroying some injurious insects consists in introducing into the region where they abound parasitic or other insects which will kill great numbers of the objectionable species. Plant lice, for instance, are thus killed by ladybugs. Vigorous attempts are now being made to exterminate the gypsy moth in New England by means of parasites and by carnivorous insects which attack and kill the moth at some stage of its existence. The caterpillars of this moth are extremely destructive to many kinds of trees, which they strip of their leaves in a short time. More than $1,000,000 have probably been expended in Massachusetts alone in trying to get rid of this pest. The moth was introduced into America in 1869 by a scientist who lived at Medford, near Boston, in the course of some most unfortunate experiments on silk-producing insects.[2]

(7) Cattle should not be pastured in woods in which it is important to protect the growth of young seedling dicotyledonous trees. They do not greatly injure mature trees. Sheep pasturing and forestry cannot thrive together, since by browsing the sheep destroy many young seedling trees. On grassy hill and mountain sides sheep, by close grazing and by cutting the turf to pieces with their sharp hoofs, soon kill the grassy cover and pave the way for extensive erosion. Great damage has been done in this way in the Rocky Mountain and the Pacific slope regions of our own country. In southern Europe pasturing sheep and goats has led to the conversion of great areas of comparatively fertile mountain sides into bare ridges and bowlder-lined torrent beds.

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[1] See "Insect Enemies of the Spruce in the Northeast," *Bulletin 28*, New Series, Division of Entomology, U. S. Dept. Agr.

[2] "The Gypsy Moth in America," *Bulletin 11*, New Series, Division of Entomology, U. S. Dept. Agr.

CHAPTER XXIII

PLANT BREEDING

377. What is plant breeding? Plant breeding means the *intentional production and perpetuation of new and especially desired varieties of plants.* As a science it is not much more than fifty years old. But some plants have been cultivated for over forty-five centuries,[1] and during all that time more or less attention has been paid to choosing and keeping up desirable varieties of plants.

378. Selection of spontaneous varieties. Plants in a state of nature produce many varieties by ordinary variation, and they may occasionally produce new species by the kind of extensive and abrupt change which is known as *mutation.*

Only a very few of all the multitude of spontaneous variations among plants are likely to be valuable to man. An example of this is afforded by the results obtained by the discoverer of the Concord grape. This familiar grape was a seedling from a rather promising wild variety. The original Concord grape is so valuable on account of its productiveness and hardiness and the size of its fruit that it has been disseminated by cuttings over a large part of the United States and portions of Europe. The annual world's crop of this variety is now exceedingly large. The grower of the Concord mother vine raised more than 22,000 seedlings from Concord seeds, and found only 21 of these worthy of further trial. Not one of these seedlings is now a well-known grape.

Most farm crops afford many variations in the same field. These variations do not show themselves merely in slight matters of proportion or size of organs, — details interesting only to the botanist; they may greatly affect the economic value of

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[1] See De Candolle, Origin of Cultivated Plants, chap. i.

the plant. In the case of timothy, our most valuable grass for hay, the important variations concern such points as these[1]:

(1) Duration, whether annual or perennial.

(2) Power to spread by branches from the base of the stem (*stolons*), some plants producing 10, others 250 heads.

(3) Relation of seed production to leaf production, — some plants leafy and making good pasture but bearing little seed.

(4) Yield, — single plants sometimes producing less than ¼ pound of hay and others over 1¼ pounds, or more than five times as much.

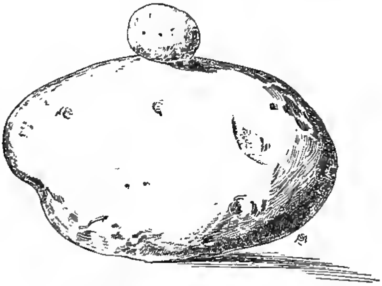

Fig. 331. Increase in size of the potato tuber due to cultivation

The upper tuber is a wild one, the lower a small cultivated tuber of the Vermont variety. Each one half natural size. Wild potato after J. Sabine

379. "Coming true from the seed." Only careful trials can settle the question whether in any given case (as in that of timothy) variations from the usual type will be fully transmitted from the seeds of a plant to the offspring, or, as farmers and gardeners say, will "come true." But there is enough chance of success to make it worth while to try to perpetuate any promising new plant or variation. The reason why cultivated plants show such improvement over their wild originals (Fig. 331) is, in the case of those grown from seed, because desirable modifications in these plants have occurred, and the seed of the improved individuals has been saved and has transmitted the improved characteristics to new generations.

380. Variation in wheat. Wheat has been cultivated in China for not less than 4600 years, and for thousands of years many varieties have been grown throughout the vast temperate region from China to western Europe. It is thought

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[1] See Bailey, Plant Breeding. The Macmillan Company, New York.

that perhaps the wheat plant originated in the once highly fertile portion of Turkey in Asia between the Tigris and the Euphrates rivers, and was gradually spread by cultivation both eastward and westward from its place of origin.[1] About eight species of wheat are recognized, and the number of varieties is too great to be readily counted. In view of the great number of existing varieties, it is not strange that there are among them enough types to suit highly unlike soils and climates. Accordingly there are varieties that meet the needs of the soil and climate of Japan, others that resist the drought and cold of eastern Russia and Manitoba, others still that can endure the drought and heat of southern Russia and Turkestan, while in North America there are varieties best suited to each of the leading wheat-growing regions.

Wheat grown anywhere without attention to the selection of pure seed is likely to show many variations in the same field, — a fact most familiar to the experts in our agricultural experiment stations. In the early part of the nineteenth century a wheat farmer named Le Couteur, living in the Isle of Jersey, near the coast of France, was visited by Professor La Gasca, of the University of Madrid, who discovered twenty-three different kinds of wheat in a field which was supposed to be all nearly alike. Le Couteur was much impressed by the possibility of obtaining desirable new breeds of wheat by selecting all the heads of each of the best types found in the field and growing each type by itself until he could find out all necessary details about its productiveness and other characteristics. In this way he obtained several new varieties, among them one excellent kind still much grown in England and northern France, known as "Bellevue de Talavera." This famous wheat comes true to such an extent that no other varieties have been derived from it.[2]

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[1] For another view see *Bulletin 274*, Bureau of Plant Industry, U. S. Dept. Agr., 1913.

[2] See Hugo de Vries, "Plant Breeding"; and "Species and Varieties: their Origin by Mutation." The Open Court Publishing Co., Chicago.

381. Wheat breeding: its purpose. Wheat is the most important grain for human food in temperate climates, and North America is by far the greatest wheat-producing region in the world. The annual value of the crop of the United States ranges from $250,000,000 to $500,000,000. Scientific wheat breeding began hardly a century ago, and has progressed more in the United States since 1890 than during all our previous history.

Some desirable qualities to be sought in wheat breeding are (1) large yield per acre; (2) good quality for bread making, requiring a high per cent of the tenacious *gluten*, the main protein portion of the grain; (3) hardiness, shown in winter wheat, in resisting severe winter conditions; (4) resistance to rust; (5) resistance to drought.

Not all of these qualities can be combined in the highest degree in any one variety, and therefore every region should grow the particular kind of wheat best suited to the local conditions and market.

382. Wheat breeding: the method. In order to show how carefully the process of wheat breeding is managed in our best agricultural experiment stations, the principal steps of the operation are here given in the barest outline, omitting many most important details.[1]

(1) Ten thousand large, sound kernels of a single good variety of wheat are selected, planted in hills, and each hill numbered. About 95 per cent of the poorer plants are rejected as they mature. The heads of each of the chosen plants are put together in an envelope and preserved. When thoroughly dry the product of each plant is weighed, and only a few of the heaviest groups of heads are kept for seed.

(2) The second year about a hundred of the seeds of each mother plant are planted in a group to which is given a special designating number (hundred-group or *centgener*). Heads of

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[1] See *Bulletin 62*, University of Minnesota Agricultural Experiment Station, and *Bulletin 29*, Division of Vegetable Physiology and Pathology, U. S. Dept. Agr.

several of the best plants in each hundred-group are reserved for seed. The total produced by each hundred-group is weighed to enable the experimenter to estimate the comparative value of the mother plants of (1).

(3) The third year the process of the second year is repeated.

(4) The fourth year the same process is repeated.

(5) The fifth year the most promising varieties are planted in small fields in the ordinary way. Those varieties which yield abundantly in the field and turn out well in the milling tests applied to the harvested grain are distributed among farmers for seed wheat.

A new variety can soon be introduced over an immense territory. It is estimated that in fifteen years from the time of planting one seed, its descendants might be made to cover more than 5,000,000 acres of wheat fields.

Wheat breeding is still making such rapid progress that it is not now possible to say how much the quality and quantity of our wheat crop may yet be improved by the introduction of better varieties. The total number of acres in the United States differs considerably from year to year. It seems likely, as a rule, to exceed 45,000,000 acres.[1] The average yield ranges between 10 and 15 bushels per acre, although it is possible with the most improved seed on the best soils to raise more than 40 bushels per acre.[2] Choice of the best seed would undoubtedly increase the average yield to from 13 to at least 18 bushels. It is easy to see how important a gain this would be if it were calculated in terms of the current price of wheat.

383. Principles upon which wheat breeding depends.[3] The work of Le Couteur and of a Scotch breeder of small grains named Patrick Shirreff, who discovered his first valuable

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[1] See Carleton, "The Future Wheat Supply of the United States," *Science*, August 5, 1910.

[2] See Hopkins, Soil Fertility and Permanent Agriculture. Ginn and Company, Boston.

[3] See De Vries, Plant Breeding. Open Court Publishing Co., Chicago.

variety of wheat in 1819, was not based on any general knowledge of the laws of plant variation and inheritance. The principles of breeding, as applied to the small grains, were first worked out by Professor W. M. Hays of the University of Minnesota Agricultural Experiment Station, and by Dr. Hjalmar Nilsson, director of the experiment station at Svalöf, Sweden. Some of the main principles upon which wheat breeding depends may be stated as follows:

(1) Every species of cereal usually comprises many well-marked varieties, or, as they are sometimes called, *elementary species*. Sometimes there are several hundreds of these included in each of the longest-cultivated species of grain, notably so in the case of wheat.

(2) The varieties may, while still growing in the field, be distinguished by such botanical characters as the position, shape, size, and bearded or beardless condition of the head; the form, size, and appendages of the spikelets which it contains; and the size, shape, color, and hardness of the grain.[1]

(3) The varieties distinguished by such characters as are mentioned in (2) often differ much in their economic value, depending on such qualities as productiveness, resistance to drought, resistance to rust, and the grade of flour which they produce.

(4) Varieties usually come true from the seed, so that when one has been chosen and isolated it may be grown indefinitely with little change.

384. Variation in corn. Indian corn is preëminently an American plant. At the time of the discovery of America, and probably for a long period before that time, it was grown by the Peruvians, the Mexicans, and by many tribes of Indians. It is supposed to have originated in South or Central America, near the west coast. The corn plant differs greatly in size and in the time required for maturing. The smallest pop corn is 1½ feet high, while field corn has been known to reach a

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[1] The hardness cannot be accurately known until the grain is ripe and dry.

height of over 22 feet. Some corn in Paraguay is said to ripen in one month, while Illinois field corn requires from four to five months.[1]

Six well-defined types of corn are recognized, but only four are of much economic importance. These are *pop corn*, with small kernels and endosperm all or nearly all horn-like; *flint corn*, with much horn-like endosperm and a grain too hard to be fed to most animals without being ground; *dent corn*, with the kernels indented at the outer end: and *sweet corn*, in which most of the starch of the endosperm is replaced by a kind of sugar. Of these four kinds, dent corn is by far the most important, constituting the great bulk of the crop in the corn belt. Each of the types of corn has many varieties; of dent corn alone more than three hundred have been named and described. Most of these varieties are found to show slight variations, which make them more or less desirable for the corn grower, and his efforts must be directed mainly to improving the quality of existing kinds.

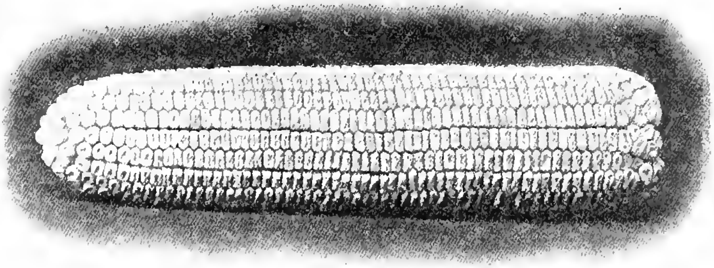

FIG. 332. A prize ear of "Johnson County White" corn[2]
An admirable type of dent corn. Photograph by L. B. Clore

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[1] See *Bulletin 57*, Office of Experiment Stations, U. S. Dept. Agr., 1899.

[2] This ear of corn was bid in by the grower (Mr. Clore) at an auction sale of exhibits at the Chicago National Corn Exposition in October, 1907. The price paid was $250.

385. Qualities sought by the corn breeder.[1] Of the many qualities that may be sought by the corn grower it will be enough here to mention only four of the most important: (1) productiveness; (2) high percentage of proteins; (3) high percentage of oil; (4) low percentage of oil.

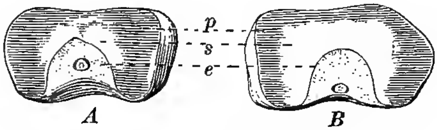

FIG. 333. Kernels of corn with high and with low percentage of proteins

A, high proteins; B, low proteins; p, horny layer, consisting largely of proteins; s, white starchy portion; e, embryo. After *Bulletin 87*, University of Illinois Agricultural Experiment Station

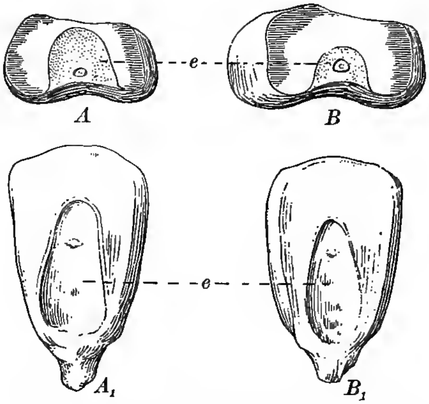

FIG. 334. Kernels of corn with high and with low percentage of oil

A, A_1, cross section and face view of high-oil kernels; B, B_1, cross section and face view of low-oil kernels; e, embryo. Most of the oil (as well as a good deal of proteins) is contained in the embryo, so that a large embryo means a high percentage of oil in the grain. After *Bulletin 87*, University of Illinois Agricultural Experiment Station

With reference to (1) it suffices here to say that the average yield of corn for the entire United States, according to statistics for 1908, was a little over 26 bushels per acre; for the New England States, with no better soil and a poorer climate, it was 40.5 bushels; and for some New England growers it was 100 or more bushels per acre. No small part of the difference between the average 26-bushel yield and the 100-bushel yield depends on the choice of seed.[2] Greatly increased care in its selection would probably at once add

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[1] See *Bulletins 55, 82, and 87*, Illinois Agricultural Experiment Station.

[2] See *Massachusetts Crop Report*, May, 1910.

more than $100,000,000 to the annual value of our corn crop. The structure of the grain of corn, as shown by the diagrams in Figs. 333 and 334, is such that the relative amounts of proteins, starch, and oil can be estimated roughly by a mechanical examination of the grain. This most important fact was discovered by Professor C. G. Hopkins, of the University of Illinois. The proteins are largely stored in the horn-like part of the endosperm (Fig. 333, *p*) and in the embryo; the starch is mainly found in the white, floury part of the endosperm (*s*); and the oil is nearly all in the embryo (*e*). If seed corn is chosen from ears with kernels in which the horn-like portion is highly developed, the result will be to secure a crop with a large percentage of proteins; seed corn with large embryos will yield a crop rich in oil, and seed corn with small embryos a crop poor in oil.

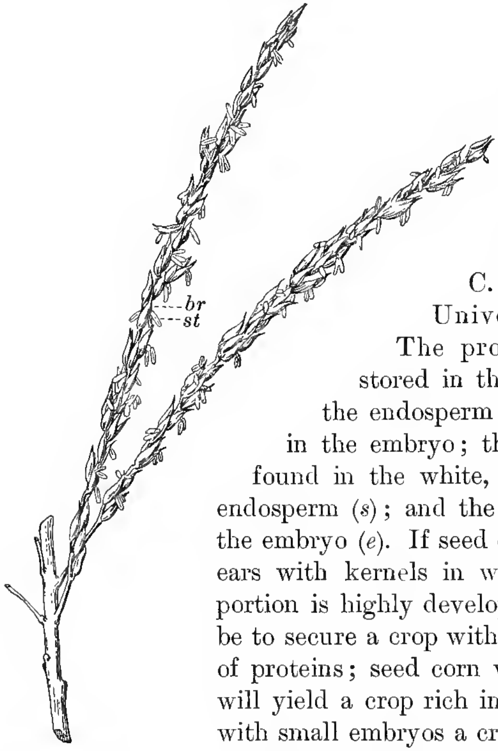

FIG. 335. Part of a corn tassel (staminate flower cluster)

br, a bract; *st*, stamens. One half natural size

Corn with high proteins is especially valuable as a food for man and the lower animals, since the most serious fault found with corn as a cereal food is its low percentage of proteins compared with its oil and carbohydrates. Corn with high oil value is especially desired by the glucose manufacturers, since they also manufacture corn oil, which is the highest-priced component of the grain. Corn with a low percentage of oil is in demand for feeding hogs for bacon, especially for exportation. It has been found possible, at the University of Illinois Agricultural Experiment Station, to breed low-protein corn with an average percentage of 6.7 proteins, and high-protein corn with an average percentage of 14.4 proteins. At the same station the average low-oil corn contained 2.5 per cent of oil and the high-oil corn 7.0 per cent. The process of selection must be kept up, for the variations thus obtained are not permanent varieties.

386. Method of corn breeding. It may be said in a general way that the method of breeding corn is based on the same principles as those adopted for wheat and other cereals. There are, however, many variations in details, some of the most important depending on the fact that the plants should be pollinated

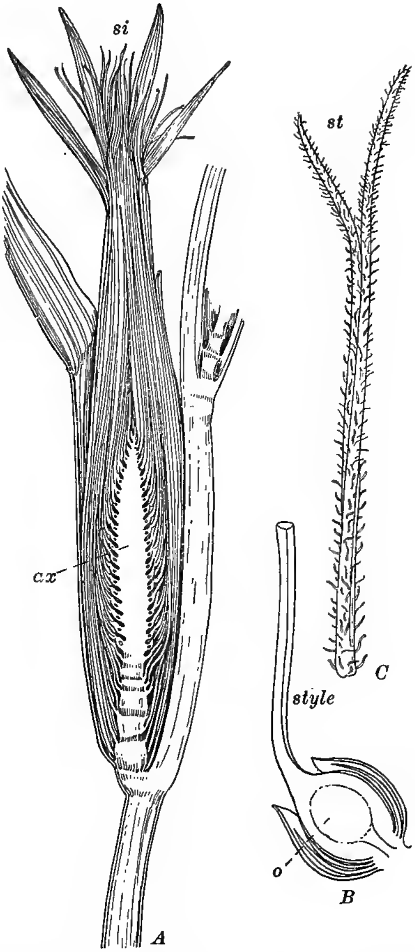

Fig. 336. Structure of an ear of corn (pistillate flower cluster)

A, section of young ear before fertilization of the ovules (grains): *ax*, axis of spike (cob); *si*, ends of silk (styles and stigmas). *B*, magnified section through a grain, showing bracts around the ovary, the ovule (*o*), and the base of the style; *C*, upper portion of style, with the stigmas (*st*) considerably magnified. After F. L. Sargent with pollen from other individuals, but that these should, as far as possible, all be of the same stock. It is not sufficient that all should be of the same variety; the most rapid progress will be attained if all the parent plants are descended from the same ear of corn.

It will not be necessary to give in detail all the methods followed in the selection of seed, and the precautions which are adopted to prevent mixture of varieties in the growing crop. Successful corn breeding demands:

FIG. 337. Cross-pollination and self-pollination

The effect of cross-pollination and of self-pollination on the growth of corn from the seed. The two rows of spindling plants at the left grew from seed produced by self-pollination, the larger plants of the other rows from seed produced by cross-pollination. Photograph furnished by Funk Bros. Seed Co.

(1) The choice of the most desirable known variety as a basis for breeding for any given purpose.

(2) Selection of well-matured ears from the best plants *in the field.*

(3) Growing trial rows the next season from the ears of (2), each ear planted in a row by itself. Every other row should be detasseled to prevent the plants from pollinating

their own ears, and seed ears should be saved only from the detasseled rows.

(4) The continuation during subsequent seasons of the process of seed growing from the best plants obtained in (3).

In beginning to breed corn it is better to use seed obtained from the locality in which the experiment is to be made. That grown under decidedly different conditions may not succeed. If high- or low-oil corn or high- or low-protein corn is desired, the ears used for seed must be carefully chosen with reference to the development of the horn-like endosperm or of the embryo (Figs. 333 and 334). Selection in the field, as mentioned in (2), is necessary in order to insure that the ears chosen grew on vigorous plants, and that ears from the same plant are kept together. If detasseling is not thoroughly carried out, much self-pollination and self-fertilization is sure to occur. Corn which is self-fertilized produces smaller and less vigorous plants the next season than cross-fertilized corn (Fig. 337). Detasseling has, therefore, been found to increase the yield of corn more than ten bushels per acre.[1]

387. Williams's method. The method of corn breeding as above outlined has been criticized on the ground that little or no attention is paid to the productiveness of the plant used as the source of pollen. A new system devised by Professor C. G. Williams, of the Ohio Agricultural Experiment Station, provides for equally careful selection of the staminate and of the pistillate parent. The system in its barest outlines, as stated by Professor Williams, provides for:

1. The usual ear-row test. Only a portion (usually about one half) of each ear is planted. The remnant is carefully saved, and when the ear-row test has shown which ears are superior, recourse is had to the remnants to perpetuate these ears.
2. An isolated breeding plot in which are planted the four or five best ears as demonstrated by 1. *Not the progeny* of the best ears, but

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[1] For details about corn breeding see De Vries, Plant Breeding, Open Court Publishing Co., Chicago; *Bulletin 100*, Illinois Agricultural Experiment Station; and *Circular 66*, Ohio Agricultural Experiment Station.

the *original ears.* Usually the best ear is used for staminate plants and planted on each alternate row in the small breeding plot. All the plants from the other ears going into the plot are detasseled.

The pedigreed[1] strains produced in the breeding plot are multiplied for general field use and also furnish ears of varying worth for a second ear-row test, if it is desired to continue the improvement.

The ear-row test need not be isolated, for no seed is taken from it. Neither is there any need for detasseling until the breeding plot is reached.

388. Sugar beet breeding. Almost all the sugar that is used by civilized peoples is manufactured from sugar cane and sugar beets, the latter furnishing the greater part of the world's supply. Beets of many varieties have been cultivated since the sixteenth century or earlier. But it was only as late as the middle of the nineteenth century that scientific efforts were made by Louis Vilmorin to increase the percentage of sugar in beets grown for sugar-making. The sweetest roots are usually the heaviest in proportion to their bulk,[2] and therefore Vilmorin tested whole beets or pieces cut from them by placing them in brine strong enough to float all of the roots except those which contained an unusually large per cent of sugar. The sugar beet is ordinarily (though not always) a biennial, and the root produced in one year is used for growing seed in the second year. These selected beets were planted for seed and became the parents of valuable new races.

At present the process of producing beets of the highest value for the manufacture of sugar is a long and complicated one, consisting, as usually carried out, of the following steps:

(1) Planting the best seed that can be bought.

(2) Chemically testing average samples of the roots that are grown from the seed of (1) to see if they are good enough to breed from.

(3) Selecting the best single roots by a chemical test. Less than one half of one per cent of all the beets tested pass this examination in a satisfactory way.

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[1] Pedigreed, because the pedigree on both sides is a matter of record.

[2] That is, have the highest *specific gravity.*

(4) Planting the mother roots selected in (3) for the production of what is called "elite seed."

(5) Growing from elite seed small beets which are planted to secure commercial seed.

It requires five years to obtain seed in large quantities from the very few selected roots with which the process of securing improved seed is begun.[1]

Some notion of the thoroughness with which European seed growers choose their beets may be gathered from the fact that in 1889–1890 one of the most important firms tested 2,782,300 roots, from which it selected only 3043 to be planted for seed production. Constant pains must be taken in maintaining the best possible seed supply, as the quality becomes lowered at once when the seed is grown without special precautions. This is due to the fact that the variations in beets are not elementary species (Sect. 383), and therefore are not sure to come true from the seed. Two of the most serious ways in which a poor stock of sugar beets falls short are in the low percentage of sugar and in the production of many worthless annual plants. In central Europe the annual individuals sometimes constitute 20 per cent of the entire crop.

The average yield of sugar from American-grown beets is at present 12 per cent or less. Exceptional beets have been found to contain more than double this amount. It is impossible at present to produce the roots in large quantities with anywhere near this high percentage of sugar, but decided gains may easily be secured, and an increase of 2 per cent in the yield would mean a gain of something like $100,000 per year in the beet-sugar production of the United States.

389. Constant and inconstant varieties. Beets, as stated in Sect. 388, do not long remain true to type unless there is *continued selection* of the seed. There is a constant tendency of the high-bred sugar beet to "run out," — that is, to revert to the average sweetness of beets grown from unselected seed. In this respect beets differ sharply from the cereals, most of

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[1] See Yearbook of the Department of Agriculture, 1904.

which do not quickly revert to the original type, unless as a result of miscellaneous crossing. Plant breeding, as a science, is much too young to enable us as yet to answer the question how far varieties tend to "run out" and what plants are most subject to this reversion.[1] It is probable that most cultivated plants grown from seed will be found to be decidedly less constant in maintaining their character for years than are the grains.

390. Hybridizing. Hybridizing, as the term is now generally used, means *the production of seed by the action of pollen of one variety or species on the ovule of another variety or species.* In order to produce seed that will grow, both species must usually belong to the same genus. Frequently different species of the same genus hybridize with difficulty; that is, the result of the attempted cross is to produce no seed, or seed that does not grow well. The offspring produced by hybridization are known as *hybrids.*

It has long been known that hybrids are often extraordinarily variable, but the law (Mendel's law) which in many cases, though not in all, determines their characteristics and their mode of variation, was not discovered until 1865,[2] and did not become well known until some thirty-five years later.

Recently much use has been made of hybridizing in order to set plants to varying, and the most desirable varieties thus produced have then been selected and used in breeding as already described.

391. How hybrids are artificially produced. Hybridizing, or *crossing* plants, is sometimes an easy, sometimes a rather difficult, process. It is simplest in unisexual flowers, for example, in those of Indian corn. Here the "tassel" (Fig. 335) is a cluster of spikes of staminate flowers, and the "ear" (Fig. 336) is a spike of pistillate flowers, each thread of the "silk" representing a stigma and style attached to an ovary (grain of

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[1] See Bailey, The Survival of the Unlike, Essay XXIV. The Macmillan Company, New York.

[2] See Bailey, Plant Breeding, chap. iv. The Macmillan Company, New York.

corn). In hybridizing corn it is only necessary to tie a paper bag over the ear before the silk appears, in order to keep off stray pollen, and leave it covered until full-grown; then remove the bag, dust the silk thoroughly with pollen from tassels of the desired crossing variety of corn, and thereafter keep the ear covered until the silk is entirely withered. Sometimes in hybridizing corn the stalks are detasseled just before the ears are ready to receive pollen. If all the stalks of one kind or one row are thus detasseled, it is made probable that pollen, if received at all by the ears of the detasseled stalks, must come from another row or another kind of corn. The detasseling of alternate rows is a rather common mode of insuring cross-pollination. In most cases of hybridizing with bisexual flowers it is necessary to carry out processes similar to the following ones:

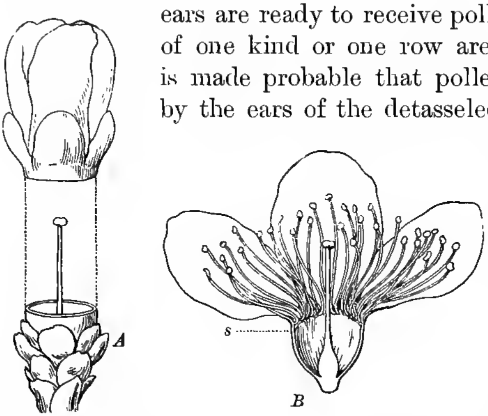

Fig. 338. A peach flower prepared for hybridization

A, flower cut round for removal of the stamens, with the removed parts of the young flower showing above; *B*, longitudinal section of a flower showing level (*s*) at which the cut was made in *A*

(1) Select the flower to be pollinated before it opens or its own pollen is mature. If it is one of a cluster of flowers, as in the wheat or the apple, remove from the cluster of the flowers all that are not to be operated on.

(2) Open the remaining flowers and remove the stamens by taking hold of the filaments with fine forceps, or cut away all the stamens at once, as shown in Fig. 338. Then cover the flower or the entire twig with a paper bag until the stigma is mature.

(3) When the stigma is mature, pollinate it with the desired kind of pollen. This may be done with the finger tip, or

with a camel's-hair brush or other implement. It is safer to take pollen from a flower that has been kept covered with a paper bag to keep off foreign pollen.

(4) Cover the pollinated flower again with a paper bag until the fruit has grown considerably.

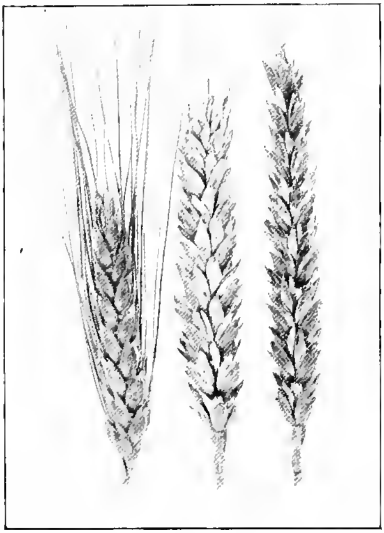

FIG. 339. A hybrid wheat and the parent forms

The hybrid is in the middle. It is somewhat intermediate between the parents, being nearly (but not quite) beardless like the right-hand parent, with a length of head intermediate between the two and with the grains and their covering bracts stout, as in the left-hand parent. Photograph by Minnesota Agricultural Experiment Station

392. General results of hybridizing. As was mentioned before (Sect. 390), hybrids are likely to be extremely variable. Not only may they differ from either parent, but they may also be unlike each other. The differences include such features as the form, size, quality, and other characteristics of the entire plant or of its roots, stems, leaves, flowers, fruit, and seeds. Physiological differences, such as early or late maturing, ability to grow in new conditions of soil and climate, unusual susceptibility to or immunity from the attacks of parasitic fungi, may appear and are sometimes (Sect. 398) of great economic importance. It is much easier to perpetuate new varieties unchanged in the case of plants propagated by vegetative means, as by cuttings from roots or stems or by bulbs or tubers, than in the case of those grown from seed. If a desirable variety of potato is obtained by hybridizing and then planting seeds from the berries ("potato balls"), the hybrid can be perpetuated with certainty by planting tubers of the new variety. But if a hybrid bean, pea, or wheat plant is produced, only a few of its seeds will "come true to seed"; that is, the offspring of the hybrid seeds will, many of them, be what breeders call "rogues," or undesirable varieties, not closely resembling their hybrid parent. Year after year, for several generations, the garden plots containing descendants of the new hybrid must be rogued, or gone over plant by plant, in order to destroy all individuals but those of the desired variety. In the case of wheat, after the fourth generation some plants are usually to be found that will "come true to seed."

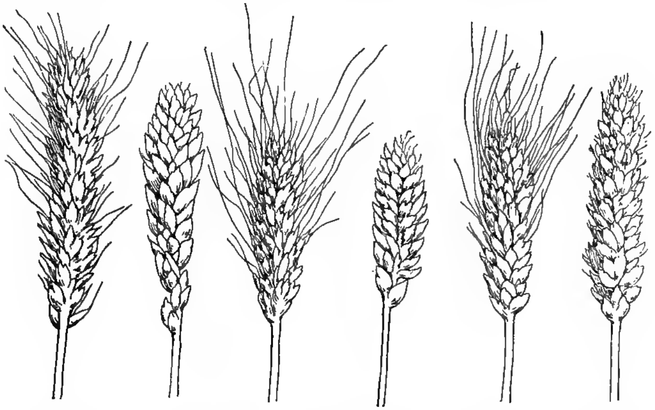

FIG. 340. Variation in wheat, the hybrid offspring of hybrid parents

After figure redrawn from *Transactions of the Highland and Agricultural Society of Scotland*

393. Results of hybridizing the grains. In this country especial attention has been given to hybridizing Indian corn and wheat. Some valuable varieties of corn have already thus been obtained, and many more seem likely to be secured. Hybrid wheats are of importance for use as stocks from which to breed and select. At the agricultural experiment stations of the great wheat-growing states much time is now spent in hybridizing wheats for breeding purposes.

394. Results of hybridizing small fruits. The most familiar hybrids among small fruits are grapes. It is probable that the Delaware and the Catawba are hybrids, and the Salem, Brighton, and Diamond certainly are. Many varieties are directly or remotely descended from hybrids between the European wine grape and our northern fox grape, two wholly distinct species.

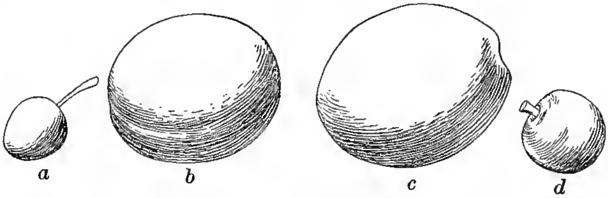

Fig. 341. Hybrid plums

a, a stoneless wild plum; *b*, *c*, *d*, fruit of hybrids of *a* with the French prune plum
All drawn to the same scale

A favorite blackberry, the Wilson Early, is a hybrid between two common wild species, the high blackberry[1] and the dewberry.[2] Among the descendants of hybrids between an almost inedible species[3] from Siberia and an edible one[4] from California is a new constant species (not a variety), the Primus blackberry.

Hybrid plums in the greatest variety have been produced by plant breeders, especially by the well-known grower of horticultural novelties, Luther Burbank. The amount of variation in the offspring of a single hybrid is suggested by Fig. 341. One fruit of great value, the Climax plum, was bred by Burbank as a hybrid between a bitter, tomato-shaped Chinese plum and a Japanese plum.

395. Results of hybridizing citrous fruits. Most valuable and interesting work in hybridizing plants of the Orange family has been done by the United States Department of Agriculture, under the direction of Dr. H. J. Webber.[5] The hardy

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[1] *Rubus allegheniensis.*

[2] *R. villosus.*

[3] *R. cratægifolius.*

[4] *R. vitifolius.*

[5] See Yearbook of the Department of Agriculture, 1904.

trifoliate orange, which resists our winters as far north as Philadelphia, but bears a small, bitter, worthless fruit, was hybridized with the common sweet orange. Three valuable hardy hybrids known as citranges were produced. One of them makes a good substitute for grape fruit, another for lemons, and the third for rather sour oranges. They may be grown from two hundred to four hundred miles farther north than ordinary oranges.

Another citrous hybrid is that between the tangerine and the grapefruit. This is called the tangelo, and has characteristics somewhat intermediate between those of the parent species. It is smaller in size, and the pulp is less bitter and acid than that of the grapefruit, while the "kid-glove" skin, readily peeled off with the fingers, is like that of the tangerine.

Our most valuable citrous fruit is the Washington navel orange, nearly or quite seedless. It originated from chance seedlings found in a swamp along the Amazon and brought from Bahia, Brazil, to the United States Department of Agriculture in the early seventies. This orange forms by far the greater portion of the entire California crop of over 10,000,000 boxes a year.

396. Results of hybridizing ornamental flowers. Some of the most showy flowers of our gardens and greenhouses are hybrids. Among the most important examples are the genera *Canna*, *Amaryllis*, and *Gladiolus*. Orchids, too, have been hybridized to such an extent that a dictionary of hybrid orchids has been prepared.

In most cases of flowers which have been bred and hybridized for many years, the process of improvement has been due partly to crossing and partly to selection. It is often impossible to find out how many parent species or varieties have entered into the production of the final hybrid.

397. Summary of methods and results. Successful plant breeding requires a continuous effort to get better plants, either by picking out and growing chance varieties, or by continued selection, first of a set of choice parent plants, then of their best offspring, and so on for several generations.

Hybridizing sometimes (but not nearly always) aids the plant breeder by giving him a large number of marked variations from which to select.

High cultivation, together with plant breeding, has brought about many astonishing results. Plums three inches long have recently been produced. A hybrid beach plum bears so abundantly that the twigs are entirely hidden by the fruit. The largest cultivated apples are many hundred times the bulk of their remote wild ancestors. A new variety of blackberry plant covers one hundred and fifty square feet of soil and bears a bushel or more of fruit.[1] Most cultivated roots and tubers have been greatly changed from their wild condition, losing in the proportion of woody fiber which they contain, and gaining immensely in size.

398. Securing varieties immune to disease. One of the most important problems for the plant breeder is how to secure varieties immune to diseases. Two of the most notable achievements of our Department of Agriculture in this direction have been the production of a disease-resisting variety of sea-island cotton and of watermelon. The soil of valuable cotton plantations had come to harbor a fungus (*Fusarium*) which attacked the roots of the plants, plugged the vessels with its hyphæ, and destroyed almost the entire crop. In consequence of this many planters gave up cotton growing. Observation showed that often in a field where nearly all the plants were killed, here and there an individual survived, blossomed, and ripened its capsules. For four years plants were bred from the seeds of these resistant individuals until a variety was secured which withstood the attacks of the fungus and made it possible to resume cotton growing on the abandoned plantations.

Extensive areas in the South, once devoted to the culture of watermelons, became so infected with a fungus that melon growing was no longer possible. The destruction was so

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[1] See the article by D. S. Jordan, "Some Experiments of Luther Burbank," *Popular Science Monthly*, January, 1905.

complete that no process of selection could be adopted, as in the case of the cotton. It was, however, found that the roots of the so-called "citron," a plant of the watermelon genus, were not attacked by the fungus. Watermelons were hybridized with "citrons," and about a thousand varieties were grown from the seeds thus obtained. Many of these proved resistant, but only one was found to be resistant and at the same time desirable in most other respects. This one variety is now grown with good success even on fungus-infected soils.[1]

COLLATERAL READING

The terms "Yearbook," "*Farmers' Bulletin*," "*Bulletin* . . . Bureau of Plant Industry," all refer to the publications of the United States Department of Agriculture.

A very detailed list of books and articles on plant breeding will be found in Bailey, Plant Breeding. The Macmillan Company, New York. Other titles not already referred to in this chapter are as follows:

General

Yearbook, 1898, "The Improvement of Plants by Selection."
Yearbook, 1906, "The Art of Seed Selection and Breeding."
Farmers' Bulletin 334, "Plant Breeding on the Farm."
Bulletin 167, "New Methods of Plant Breeding," Bureau of Plant Industry.
Cyclopædia of American Horticulture, article "Plant Breeding." The Macmillan Company, New York.
Cyclopædia of American Agriculture, article "Plant Breeding." The Macmillan Company, New York.
The Principles of Breeding, Davenport. Ginn and Company, Boston.

Special

Farmers' Bulletin 229, "Production of Good Seed Corn."
Yearbook, 1906, "Corn-Breeding Work at the Experiment Stations."
Yearbook, 1902, "Improvement of Cotton by Seed Selection."
Farmers' Bulletin 342, "Potato Breeding."

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[1] See an address by Dr. Erwin F. Smith on "Plant Breeding in the United States Department of Agriculture," before the Royal Horticultural Society's conference on genetics.

CHAPTER XXIV

FURTHER DISCUSSION OF PLANT INDUSTRIES

399. Introductory. Agricultural and horticultural industries are fundamental, since they produce most of the things upon which people live. A scientific study of what plants are and how they live has been the means of raising these industries to their present high efficiency. In preceding and in later chapters there is frequent reference to the practical nature of a knowledge of the principles of botany, but in the present chapter there are presented three topics which relate specifically to agriculture and horticulture. The topics presented are: I. The Soil and the Plant; II. Special Care of Plants; III. Leading Agricultural and Horticultural Plants.

I. THE SOIL AND THE PLANT

400. Composition of the soil: rock material. One of the most important lines of botanical study has to do with the interrelations of plants and the soil in which they live. Any extended consideration of agricultural and horticultural industries must involve a comprehensive study of the soils, but in the present connection only an outline of the subject is given.

In a general way it may be said that the basis of soils consists of more or less finely divided rock. A study of the dumping ground of a stone quarry will show that weathering processes are bringing about the disorganization of some of the stones, and as a result soil is made possible. Sometimes water freezes and expands within the crevices of the stone; or roots of trees and other plants may grow in these crevices, and by expanding may break the stone. Organic material from plants and animals may help in disorganization, and landslides may crush the stones, or streams of water may wear them into smaller pieces. In ancient times great glaciers crushed and wore the stones, reducing enormous masses to smaller ones, gravel, and finely pulverized material. All these agencies and others have reduced the rocks so that in soils we are sometimes unable to find sand particles except by means of the microscope.

FIG. 342. Production of humus in the soil

A partially reclaimed swamp in which dead plant material several inches deep is decaying. In the foreground is a cluster of young skunk-cabbage leaves, and just back of these and in front of the tree is a cluster of unfolding leaves of Clayton's fern

In a *gravelly soil* there are present small pebbles which usually show by their form and sometimes by their markings the kind of treatment they have undergone. In *sandy soil* the reduction of the rock is more uniform and has gone further. In *clayey soil* the particles are so small and fit together so compactly that the rock origin is not very evident. *Peaty soil* contains comparatively little rock material but much more of the results of partial decay of plant and animal bodies. There are all possible gradations between these different kinds of soils.

401. Composition of soils: organic matter. A brief study of soils under the microscope would show that in addition to rock in different stages of decomposition, there is usually present considerable other material. Leaves, twigs, wood, herbaceous plants, and the bodies of animals decompose, and the products make up a most important part of the soil (Fig. 342). In almost all soils some organic matter may be found. When a large quantity of plant material lies upon the surface of the earth and partially decomposes, it is usually spoken of as humus. In undrained or poorly drained swamps into which little soil washes from adjacent hills, the deposit at the bottom of the standing water is almost pure organic matter, which is the peaty material often found in regions which once were swampy.

402. Composition of the soil: water and air. Around and between the particles of the more or less decomposed rock, and absorbed by organic matter, there is always some water, though it may be present in amounts so small as to be difficult of detection. Some water adheres closely about solid particles of the soil. Water also may fill the spaces between the particles of solid material, and such water is known as the free water of the soil. Water may take into solution some portions of the soil.

The amount of water in the soil varies largely and depends upon many factors. If there is little rainfall and the supply is not replenished from below, the coarse soils (gravel and coarse sand) will soonest become dry. But the amount and nature of the organic matter in the soil has much to do with ability to hold water. A good supply is usually held by fine sandy and clayey soils in which there is an abundance of organic matter. At times of continued heavy rainfall all kinds of soil may become filled with water, and the prevention of dangers from this surplus is discussed in the later sections of this chapter.

In the spaces between the solid particles of the soil air is also found. Even in soils that are below ponds and streams there is some air, though its amount is usually so small that only water-enduring plants can grow therein. Observation of any porous soil immediately after a heavy rainfall will enable one to see bubbles of air emerging from the soil as the spaces which they have occupied begin to be filled by the water. After prolonged rains most of the air of the soil may have been expelled, and it is generally supposed that in such cases it is the absence of air as much as the overabundance of water that brings injurious results to suddenly submerged plants. Obviously the quantities of water and air in the soil are factors that are constantly varying in amount. As a given soil becomes dry it may also become compact, and it by no means follows that the total space occupied by water and air together remains constant.

403. Composition of the soil: living things within it. A highly important factor of the soil consists of the many kinds of living things that inhabit it. Microscopic plants and animals of many kinds and in great numbers live upon one another, upon plant roots, or upon dead organic matter, and as they do so are constantly affecting the composition of the soil. Then the roots of living plants, the molds, and the burrowing animals such as the larvæ of insects and the earthworm, constantly take from, add to, or otherwise change the soil. Earthworms eat their way through the soil, and as they do so they make it more porous and excrete materials that add to the soil's organic matter. Certain groups of soil bacteria have already been discussed (Sect. 343). The living things of the soil may be said to constitute an extensive and intricate society of plants and animals living close together and greatly affecting the nature of the material in which they live.

404. Drainage. The annual rainfall in different parts of the United States varies from ten inches or less to more than sixty inches per year (Fig. 381). In some parts of the country the total annual rainfall occurs within a short period, while in other regions it is usually fairly well distributed throughout the year. In all regions shortage of water is often a source of danger to plants, and surplus water may also be injurious. Some of this surplus water may run off the surface without ever entering the soil (Sect. 408). If much of it enters the soil and remains for a long time as free water, it may drown the roots of plants. Sometimes the slope of the land surface is such that the free water of the soil runs off with sufficient rapidity to prevent drowning of plant roots, but in most cases growth of plants is enhanced by artificial methods of underground drainage. Ditches are made and earthen tile placed in them, thus forming drainage courses which hasten the natural underground flow of the water. The cereals ordinarily thrive best in soils which contain from 50 to 60 per cent of their total water-holding capacity.

In swampy places artificial drainage, which furthers the growth of economic plants, also restrains the growth of those swamp plants which ordinarily thrive in wet soils. Much of our best land has been made available by drainage, and there are enormous areas that would be most valuable if only they were properly drained. It has been estimated by Professor Shaler that along the Atlantic coast alone there are over 3,000,000 acres of swamp lands that it is possible to reclaim by drainage. The estimates of the United States government indicate that in our country there are nearly 100,000,000 acres of swamp land. There are thirty-five states in the eastern half of the United States in which there are over 30,000,000 acres of swamp lands. Much of this vast area can be drained, and may then become the growing place for valuable economic plants instead of the relatively valueless swamp plants.

When underground drainage for ordinary cultivated fields was first advocated, opponents asserted that while it might be helpful in removing surplus water during times of abundant rain, the same drains would be the means of depletion of the water during times of drought. Practice has shown, however, that if surplus water is removed in rainy seasons, plant roots grow deeper into the soil and are thereby better placed for enduring subsequent dry periods. Furthermore, the thin films of water which adhere to soil particles are not removed by drainage, and plant roots are better located to avail themselves of this supply than if they are placed near the surface, as happens in wet soils.

Within the last decade it has been shown that at least some of the cereals secrete and leave within the soil substances which are injurious to the kinds of plants which produce them.[1] Adequate drainage probably assists in removing some of these poisonous materials. Drainage ditches help to aërate the soil, and in this way are of great benefit to the growth of economic plants.

405. Tillage and water supply. In olden times agriculturists advised against cultivating corn and other crops during times of drought, because they thought that if constantly stirred the soil would lose its moisture more rapidly. People now know that it is of the greatest importance to till the soil during droughts in order that it may not lose its moisture. An illustration will help in studying this matter. If two pieces of loaf sugar are placed one upon the other, the lower one held in the thumb and finger and the other left lying loosely upon the first and not touching the fingers at all, and if the lower one is then placed in contact with water, two important facts are shown. The lower piece takes up water freely, but the upper one, though lying upon the lower wet piece, becomes wet only after a long time. Close connection between the solid particles is necessary for the rapid upward passage of the water.

When soils are compact, moisture from the deeper portions passes upward freely, as in the lower lump of sugar, and evaporates into the air. If, however, the surface is kept loose and finely pulverized, so that the particles are less closely connected, moisture does not readily pass through it and there is less loss from evaporation. The roots of plants being more

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[1] Schreiner, O., and Reed, H. S., Some Factors influencing Soil Fertility. "Bur. Soils," *Bulletin 40*, U. S. Dept. Agr., 1907. Also, "The Production of Deleterious Excretions by Roots," *Bulletin 34*, Torrey Bot. Club, 1907.

deeply placed, are in contact with the moist soil from which a supply of water may be secured. The depth to which roots are known to go in regions where the water is found only at great depths is discussed in Sect. 27.

For a long time it was supposed that the chief reason for cultivating plants was to keep down the weeds, but we here see that this is but a small part of the truth. Weeds have been of much advantage to agriculture, since in keeping them down the farmer has tilled the soil so as to help regulate the moisture supply for the growing plants.

406. Dry-land farming. It has been shown that the cultivable area of the earth may be extended by drainage of unused swamp areas; but it may be greatly extended if water in proper quantity and at the proper times is placed upon arid lands. It is said that approximately two fifths of the area of the United States is too dry for cultivation without irrigation.

Dry-land farming is one method now being tried in regions where there is some rainfall, but an amount that is insufficient to produce a good crop. By careful tillage of the soil the scanty rainfall is conserved, and in this way most of the rainfall of two or more years may be used for one crop. Good crops have been grown in this way, but it is evident that much work over a long period is necessary in order to accumulate enough water for one crop. It is hoped that drought-enduring and drought-resisting varieties of economic plants, especially wheat and other cereals, may be found or developed, thus increasing the outlook for dry-land farming.

407. Irrigation. The practice of irrigating lands is in some parts of the earth a very old one. Its extensive use in the United States is recent and both the government and private enterprises have expended enormous sums of money in supplying water from lakes and rivers to lands which previously were non-productive. In some cases this has involved damming the mountain streams and diverting the water over, around, or through mountains, and finally to the valleys to be cultivated. With control of the water supply, fertile soil, abundant sunshine, and freedom from sudden changes in climate, it is evident that there is a great future for irrigated lands. Already over 13,000,000 acres are under irrigation, and other projects that are now under way will add largely to that amount. Even with this large acreage added to our tillable soil, it must be kept in mind that only a very small portion of the arid lands has been or apparently can be supplied with water from the sources that are now available.

408. Removal of soil by winds and water. Currents of air constantly carry particles of dust. During periods when the earth's surface is dry the amount of dust thus carried is large. If a pane of glass that has been moistened with oil is exposed for a time to the wind on a dry day, and then examined with a strong magnifying glass, it will furnish a good demonstration of the dust-carrying power of moving air. Further illustrations are found in the dust that strikes our faces on windy days, and in that which is deposited on window sills. Window panes in the houses near the end of Cape Cod finally become translucent, like ground glass, from the action of sand driven by the wind. When cultivated fields become dry the wind may carry away large quantities of soil. This is sometimes well shown in winter when snow covers the ground in such protected places as the leeward slopes of hills. Soil which has been frozen dry is often carried from other regions by the wind and dropped upon these leeward snow banks in such quantities as to bury the snow completely. Good windbreaks about cultivated fields help to prevent loss of soils by wind.

Rapidly running surface water often carries away part or all of the fertile soil. In grasslands, meadows, and forested areas, surface water is retarded in its rate of flow, and consequently does not carry away much soil. In regions that were once forested and from which the timber has now been largely removed, the surface water soon erodes ditches (Fig. 343), which, with rapidly deepening channels and developing tributaries, will in a few years carry away much of the fertile soil of the forest floor. After forest fires, which themselves destroy much of the humus of the forest soils (Fig. 344), the surface water, which is no longer retarded and absorbed by humus, flows with increased rapidity. In so doing it carries away large quantities of soil, sometimes uncovering the burned roots until the trees are easily overturned by winds. An area once forested may soon be cut into trenches and ridges until the only remaining evidence, if any, of its previously forested condition is seen in the presence of a few plants such as young trees that are trying to grow in the poor soil that is left (Fig. 346).

FIG. 343. Erosion of the soil following removal of the forest

This land was covered with a heavy pine forest, and had a good soil, which was held upon the forest floor. When the timber was removed, erosion soon cut ditches through the pasture land

There are several means of preventing much of this loss of soil by erosion. In wooded regions judiciously cutting part of the timber each year rather than cutting all of it at once gives opportunity for new plants to occupy and hold the soil. There

FIG. 344. Humus of the soil, and roots of red spruce and balsam fir burned by forest fire. Photograph by United States Forest Service

are many kinds of soil-holding plants which, if properly placed, will prevent erosion in its earliest stages, and these should be used. In open, hilly fields which are exposed to erosion, grass and meadow crops are desirable, since their roots help to hold the soil throughout the whole year. In such cases the roots and stems help to prevent the rapid run-off of the surface water. The very things that need to be done in the cultivation of plants increase the danger of loss of soil where rapid flow of the surface water cannot be prevented. In hilly fields it is often difficult, sometimes impossible, to prevent erosion. In some localities the rows of growing plants are arranged across the slope of the hill (Fig. 345), thus assisting somewhat in retarding the surface flow of water. If cultivation is continued in such places, the soil soon erodes, and it is with extreme difficulty that any plants gain a foothold (Fig. 346). In some foreign countries hillsides have been saved for cultivation by a process of terracing. The terraces are constructed in such a way that the soil upon each is level or slopes toward the hill, thus retarding or preventing erosion (Fig. 347).

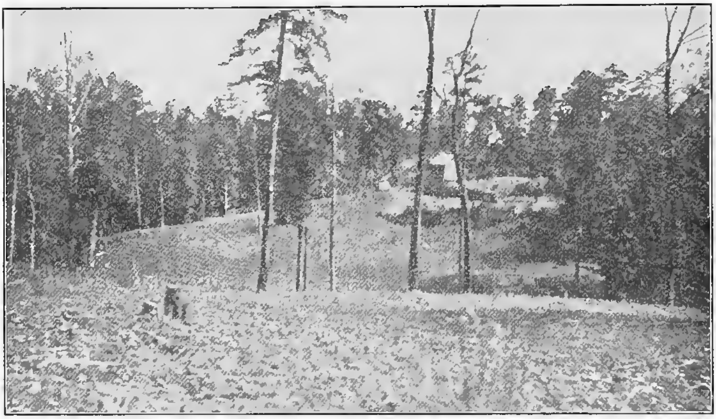

FIG. 345. A Mississippi hillside farm, newly cleared

It is plowed and planted in rows around the hill to retard erosion. In such regions the soil when plowed washes away rapidly. Photograph furnished by W. N. Logan

FIG. 346. A hillside which once was forested, but is now washed into gullies and ridges

Not enough plants have gained a foothold to prevent erosion. Photograph by United States Forest Service

Terraced farms sometimes are desirable for vineyards, but it is obvious that for ordinary crops such elaborate care will prove profitable only where available land is extremely scarce.

FIG. 347. Landward slope of an Italian promontory, the loose, loamy soil terraced to prevent erosion when under cultivation as a vineyard

Modified from a photograph

In localities with moderate slope of the surface, underground drains may prevent erosion except at times of extremely heavy rains. Many ditches that were formerly supposed to be too large to be taken underground have been so placed with great advantage.

409. Soils and plant nutrition. Soils differ widely in their ability to support vegetation. Even the roots from one plant may develop quite differently in different soils, as is shown when the roots are arranged so that part of them grow in clean sand and part in rich loam (Fig. 348). A comparison of plants of the same kind that have been grown in regions that have different kinds of soil will show wide differences. From the point of view of the growth of our economic plants, that soil is best which with the proper amount of cultivation will produce the best and largest yield of plant material. Such a soil is said to be fertile.

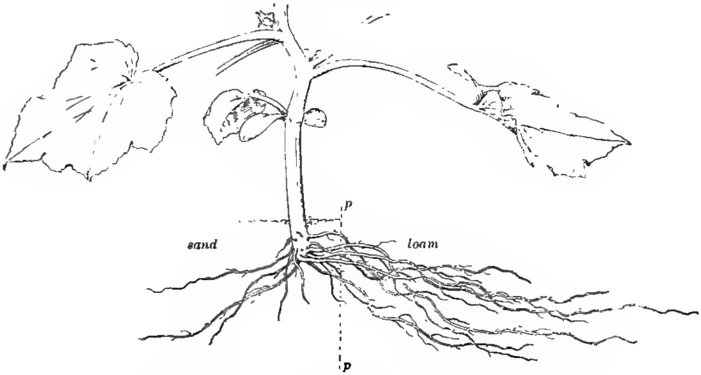

FIG. 348. Effect of quality of soil on growth of roots

The cucumber plant shown in the figure was grown in a shallow box, one end of which was filled with sand and the other with rich loam. The seed was planted in the sand, quite near the partition (*p*) of mosquito netting, which separated the sand from the loam. When the plant was one foot high the earth and sand were washed away and the roots sketched. Those grown in the loam weighed nine times as much as those in the sand. Three eighths natural size

There are now in progress many experiments relative to the nature of soil fertility, and many disputed questions are involved. Into these difficulties we shall not enter. However, a study of the way in which plant foods are built up (Sect. 17), and of the chemical analyses that have been made of plants and of soils, enables us to know some of the facts concerned. Carbon dioxide comes from the air, water from the soil, and with the water there are carried into the plants compounds of nitrogen, potassium, phosphorus, magnesium, calcium, iron, sulphur, etc. Uncombined nitrogen exists in the air, but as such it is unavailable to green plants. In the soil, when nitrogen exists in combination with oxygen as a nitrate (NO_3) green plants may use it. The following tables show the amount of these substances contained in the soil and the amount used in a given quantity of plant product.

RELATIVE "SUPPLY AND DEMAND" OF SEVEN ELEMENTS[1]

SUBSTANCES	Pounds in 2,000,000 pounds of the average crust of the earth	Pounds in 100 bushels of corn (grain only)
Phosphorus	2,200	17
Potassium	49,200	19
Magnesium	48,000	7
Calcium	68,800	1¼
Iron	88,600	½
Sulphur	2,200	¼
	Pounds above one acre of ground	
Nitrogen	70,000,000	100

MINERAL PLANT FOOD IN WHEAT, CORN, OATS, AND CLOVER[2]

PRODUCE		Phosphorus (pounds)	Potassium (pounds)	Magnesium (pounds)	Calcium (pounds)	Iron (pounds)	Sulphur (pounds)
KIND	AMOUNT						
Wheat (grain)	50 bu.	12	13	4	1	.3	.1
Wheat (straw)	2½ tons	4	45	4	9.5	1.5	2
Corn (grain)	100 bu.	17	19	7	1.3	.4	.2
Corn (fodder)	3 tons	6	52	10	21	4.8	5.8
Oats (grain)	100 bu.	11	16	4	2	.5	.6
Oats (straw)	2½ tons	5	52	7	15	2.8	3
Clover (seed)	4 bu.	2	3	1	.5		.1
Clover (hay)	4 tons	20	120	31	117	4	6.4

[1] After Hopkins, C. G., Table 8, Soil Fertility and Permanent Agriculture, 1910.

[2] Ibid., Table 13.

410. The nitrogen supply. The nitrogen supply of plants has already received attention in Sect. 343, Chapter XXI, which should be reviewed in the present connection. Long before the action of the soil bacteria was known, agriculturists knew of the value of clover and other leguminous plants as a means of helping to maintain or regain the fertility of the soil. It is now known that when soils are poor in nitrogen compounds it is possible to replenish the nitrates from the atmospheric nitrogen by the use of clover and its relatives, upon the roots of which grow tubercles containing the nitrogen-fixing bacteria. Sometimes it is difficult to get clover to grow in old and much-worn soils. This may be due to the fact that there are no nitrogen-fixing bacteria in the soil to start the tubercles. In such cases they must be introduced from a soil in which they are growing, or from artificial cultures. The best way of introducing them consists in scattering over the impoverished field some soil from fields in which tubercle-bearing plants have grown. Successful clover fields and waste places in which the common sweet clover (*Melilotus*) grows, furnish good soil for infecting worn-out lands.

Some much-used soils have become quite acid, and this acidity seems to interfere with growth of the tubercle-forming bacteria. It has been found necessary in many cases to counteract this acidity with limestone before the tubercle bacteria can flourish upon the clover roots and thus produce the nitrates that are needed for nutrition of the clover and the enrichment of the soil.

411. Is fertility permanent? It is a fact of common observation that when a given crop of plants is cultivated upon the same soil for a long period of years the yield of the crop diminishes. Agriculturists learned a very long time ago that by growing different crops in rotation better yields were secured. But even with this rotation of crops and with careful cultivation, the annual yield decreases unless the soil is replenished in some way. The oldest experiments of which there are complete records are still in progress at the Rothamsted

Experimental Station, Harpenden, England. Some of these began in 1848. Certain crops have there been grown year after year upon the same soil. A barley field, which has been unfertilized since the experiments began, produced in the year 1849 a little over 40 bushels per acre. Each year thereafter, with no fertilization, barley has been grown on the same field, and the yield has steadily decreased, so that during the twenty years closing in 1909 the average per year was less than 15 bushels per acre. Another piece of ground was used for wheat, turnips, and clover, in rotation, with three years given to each rotation, and was fertilized by use of nitrogen and mineral fertilizers. Considering only the wheat records, we have the following: In the first twenty years the average yield of wheat for the years in which wheat was grown was 35.3 bushels per acre; in the second period of twenty years the average yield was 32 bushels per acre; and in the third period of twenty years the average yield was 36.4 bushels per acre. In the second twenty-year period one year of general wheat failure materially reduced the average for that period.

412. Soil improvement. Since plants use such large quantities of the materials that are named in the tables given above, it is apparent that any soil to be fertile must contain these materials. Merely containing them, however, does not make a soil fertile. They must be in the particular combination in which plants can take them; the soil must be of such a texture and physical nature as to permit the processes through which plants secure their foods. Such chemical substances within the soil as strong solutions of injurious salts, if present in sufficient quantities, will prevent the passage of materials into the plant.

A fertile soil, then, is one that has the following requisites: a favorable water content, a good supply of mineral substances necessary to plant growth, freedom from harmful chemical substances, and favorable texture and physical composition. Many soils that once were fertile have become almost or quite unproductive, either through exhaustion of food elements, or through accumulation of harmful substances, and vigorous study is now being made regarding the nature of these limiting factors. The Rothamsted experiment and hundreds of others that have been made in the United States show the good effects upon soil fertility that may be secured by proper rotation of crops and proper care of the soil.

II. SPECIAL CARE OF PLANTS

413. Horticulture and gardening. Scientific study has aided much not only in the matter of the better growth and care of field crops and the forests, but in gardening and agriculture as well. All that has been said about what a plant is and how it lives, and about soils, cultivation, and plant food, applies in some way to gardening and agriculture; it must be recognized, moreover, that each garden or orchard crop is a specialty in itself, and requires special study for mastery. Almost every kind of garden or orchard plant thrives and yields best in certain climates, in certain kinds of soils, often with certain kinds of exposure to light; has its own peculiar diseases, and requires particular treatment in caring for its matured product. It can be no part of this general discussion of botany to deal with such matters in detail, but two or three kinds of special care should be discussed as illustrations of the nature of the work that is being done.

414. Pruning. In Sect. 60, Chapter IV, there was a discussion of the way in which natural pruning occurs. Artificial pruning has become a general practice, and the botanical relations of the process are therefore significant.

In *injured plants*, whose branches have been broken by wind or other destructive agencies, cutting away the broken parts discontinues the passage of food into the injured portions, makes it possible for new branches to grow into the space occupied by the injured branches, and decreases the danger of disease infection. Often the last result is not secured because the cut area is not treated so as to prevent entrance of fungus spores, bacteria, or insect parasites. When the wound that is made by pruning is small, the cambium layer sometimes grows over the cut surface, the wound thus healing without becoming the place of infection. But large wounds are almost certain to become infected with fungus spores before they heal, and they thus become the means of injury or destruction of the whole plant. A heavy coat of paint placed upon the cut surface usually prevents the entrance of destructive organisms.

At *transplanting*, all injured roots are pruned away and new, vigorous roots are soon developed. During the time when the roots are becoming established, transpiration of water from the aërial parts may greatly endanger the plant. This is one of the reasons for heavy pruning of the top at the time of transplanting. After the top has been pruned new growth develops, and by the time the root system is established and is thus in position to take up water, the increased transpiring surface produced by the new growth may be supplied with water. When transplanting potted plants into the garden it is often necessary to cover or otherwise protect them against excessive transpiration until the roots are established. This serves the same purpose that pruning does in transplanting woody plants. Indeed, succulent potted plants are sometimes pruned when they are transplanted.

Pruning for *better form* is extensively practiced in caring for the shrubs and trees of lawns and parks. By pruning to determine just what part of a plant may develop, almost any desired form may be produced. In this way apple trees have been made to grow as vines, roses have been made to grow like box hedges, and grapevines have been made into upright and self-supporting shrubs.

In pruning for better *flowers and fruit*, only a comparatively small number of vigorous buds or branches are permitted to grow. In this way each bud which grows receives proportionately much more nourishment from the whole plant than would be true if all the parts had remained. If all but one or two of the flower buds of a tomato plant are pruned away, larger and better fruit is produced. Chrysanthemums and roses are often treated in the same way with striking results. Many of the large and perfect flowers and fruits that are shown in exhibitions are developed in this way. Successful orchard growers prune their trees moderately each year, and thus maintain the quality and quantity of woody branches from which the largest yield of good fruit may be secured (Fig. 350). Checking the vegetative growth of the plant at the right time seems to stimulate flower and fruit production. All kinds of orchard trees are more productive when properly pruned. In recent times pruning in order to facilitate proper spraying has become a prominent feature of the work. The various factors that are now involved in the practice of pruning are of such importance that the subject has become almost a specialty in itself.

FIG. 349. Photograph by the New York Agricultural Experiment Station illustrating the results of spraying potatoes to prevent disease

Those that were not sprayed yielded at the rate of 161 bushels per acre; those sprayed three times during the season yielded at the rate of 350½ bushels per acre; those sprayed every two weeks yielded at the rate of 380 bushels per acre. In other experiments the results are even better. In this same station, during the year 1904, the average gain per acre in the yield for three sprayings is 191 bushels, and for spraying every two weeks is 233 bushels

415. Checking and removing disease. The prevalence of plant diseases has been made apparent in preceding chapters. Although the nature of many of these diseases is not known, scientific study has contributed methods of prevention, control, or elimination in many cases. Oat smut, which on an average is said to destroy each year from one dollar to five dollars' worth of oats per acre, can be removed by application to the seed of a formalin solution at a cost of a few cents per acre. It is not uncommon for the yield of an apple orchard to be doubled by proper spraying, and the accompanying improvement in the quality of the fruit changes it from a poor quality with a poor market, if it has any at all, to a good quality with good market.

FIG. 350. Results of proper pruning and spraying in growing Jonathan apples, Spokane, Washington

The number and average size of the apples are increased and the quality is improved. Photograph by August Wolf

A very carefully recorded experiment in the value of controlling the disease known as potato blight illustrates the possibilities of such treatment (Fig. 349). Three rows of potatoes were planted side by side, the planting and cultivation of all being the same. The results from different kinds of spraying, as shown in the legend under the figure, indicate clearly the great importance of this treatment. If you will ascertain the price of potatoes in your local market, and estimate the value of the increased yield, its significance will be more fully seen. It costs as much in money and labor to plant and cultivate a poor crop as a good one.

416. An artificial association of plants. By draining or irrigating, cultivating and fertilizing the soil, planting the seed or plants at the right time and in the best way, caring for them and fighting their diseases, a highly artificial and dependent association of plants has been developed. None of these plants would naturally grow alone and unmixed with other plants. They have been cultivated and protected until, when this cultivation and protection are discontinued, their productivity rapidly decreases. They would soon be unable to hold their own against the many natural plants that would begin to occupy the previously cultivated region. Many of the characteristics for which cultivated plants are valued, such as tender stems or foliage, seedless fruits, and double flowers, tend to weaken their capacity to succeed in the struggle for existence.

III. LEADING AGRICULTURAL AND HORTICULTURAL PLANTS

417. Commercial importance of the cereals. Under the name *cereals* are included many economic plants of the Grass family. They produce grains (seeds or fruits) in which food material is stored in compact form. The principal cereals named in the order of their yields for the whole world, stated in tons of 2000 pounds, are:

Corn	109,000,000	Rice .	53,500,000
Wheat	103,500,000	Rye . .	40,500,000
Oats . . .	57,000,000	Barley	31,000,000

In the United States the average annual value of the grain and hay crops for the five years 1903–1907 was as follows[1]:

Corn	$1,132,000,000
Hay	587,000,000
Wheat	503,000,000
Oats	293,000,000
Barley	70,000,000

418. Indian corn. Indian corn is an American plant, well known to the Indians and cultivated by them long before the coming of white people. Its food value per acre is about double that of other grains.

The United States is the chief corn-raising country, producing more than three quarters of the world's crop, mainly in the "corn belt" of the Middle West. This region, with its fertile soil, its sunny summers, a fairly heavy rainfall, and a high summer temperature,[2] is especially adapted for corn growing. In northern Europe corn is grown in botanic gardens as a curiosity, but does not succeed as a field crop because the summer temperature is not high enough and there is not sufficient sunshine. In the Mediterranean region the soil is fertile and the summers are sunny and hot, but the scanty summer rainfall — sometimes less than an inch during three months — affords unfavorable conditions for corn growing.

The most important types of corn are flint corn, dent corn, and sweet corn. The flint varieties have a large proportion of hard, translucent endosperm. The dwarfed, quickly maturing kinds, which can be harvested in ninety days or less from the time of planting, and which are therefore grown in the northernmost states and Canada, are all flint varieties. The dent varieties have much soft endosperm and indented kernels (Fig. 332). The plants sometimes reach a height of eighteen feet or more, and require nearly six months to mature. Dent corn is much more productive, as a rule, than the flint varieties,

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[1] See Yearbook, U. S. Dept. Agr., 1907.

[2] Averaging between 70° and 80° F. for the month of July.

and therefore a more profitable crop. Sweet corn contains more sugar in the grain than other kinds, particularly when in the milk stage. It is much grown on the farm for home use, and by market gardeners on a far larger scale to supply canning establishments.

419. Wheat. Wheat is the most highly prized of the cereals, and has been cultivated for some thousands of years throughout large parts of the region extending from China to southern and western Europe. Most people prefer wheat preparations to those from other cereals. Wheat flour, containing a large percentage of the sticky protein material known as gluten, is particularly well adapted for bread-making.

There are two well-known classes of wheats, based on the time of sowing: *spring wheat*, which is planted in the spring as soon as the ground is dry and warm enough for tillage; and *winter wheat*, which is planted in the autumn, grows but little before winter, finishes its growth in the following spring, and is harvested in the summer. Both winter and spring wheats include hard and soft varieties, the former containing much gluten and the latter less gluten but more starch. The hardest of all are the macaroni wheats, which have a very high food value but are not usually considered well adapted for bread-making unless mixed with softer wheats.

Wheat can be grown in a cooler climate and with less summer rainfall than is needed for corn. For semi-arid regions, such as a large area in Texas and portions of Oklahoma and Colorado, the macaroni or durum wheats are extremely well adapted. Wheat will grow well on a more clayey soil than is best for corn, and in general throughout the corn belt the wheat crop takes a secondary place, often being planted on land that for some reason is not wanted for corn growing.[1]

420. Other cereals. Oats, rye, and barley may all be grown in cooler and moister climates than are suited for corn and wheat. They are therefore much cultivated in northern Europe.

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[1] On varieties of wheat and wheat culture see *Bulletin 24*, Division of Vegetable Physiology and Pathology, U. S. Dept. Agr., 1900.

Oatmeal cooked in various ways, barley bread, and rye bread are therefore more used than wheat by the poorer classes throughout that region. Oats and barley are both much used as feed for horses, and barley is largely employed by brewers in the manufacture of malt.

Rice is the great cereal crop of Asia, and a good deal is grown in South Carolina and the Gulf States. The territory in which rice is grown has been much extended in the United States within the past decade. The crop is generally cultivated on land that is overflowed during part of the year (Fig. 274).

421. Grasses cultivated for hay, forage, or pasture. In addition to the high value already stated for the hay crop, there are many grasses which are used directly as feed, without being cut and dried as hay. It would be difficult to estimate the annual value of the forage grasses and the pasturage of the United States, but it must run into hundreds of millions of dollars. Only three or four of the most important grasses that are cultivated or somewhat protected in their growth can here be mentioned.

Timothy is the leading grass for hay, especially in the more northerly states. Redtop ranks next after timothy as a source of hay, though in its quality it is somewhat inferior to the former. Kentucky blue grass is the most valuable pasture grass in America. There are many grasses of great value in semi-arid regions, as the buffalo grass. Formerly some of these dried, as they stood, into a kind of natural hay on which the vast herds of buffalo of the Great Plains fed throughout the winter.[1] Red clover and alfalfa are also very valuable hay-producing plants. They do not belong to the Grass family, however, but to the Pea and Bean family (Leguminosæ).

422. Cotton. The most valuable fiber plant of the world is the cotton plant, which is a member of the same family as the mallows and the hollyhocks. It is grown extensively in India,

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[1] On the grasses see G. F. Warren, Elements of Agriculture, chap. vii. The Macmillan Company, New York.

Egypt, and in our own Gulf States. In 1907 the United States produced a crop worth about $675,000,000, which was approximately three fifths of the world's crop. This country ordinarily produces from 9,000,000 to 13,000,000 bales of 500 pounds each, the total value ranging from one third to two thirds of a billion dollars in value.

The cotton consists of hairs which surround the seeds. Different lengths of cotton fibers are produced by different species. There is also much variation in the same species when grown in different parts of the world and under more or less favorable conditions. The cotton plant is an annual. When grown in tropical and semi-tropical countries it requires a relatively long season for maturing. In regions which have shorter growing seasons certain kinds, as the "sea-island" cotton (*Gossypium Barbadense*), will mature in ninety to a hundred days, and it has been known to mature in seventy.

423. Fruits of the Rose family. As the cereals are found in the Grass family, the majority of fruits are found in the Rose family. A large proportion of the edible fruits of the temperate region (using the word *fruit* in its popular sense) is produced by this family. These fruits may be divided into (1) pome fruits, such as the apple, pear, and quince; (2) "berries," which are fruits that are commonly but incorrectly called berries, as the blackberry and strawberry; (3) stone fruits, such as the peach, apricot, plum, and cherry.

424. The pome fruits. Apples are the most important rosaceous fruits. They have been cultivated for several thousand years. The wild species from which they are thought to have originated, flourished in ancient times over a large area in the region about the Caspian and Black seas in southern Europe. This supposed ancestral apple is still represented by wild forms that live in Europe, the fruit of which is small, hard, extremely sour, and unpalatable. From the original wild form thousands of different kinds have developed, and these range to such extremes in size, color, quality, and time of ripening, that it is difficult to conceive of them as having a common ancestry. Cultivation has increased the bulk of the fruit several hundred times; moreover, in the plants now cultivated only one flower, or a few flowers, of the cluster develop fruit, as is also the case with the pear. The importance of the apple industry may be realized from the fact that a full crop for the United States and Canada amounts to about 100,000,000 barrels.

Apples are grown on a large scale in most of the cooler portions of the United States, but there are large areas of good orchard land not thus utilized, particularly in the central Appalachian region. Apple growing in irrigated lands is rapidly increasing in the United States.

Pears are much less extensively grown than apples. California pears, as is well known, are usually the largest and the finest that are grown. It is interesting to note that while the finest pears consumed in England were formerly of French growth, the United States is now exporting pears for the English market. *Quinces* are not of much commercial importance, being used for little else than as a basis for preserves and jellies. A large part of those produced are ordinarily grown for home use on one or two trees in a corner of the garden or orchard.

425. "Berries." In the so-called berries of the Rose family the ovaries ripen together, forming a thimble-shaped fruit upon the end of the flower stem, or receptacle, as in the blackberry; or it may be the receptacle itself which ripens, and, with its seeds upon its surface, forms the fruit, as is true in the strawberry.

Cultivated strawberries are mostly descended from a Pacific coast species which was introduced into cultivation from Chile some two hundred years ago. The plant occurs wild along the North American coast as far north as Alaska. Strawberry growing in the United States began with the once famous Hovey seedling, about 1834 or 1835, but was of little importance until after 1840. Strawberries grow readily in almost all good farming lands of the country. In favorable situations the crop is very profitable, as the yield may exceed four hundred bushels per acre. Strawberry raising on a large scale was long confined chiefly to gardens in the neighborhood of cities which served as a market. With improved quality and better facilities for shipping it has now become an extensive industry, and the season for some consumers has been extended from a few weeks to five or more months, beginning in January with the product of the Gulf States and ending in July with Canadian berries.

There are at least five species of *raspberries* in cultivation, but none of them bear transportation especially well. They are grown considerably for shipment over comparatively short distances. The red species, whether wild or cultivated, is much used in preserving-factories in making jam, and at times is prominent in the fruit markets.

Blackberries, of which, including the Pacific coast forms, there are five or more species in cultivation, are known as commercial fruit only in America. Their cultivation began before 1841, and was slow to reach its present importance. Most of the favorite varieties were for years only chance seedlings of the upright wild species, but at present improved kinds that are descended from the trailing dewberries are coming into favor.

426. Stone fruits. Our most common stone fruits are peaches, plums, and cherries. Of these three fruits the two latter occur wild, but only plums have been much used in the wild state. Of the thousands of acres of wild-plum thickets once widely scattered over the Middle West, few now remain.

Peaches are of Chinese origin, and were early introduced into America from Europe. They cannot be safely cultivated except where there is little danger of frosts after the trees have blossomed. Favorite peach-growing portions of the United States are the southerly part of the region bordering the Great Lakes, parts of Georgia and Alabama, southern Illinois, Missouri and Kansas, western Colorado, Texas, and most of California except the mountainous portion. As peaches are very perishable, most of the crop (as is the case with strawberries) must be taken to market in refrigerator cars.

Nectarines, apricots, and almonds are very closely related to peaches.

Plums, cultivated in various parts of the United States, belong to about ten groups, of Asiatic, European, and American origin. Some highly successful varieties are of hybrid origin (Fig. 341). One of these is derived from the little beach plum[1] so well known along the Atlantic coast, and the common wild plum[2] which ranges from New England to Colorado and Texas. This hybrid is extraordinarily hardy and prolific. Among the most valuable plums are those which can be dried whole for prunes, and these are now extensively grown in California.

Cherries in cultivation are of two types, the sour and the sweet, both derived from European species. The sour varieties are grown throughout a large portion of the country, the sweet ones principally in California.

427. Citrous fruits. The plants which bear oranges, grapefruit, and lemons, are not hardy but thrive in tropical or semitropical climates. They may grow in regions where frosts are rare and light. In the United States the leading citrous-fruit orchards are in Florida and California. The wild orange is probably a native of southeastern Asia. Its fruit is sour, but the tree is more hardy than some of the improved sweet varieties. Because of this hardiness the sweet varieties are sometimes grafted upon the wild stock in order to make use of the stronger wild plants. By means of experiment and cultivation many hundreds of varieties of oranges have been produced. Attempts are still being made to produce trees which will withstand the colder winters of the region farther north and at higher altitudes than where they are now grown. These efforts have been partially successful.

Oranges, lemons, and the grapefruit or pomelo, as well as the more recently developed varieties, as the tangerine and

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[1] *Prunus maritima.*

[2] *Prunus americana.*

kumquat, have peculiarly valuable shipping qualities, which make it possible for these fruits to be shipped anywhere and to be kept for very long periods.

428. The grapes. The fruit of the grape is known to have been used by the earliest civilized peoples. From the wild grapes, which though sour are edible, more than a thousand varieties have been developed. These differ in color, as white, black, blue, or red; and in texture, from the soft juicy grapes from which wine is made, to the more solid ones which are dried in making raisins. The leading grape-producing states are New York, Ohio, Michigan, and California.

Perhaps the best-known and the most widely distributed kind of cultivated grape that is native to the United States is the Concord grape, which was discovered by Ephraim Bull at Concord, Massachusetts. Part of the original vine still grows on the lawn of the old Ephraim Bull homestead.

The European grapes, which form the basis of the very large and important wine industries of France, were developed out of a different stock from that of the American cultivated grapes. Since the French grapes produced a quality of wine that differed from that made from the grapes of the United States, European grapes were brought to this country. Their roots were soon attacked, and the plants well-nigh destroyed, by a small parasitic insect known as phylloxera (Sect. 343). It was found, however, that the roots of the American grapes were able to withstand attacks from phylloxera and were not seriously affected by it. It was also found that when European grapes were brought to this country and grafted upon American stock, the quality of the European fruit might be secured without the accompanying dangers from the insect. But when grape growers transplanted American grapes into Europe the phylloxera was also transferred, and soon the native grapes of Europe were attacked and serious damage was done in the vineyards of France. In order to protect their vineyards many French grape growers adopted the practice of planting American plants and then grafting their own grapes upon this introduced stock. The grape industry of France has been greatly increased by thus growing French grapes upon the stronger and more productive American stock. Some French grape growers, still believing that the quality of their grapes would deteriorate if grown upon American stock, use carbon disulphide as a means of protection against phylloxera, but this treatment is still too expensive to be used in the ordinary vineyards.

429. Garden vegetables. Another group of plants which form the basis of a great industry includes those generally known as vegetables. The vegetables come from many plant families. According to one authority,[1] there are at least two hundred eleven distinct species of garden vegetables, and many of these species are represented by very large numbers of varieties. The parts of these plants used as food may be the roots (sweet potato, radish, etc.), the combined stem and root (beet, parsnip, carrot), the underground stem (white potato, Jerusalem artichoke), stem and leaves (lettuce, cabbage), and the fruit (tomato, squash, cucumber, eggplant, string beans). The list of vegetables is too long and varied for any common characters to be given for it.

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[1] Vilmorin, in The Vegetable Garden.

CHAPTER XXV

WEEDS

430. What is a weed? It is not possible to put into a short sentence a complete statement of what is meant by a weed. It is often said that a weed is a plant that is not wanted. Perhaps a better definition, from the farmer's point of view, would be: *A weed is a plant which interferes with some crop.* The word *crop* must, in this case, be taken in a very general sense. The dandelions which interfere with the growth of grass on a lawn, or the raspberry bushes which spring up in burnt-over clearings in white-pine woods and crowd out young tree seedlings, must be reckoned as truly weeds as the ragweeds and the pigweeds[1] that are so troublesome in cornfields.

Cultivated plants may become very injurious weeds. Horse-radish, and Johnson grass,[2] which is valued in the South as a hay plant, are good instances of this.

In the ordinary sense the term *weed* is applied only to flowering plants or to the larger representatives of the lower groups, such as ferns and horsetails. The many bacteria and higher fungi which do so much harm in the farm and garden are never spoken of as weeds.

431. Classes of weeds. Weeds may be classified in many ways, according to the kinds of resemblances and differences taken into account in grouping them.[3] The kind of classification which would first suggest itself to most botanists is that into families, such as the Grass family, the Nettle family, and the Buckwheat family. Another kind of division would be into annual, biennial, and perennial plants; still another into

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[1] *Amaranthus.*

[2] *Sorghum halepense.*

[3] See Percival, Agricultural Botany. Part V. Henry Holt & Co., New York.

sun plants and shade plants, or into drought-enduring and moisture-loving plants (Sects. 441–446). We are fortunately as yet but little troubled in this country by one obnoxious group of weeds, the parasitic flowering plants. The clover dodder (Fig. 351) is one of the most important of these, causing much trouble in fields of clover and of alfalfa. The farmer would often class weeds according to the kind of crop with which they interfere; for example, into weeds of pastures and those of cultivated ground, subdividing the latter group into weeds of cornfields, weeds of oat and wheat fields, weeds of clover fields, and others.

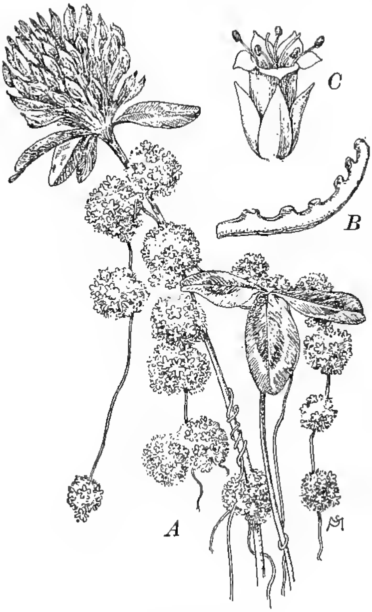

Fig. 351. Clover dodder, parasitic on red clover

A, habit sketch of part of the parasite and the host; *B*, portion of stem of the dodder, showing protuberances from which haustoria pass into the stem of the host; *C*, a single flower of the dodder. *B* and *C* considerably magnified. Modified after "Flora Danica"

432. Qualifications for successful weeds. Not many wild plants of any region can become, even in the territory to which they are native, successful weeds. The trilliums, columbines, pepperroots, fire pinks, wild ginger (Fig. 43), Dutchman's-breeches, and wild sweet William (*Phlox*), so familiar among the early wild flowers of the Middle West, are there practically unknown in cultivated fields. For various reasons the conditions of life in tilled ground are promptly fatal to them. In order to push its way among competitors, to win in the struggle for existence, under natural conditions and with the farmer and gardener against it, the weed must possess exceptional powers of reproduction or of

Fig. 352. *A*, corn cockle, a weed of the Pink family, troublesome in grainfields. The seeds are poisonous. One third natural size. *B*, cocklebur, a very troublesome weed of the Composite family, in rich land throughout a large part of the country. Two thirds natural size

resistance to unfavorable influences. Some of the chief qualifications which distinguish weeds are:

(1) The power of vegetative reproduction.

(2) Deep, tough roots, or relatively extensive development of the underground portion.

(3) The power to produce many seeds.

(4) Capacity for self-pollination (if necessary).

(5) Good means of seed dispersal.

(6) Capacity for rapid growth.

(7) The ability to resist plant diseases.

(8) Tolerance of shade (at least when young).

(9) Tolerance of drought.

(10) Tolerance of excessive water supply and lack of air in the soil.

(11) The ability to resist the effects of dust in choking the stomata.

(12) Capacity to thrive in poor soil.

(13) Ability to retain vitality of seeds buried in the soil, sometimes from fifteen to twenty-five years.

(14) Unpalatableness, offensive smell, prickles, or other disagreeable characteristics, which lessen the danger of being eaten by animals.

Few if any weeds have all the above-named characteristics in a high degree, but many kinds of plants have the greater part of them. Which characteristics are common to many weeds of woodlands? of pastures? of lawns? of roadsides? of cornfields? of fields of the small grains? Name some of the weeds which you know that have the largest number of the qualifications (1)–(14). Can you name any plant that has both characteristics (9) and (10)?

433. Effectiveness of weed equipment. In most instances it is easy to see how the characteristics listed in Sect. 432 enable weeds to persist. Evidently a plant which, like the Russian thistle, produces tens of thousands of seeds, or one which, like the dandelion, scatters seeds for miles with the wind, is likely to reproduce itself abundantly and to occupy any suitable bit of vacant ground. But there are other most effective qualifications which need a little explanation. If a sorrel plant[1] (Fig. 353) is dug up carefully, it will usually be found to have several others attached to it by the roots. This is rapidly becoming one of the worst weeds in the United States,

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[1] *Rumex Acetosella.*

being especially abundant in slightly acid soils. Many other kinds of plants, from nettles to goldenrods, are joined in colonies by long underground stems.[1] The sorrel roots and the goldenrod rootstocks produce many buds, and each bud may grow into a new plant. If the rootstock is cut to pieces with a hoe, the process of reproduction is only urged on a little. Every tuber of some sunflowers (Fig. 67), the nut grass, and many other tuber-bearing plants may grow into a new individual. Purslane plants when hoed up and left on damp soil at once begin to grow, each bit forming a successful cutting. These are only a few of the hundreds of examples that might be given of vegetative reproduction among weeds.

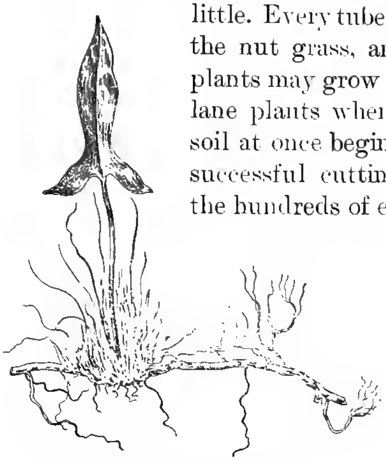

FIG. 353. Portion of a plant of the common sorrel

The leaf is drawn about one half natural size. The running roots of a large specimen would be at least sixty times as long as the piece here shown

The way in which foxtail grass maintains itself in grainfields, making slow growth while it is overtopped by the wheat, oats, or rye, and then pushes up rapidly, flowering and seeding among the stubble, is an excellent illustration of the importance to the plant of the power to tolerate shade during the early period of growth. It must be remembered that any qualification that helps the weed in its struggle for existence is a good thing for the weed, even if it is discouraging from the point of view of the farmer.

The survival of mullein and ironweed in pastures, and of dog fennel, smartweeds, and the offensive-smelling, poisonous Jimson weeds (Fig. 300) in barnyards, are only a few examples of the many that could be given to show how some weeds persist by being uneatable or positively offensive.

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[1] See *Bulletin 76*, Kansas Agr. Exp. Sta.

434. How weeds injure the farm and garden.[1] Although some weeds are of use as food for man or the lower animals and a few have medicinal properties, their presence in the farm or garden is on the whole most harmful in the following ways:

(1) Weeds take soil moisture needed by useful plants.

(2) Weeds rob the soil of valuable salts, such as nitrates and potash compounds, and it is probable that they may add secretions that are injurious.

(3) Weeds weaken other plants by shading them, thus hindering photosynthesis.

(4) Parasitic weeds, like the flax dodder and the clover dodder (Fig. 351), rob their hosts of plant food.

(5) Some weeds harbor parasitic fungi or insects injurious to useful plants.

(6) Poisonous or intoxicating plants injure horses, cattle, and sheep.

(7) Some spiny plants, such as the smaller cacti, and burs like the sand bur, may lame the feet of domestic animals. Thorny shrubs are very troublesome to woolgrowers, pulling out much wool, and burs greatly injure the quality of the fleece.

(8) Certain weeds, when eaten by cows, render milk unpalatable or ill-scented.

(9) Weed seeds injure the quality and affect the price of clover and other seeds that are raised for sale, and thus diminish the value of the grain with which they are mixed.

The harm done by weeds in shading crops is most noticeable in the case of rapidly growing species which spring up among delicate seedlings such as flax and onions. In extreme cases the weeds may almost entirely prevent the growth of the crop.

The most important example of fungi harbored by weeds is that of wheat rust on barberry bushes (Sect. 233). The potato beetle feeds on many plants of the Nightshade family,

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[1] See *Bulletin 175*, "A Second Weed Manual," Ohio Agr. Exp. Sta., for a fuller discussion.

and then transfers itself to any neighboring potato plants that are not protected by applications of Paris green or of other poisons.

A familiar example of a pasture weed poisonous to the lower animals is the common sheep laurel or lambkill.[1] There are a good many plants, such as some members of the Nightshade family, hemp, and some leguminous species,[2] which may produce symptoms both of intoxication and of poisoning in horses, sheep, and cattle.

Of the plants which give a bad taste to milk, field garlic or wild onion[3] is the most important. The bulblets of this weed may also impart an onion flavor to flour made from wheat grown in fields infested with it. As an instance of the extent to which weed seeds may contaminate commercial samples of useful seeds, the case of red clover may be cited. Inferior lots of clover seed may contain as much as 67 per cent of impurities, largely other seeds,[4] and the average of 84 samples examined at the Iowa station was 5 per cent, or 3 pounds to the bushel. In the red and mammoth clover seed examined at a single

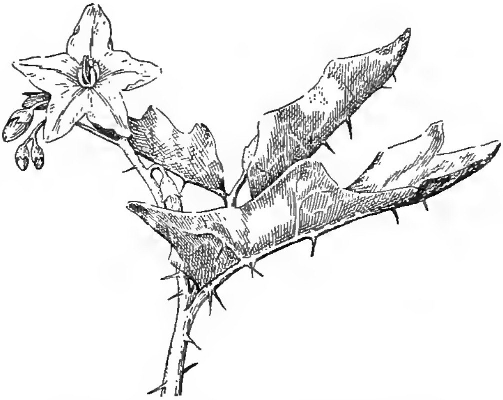

FIG. 354. Horse nettle (*Solanum carolinense*)

A very troublesome weed of the Nightshade family, which has spread extensively from the southeastern states. One half natural size

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[1] *Kalmia angustifolia*.

[2] The so-called "loco weeds," mostly species of *Astragalus* and *Aragallus*.

[3] *Allium*.

[4] See *Bulletin 21*, Iowa Agr. Coll. Exp. Sta.

agricultural experiment station there were found in all 87 species of other seeds, mostly those of noxious weeds, belonging to 23 different families of plants.[1]

435. Other injuries caused by weeds. Aside from the damage inflicted by weeds upon growing crops and farm animals, much harm is done by them in less obvious ways.

Roadside weeds of many species encroach upon roads of all kinds, from country byways to city boulevards. Among the weeds of waste ground there are many which disfigure the surface of vacant city lots, and the numerous burs among them load the passer with their clinging seeds or fruits.

Railway rights of way, if left uncared for, soon become overgrown with weeds, which shade the ties and cause them to decay more rapidly. It is estimated that the expense of removing weeds from the railway tracks in the state of Ohio alone exceeds $500,000 a year.

Streams, canals, and drainage or irrigation ditches are often infested by weeds, which may almost stop the current of water in them. The water weed, or ditch moss (*Elodea*), introduced into Europe from America, has become a nuisance there, choking small streams with its abundant growth. The so-called water hyacinth (*Eichhornia*) from South America, often cultivated in aquaria and small ponds, has been introduced into Florida and other southern waters, where it greatly impedes navigation.

436. The origin and dissemination of weeds. One of the interesting facts with which the young botanist is first impressed on beginning to identify weeds and to trace their history, is the extent to which they have immigrated from other countries.[2] No one can calculate with exactness the proportion of our weeds (that is, of individuals) which have been brought in from other countries. But it is not difficult to see how the numbers stand in comparing native and introduced

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[1] See *Bulletin 175*, Ohio Agr. Exp. Sta.

[2] See the article, "Pertinacity and Predominance of Weeds," in the Scientific Papers of Asa Gray, selected by C. S. Sargent, Vol. II, Houghton Mifflin Company, Boston; also Farm Weeds of Canada, Second Edition, Government Printing Bureau, Ottawa, Canada.

species. If we look through a list of a hundred of the worst weeds over the continental area of the United States (excluding Alaska),[1] it appears that almost exactly half of the number are from Europe. Nine others are from tropical America or from India, so that a clear majority of these hundred notable weeds are foreigners. It is rather difficult to give all the reasons why so many of our common weeds come from Europe, but it is certain that of the prevalent weeds on that continent many represent the result of a gradual sifting-out process which has lasted for tens of centuries. During all that long period the tilled lands of Europe have gradually become populated by such European plants as proved able to live in cultivated ground in a temperate climate against human opposition. Together with these are found such other persistent species as may have found their way in from Asia and Africa. When the soil of temperate North America first began to be cultivated by the whites, it was inevitable that great numbers of European weeds should be brought in along with farm and garden seeds, in the ballast of vessels, and in other ways, and rapidly gain a foothold on the new continent. The history of the spread of many weeds has been preserved, and it forms a most interesting chapter of economic botany.[2]

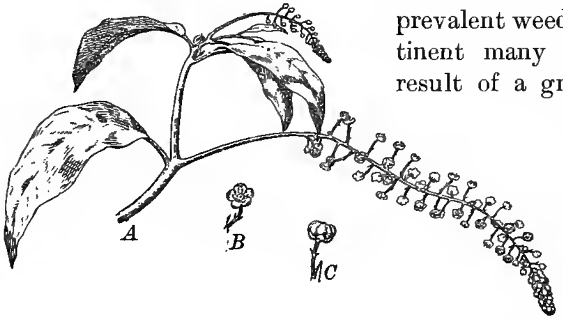

FIG. 355. Pokeweed, a common weed of waste ground
A, a flowering branch; *B*, flower; *C*, fruit

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[1] *Farmers' Bulletin 28*, U. S. Dept. Agr.

[2] See the essay of Dr. Gray already cited; also *Farmers' Bulletin 28* and *Bulletin 15*, Division of Botany, U. S. Dept. Agr. Consult also all the attainable weed reports of the state agricultural experiment stations.

It is a well-known fact that new weeds are particularly likely to be found in places where ballast from vessels is dumped, where cargoes of foreign grain are cleaned, and where foreign wool is scoured and cleaned from burs and other seeds.[1] Some very troublesome weeds, as the common carrot and the orange hawkweed, have been cultivated for use or ornament and escaped into fields, meadows, and pastures.

437. Weeds of various regions. Any two regions which differ widely in soil or climate are sure to differ also in the weeds which predominate there. Such tropical plants as the sensitive plant[2] and the rosy periwinkle,[3] not uncommon in our greenhouses and gardens, are troublesome weeds, the former in tropical South America and the islands of the South Pacific, and the latter in the West Indies. But in our climate it requires care and protection to keep them alive. Even in the various climates afforded by the United States, there is range enough to make one weed troublesome in one portion of the country and another in another portion. The quack grass, or couch grass,[4] so injurious from its creeping rootstocks in fields and gardens from Maine to Minnesota, is replaced as a weed in the southern states by the Johnson grass,[5] which has still stronger and longer rootstocks. The wild gourd,[6] troublesome in the far Southwest, is not found as a weed northeast of California and New Mexico, and the cacti,[7] annoying weeds in central and southern Kansas and westward and southward, are of no importance farther east.

The amount of moisture in the soil is an important factor in the distribution of weeds. Such plants as the cacti just mentioned, some cinquefoils, St.-John's-worts, lambkill, some species of vervain,[8] the common mullein, rib grass,[9] and the

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[1] A curious case of distribution of a bur is that of the grass *Andropogon acicularis*. A buffalo with his hair filled with the needle-like fruits of this grass was sent as a present to the so-called king of Ternate, in the Malay Archipelago. From this one animal the grass soon spread over the whole island.

[2] *Mimosa pudica*. [3] *Vinca rosea*. [4] *Agropyron repens*. [5] *Sorghum halepense*. [6] *Cucurbita perennis*. [7] *Mamillaria*, *Opuntia*, and other genera in the Southwest. [8] *Verbena*. [9] *Plantago aristata* and *P. lanceolata*.

everlastings are especially frequent in dry pastures. A few ferns, such as the sensitive fern and the ostrich fern,[1] horsetails, rushes, sedges, many worthless coarse grasses, smartweeds, docks, some buttercups, mints, and the ironweeds are common only in moist fields, meadows, and pastures.

438. How to avoid weeds. The methods of destroying weeds are fully discussed in treatises on agriculture. A great deal can be done toward the prevention of weeds by taking pains not to use poor seed for the farm and garden, since the cheaper kinds often contain many weed seeds. Stable and barnyard manure frequently contains many seeds of the most objectionable weeds, and in caring for lawns it is often found cheaper to use ground bone or chemical fertilizers, such as superphosphate of lime, than to spread over the grass fertilizers which may introduce multitudes of troublesome weeds.

Fig. 356. Tumbleweeds (*Cycloloma*) drifted into heaps by the wind

One of the most obvious means of keeping one's premises free from weeds is not to allow them any avoidable breeding

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[1] *Onoclea.*

places. All fence rows, hedges, clumps of blackberry and raspberry bushes, and similar lurking places for weeds, as well as grassland and tilled ground, should be kept as clean and as nearly weedless as possible. Weeds which have gone to seed should not be plowed or spaded under, but allowed to dry and then burned. It will be found well worth while to rake away from fences and burn all such accumulations of tumble-weeds as those shown in Fig. 356. Wild mustard, which is a very troublesome weed in fields of the small grains, is readily killed by spraying with a solution of copper sulphate or iron sulphate. Weedy lawns are sometimes improved by very careful salting, which does not injure the grass. Gravel walks may be cleared of weeds by watering them with a solution of sodium arsenate or of crude carbolic acid.

CHAPTER XXVI

ECOLOGICAL GROUPS; REGIONAL DISTRIBUTION OF PLANTS[1]

439. Ecology in earlier chapters. The term *ecology* has already been defined (Sect. 110). In the preceding chapters of this book the ecology of the plant has usually been somewhat discussed along with the account of the plant itself and of its organs. For instance, much of what was said about the relations of the root to the soil (Chapter III), root-tubercle bacteria (Chapters III and XXIV), mycorrhiza (Sect. 38), and the relations of stem and leaf to light supply (Chapter IV) is a part of plant ecology. So, too, is the treatment of pollination (Chapter VIII), of seed dispersal (Chapter IX), and much of the chapter on Weeds. The relation of parasites to their hosts and of symbionts to each other (Chapter XXI) constitutes a most important part of ecological botany. In the cases here referred to, however, the main emphasis was laid on the

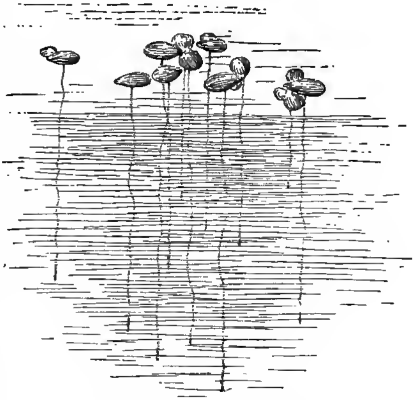

FIG. 357. The duckweed, one of the simplest floating seed plants

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[1] See Warming, Œcology of Plants (Clarendon Press, Oxford); Schimper, Plant Geography on a Physiological Basis (Clarendon Press, Oxford); and Coulter, Barnes, and Cowles, Textbook of Botany, Part II (American Book Company, New York).

An excellent bibliography of the subject will be found in Warming's work.

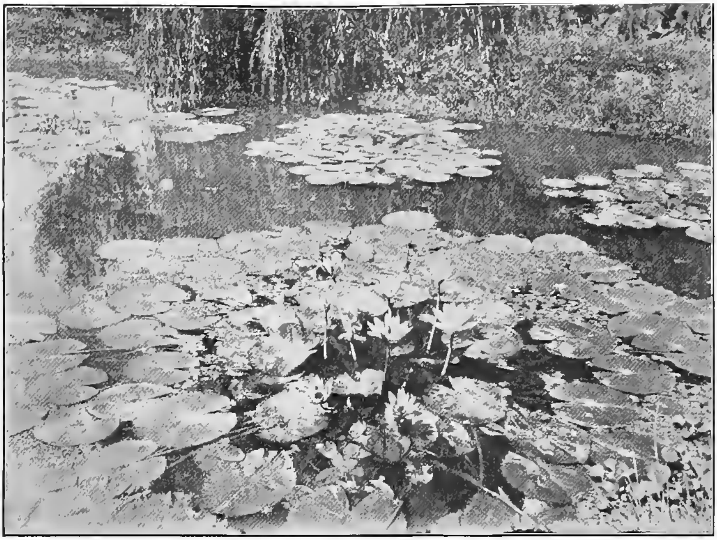

Fig. 358. The pond lily, an aquatic with floating leaves and submerged stems

Fig. 359. Free-floating aquatic plants in a pool

Aquatics with aërial leaves, the most conspicuous of which is the arrowhead (*Sagittaria*), grow in the mud about the pool. Photograph by Charles Gordon structure and mode of activity of the plant or organ under discussion. From the point of view of the ecologist the principal things to be considered are the relations (often very intricate) between the plant and other plants or animals, how the plant meets the conditions of soil and climate under which it exists, and why plants are distributed in the various regions of the earth's surface as they are.

440. Systematic groups not ecological. The way in which plants are classified according to their relationships has already been described (Chapter X). The systematic grouping into classes, orders, families, and so on, has no necessary relation to the life habits of the plant. The Heath order, for example, includes ordinary plants with the capacity for photosynthesis (Fig. 299), and also saprophytes (Figs. 307 and 308). Some of its members are sun-loving plants and some are shade-enduring, some can live in very dry soil and others occur only in swamps. One familiar genus of the Morning-glory family (*Cuscuta*, Fig. 351) is parasitic, while most of the genera of this family get their living in the ordinary way, from air and soil. Several genera of the Figwort family (such as the painted cup) are root parasites, while most are not.

441. Ecological groups. In classifying plants according to their ecological relations they are generally grouped with regard to their water requirements, as follows:

(1) *Water plants*, those which usually live only in the water[1] or in marsh soil saturated with water[2]; they may be unattached, like many algæ (Chapters XII, XIII) and duckweed (Fig. 357); or rooted, like arrowhead (Fig. 359), cat-tails, pickerel weed, and pond lilies (Figs. 55 and 358).

(2) *Land plants*, those which live in ordinary soil or on rocks, the bark of trees, and so on.

The two main ecological divisions of land plants are as follows[3]:

(*a*) *Xerophytes*, plants which can tolerate extremely dry conditions, as many lichens (Figs. 190–193), cacti (Fig. 68),

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[1] *Hydrophytes.*

[2] *Helophytes.*

[3] For halophytes see Sect. 452.

and in general plants which inhabit exposed or excessively dry regions.

(*b*) *Mesophytes*, plants which require a moderate amount of moisture, such as most cultivated plants and our commonest deciduous trees and shrubs.

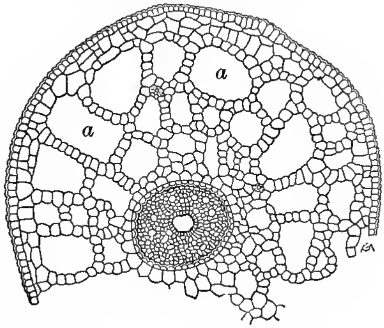

FIG. 360. Cross section of stem of pondweed (*Potamogeton*) showing air passages *a*, much magnified. After Green

FIG. 361. A marsh plant (*Limnophila*)

The thread-like lower leaves are water leaves. There are some of an intermediate form just above the middle, and the upper ones are air leaves. About one half natural size. After Goebel

442. Characteristics of water plants. Those water plants which live wholly submerged generally differ far more in their form and structure from land plants than do those which (like many grasses and sedges) grow in very wet soil. From the situation in which they grow, submerged plants are less familiar to us than common land plants; but most people who know out-of-door things well, have seen pondweeds, water crowfoots, bladderworts (Fig. 362), mare's-tail, water weed (*Elodea*), or some of the aquatic mosses. It is important to notice how thoroughly most of these are buoyed up and supported by the water. All such plants are soft and limp, without the distinct tough epidermis of land plants, and the leaves are often slender or thread-like.

Definitely stated, some of the most noticeable characteristics often found in submerged aquatic seed plants are[1]:

(1) Slight development of the root system.

(2) Slight development of wood cells and vessels.

(3) Stiffening structures scanty or lacking.

(4) Air spaces large and abundant.

(5) The epidermis thin and the cuticle very thin or wanting.

(6) The leaves often dissected into thread-like divisions.

What are probable reasons for characteristics (1)–(5)? The thread-like divisions of the leaves mentioned in (6) are thought to favor exchange of gases between the water in which they are dissolved and the leaf interior and to offer little resistance to currents of water.

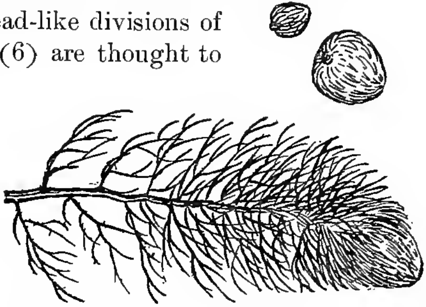

FIG. 362. A free branch and two buds of a large, common bladderwort

After Beal

443. Characteristics of xerophytes. There are so many types of xerophytes that it is not possible in a few words to sum them up or to give the student a comprehensive idea of their peculiarities of structure and of function. Perhaps the easiest way to suggest the leading characteristics of the group is to mention a few familiar representatives of the leading types as follows:

(1) The olive (Fig. 51), the rubber tree (*Ficus elastica*), and the wax plant (*Hoya*), not uncommon in greenhouses, are good examples of xerophytes with hard, thick-skinned leaves, which have a compact interior parenchyma, without the abundant air spaces shown in Fig. 11.

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[1] The student must not think of these characteristics as abnormal and of those of ordinary land plants as normal. It is possible that the earliest plants were aquatics and that the aquatics of to-day are more like primitive plants. But it is better to leave such reasoning for more advanced studies.

(2) The various kinds of heather, knotgrass (*Polygonum aviculare*), knawel (*Scleranthus annuus*), and the rushes are instances of xerophytes with small leaves, exposing comparatively little surface to the sun and air.

(3) Century plants (Fig. 62), houseleeks, and aloes are good examples of fleshy-leaved xerophytes.

(4) Many xerophytes combine in their leaves some of the characteristics of groups (1), (2), and (3). The leaves of cedars, hemlocks, firs, and spruces have a thick epidermis and close interior structure, like that shown in Fig. 249, and are also small, exposing little surface. The common purslane, the portulaca, and the ice plants (*Mesembryanthemum*) have small and rather fleshy leaves.

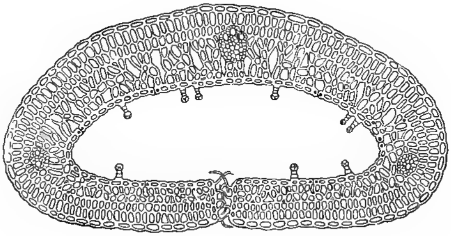

FIG. 363. Cross section of rolled-up leaf of crowberry (*Empetrum nigrum*) Magnified

Many xerophytes have extraordinarily developed root systems, as in the case of the mesquite (Sect. 27), and so can draw moisture from great depths in the earth. Others have extensive provisions for water storage (Sects. 34, 66, 67). Among these the cacti are notable for the amount of water which they can store in their succulent stems, which are often fluted, so as to expand and contract readily. This water has been rapidly absorbed by the spreading, shallow root system from the layer of earth (only an inch or two deep), which is moistened by the rare rains of the desert regions where many such cacti grow. Between rains the roots of these cacti serve only for anchorage.

Xerophytes in general are so constituted as to transpire little at any time, or else to be able, in case of danger from excessive dryness, to reduce the amount of transpiration to a very low value.

In order to realize the extreme danger to which plants are exposed from dryness, one needs only to remember how often harvests in great part fail from the effects of drought. This may mean that the entire plants have been killed, or only that they have not borne much fruit or seed, or that the roots, stems, or leaves are stunted. Many wild plants are as sensitive to prolonged drought as are ordinary field crops, and irrigation of a desert region which has a rich soil helps the growth of weeds as much as it does that of the crops among which they spring up.

444. Means of limiting transpiration. Some of the principal means of limiting transpiration are as follows[1]:

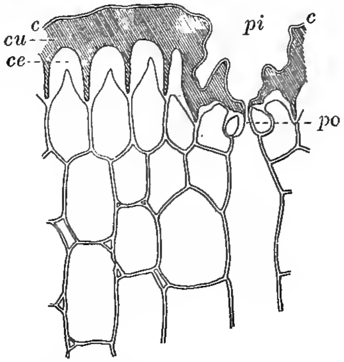

Fig. 364. Waterproof epidermis and protected stoma of the century plant

c, cuticle; *cu*, cutinized (waterproofed) layer of epidermis; *ce*, cellulose layer of epidermis; *pi*, pit, at the bottom of which the stoma is situated; *po*, pore of the stoma. Magnified about 220 diameters. After Luerssen

(1) Compact arrangement of the parenchyma cells in the interior of the leaf.

(2) Development of a thick-walled epidermis (Figs. 249 and 364).

(3) Situation of the stomata in pits or furrows (Figs. 249 and 364).

(4) Inclosing the stomata in a sort of tubular cavity formed by the curving-in of the margins of the leaf (Fig. 363).

(5) Presence of a coating of dead hairs, filled with air, on one or both surfaces of the leaf (Fig. 57).

(6) Temporary reduction of the evaporating surface, as by rolling up leaves (Fig. 2), shedding leaves, reduction of living parts to a buried root, bulb, tuber, rootstock, or some combination of thickened roots and underground stems.

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[1] The subject is a very extensive one, fully treated in the writings of Warming, Schimper, Goebel, Volkens, and other ecologists.

(7) Reduction of leaf surface, as in the case of needle-shaped (Fig. 248), scale-like, or other small, narrow kinds of leaf.

(8) Partial or complete absence of useful leaves, as in the "switch plants," such as *Spartium*, *Casuarina* (Fig. 365), and so on; and in asparagus, the cacti (Fig. 65), and some euphorbias (Fig. 366).

FIG. 365. *Casuarina*, an Australian switch plant destitute of foliage leaves and depending on the chlorophyll-containing cells of the bark for photosynthesis

Photograph by Robert Cameron

445. Discussion of xerophytic characters. The first four kinds of characters operate, as may be readily understood, greatly to limit the loss of water. Closely packed parenchyma cells in the leaf interior, with few air spaces, give little opportunity for the water in the interior cells to escape into the internal atmosphere of the leaf and so gradually pass off into the air. When the epidermis is thick, especially if it is covered with a heavy, waterproof *cutinized* layer (*cu*, Fig. 364), transpiration when the stomata are closed is very scanty. Stomata situated at the bottoms of microscopic pits or furrows are much protected from drafts of air and therefore give off vapor slowly. And when the stomata-bearing leaf surface, as in the crowberry (Fig. 363), forms the interior of a nearly closed tube, transpiration is still more hindered.

Hairy leaves (5) are characteristic of plants of dry climates, as the Mediterranean region, and of dry exposed areas like

Fig. 366. Part of a euphorbia stem, the branches showing considerable resemblance to those of some cacti

the higher portions of the great Western plains in this country. Generally the hairs are relatively simple in their structure and do not completely cover the surface. But in many instances the hairs assume shield-like or other flattened forms, and they may overlap so as more than to cover the surface on which they occur most abundantly (usually the lower one, Fig. 57, *A*). The same species or individual sometimes becomes more hairy when subjected to a drier atmosphere. Experiments show that shearing off the hairs from the surface of the living leaf increases the loss of water by transpiration, sometimes even doubling its amount.

Rolled-up leaves (6) are familiar in the case of corn (Fig. 2). It would not be easy to perform a field experiment to prove exactly how much the loss of water is lessened in the rolled corn leaves, but it would seem that the surfaces are considerably less freely exposed to the air in the rolled condition than when the blades are flat, and free exposure is a well-known factor in increasing transpiration. In some xerophytic grasses there is a complicated arrangement of folds in the leaves by means of which they can close up the transpiring surface (almost as in Fig. 363) or open it completely to the air.

Shedding the leaves (6) is the principal means by which our deciduous trees and shrubs escape the dangers of dry winter weather when no moisture can be absorbed from the ground. It has been found that the larch (which sheds its leaves) is more resistant to such conditions than are most of the evergreen conifers. Some shrubs retain or shed their leaves in a rainless summer according to the amount of soil moisture with which they are supplied. The *Euphorbia splendens* (Fig. 292, *A*) is a commonly cultivated plant which well illustrates this capacity to adjust the amount of leaf surface to a varying moisture supply.

Plants with bulbs (6) are notably common in regions where there is a long rainless summer. To a botanist one of the most interesting sights of the Mediterranean coast region is the sudden blooming of many bulb-bearing plants toward the close of the summer. Most conspicuous of these is a member of the Lily family, *Urginea Scilla*, which sends up its stout flower stalk, almost as tall as a man, out of the earth baked hard by two or more months of hot weather almost without rain. Since there are no living leaves at the base of the flower stalk it has the curious appearance of a blooming stem stuck upright in dry earth.

Absolutely leafless plants (8) are not very numerous, but there are plants, like the common asparagus and most cacti, which have very small and short-lived leaves that are often nearly or quite functionless. In the common garden asparagus these may be seen as triangular scales on the fleshy shoots sent up in early spring. The green, bristle-like growths on the main branches of asparagus plants throughout the summer perform the offices of leaves but are stem-like in their origin. In the cacti the leaves often appear as awl-shaped, or rather stout, bristle-like organs, borne at the nodes, which soon wither and fall. In such plants the photosynthetic work all the year round is done by chlorophyll-bearing cells close under the epidermis of the stem. In some switch plants a crop of small leaves, borne only during two or three months of early spring, perform active photosynthesis while they last.

446. Characteristics of mesophytes. Since mesophytes do not live under such conditions as frequently to run the risk either of drowning or of drying up, they do not, as a rule, show extraordinary modifications of structure, such as would enable them to carry on exchange of gases under water or to prevent excessive transpiration in dangerously dry air. A large part of what has been said in the preceding chapters about the structure and functions of seed plants has had reference to mesophytes, — the average plants, — and it is therefore unnecessary in this place to go into details in regard to their characteristics. In many respects these are midway between the characteristics of water plants and those of extreme xerophytes. In order to fix his knowledge of the subject, the student, after doing what laboratory and field work he can upon the ecological groups discussed in Sects. 440–446, should summarize his impressions by comparing three or more plants, each typical of one of the groups, in tabular form somewhat as follows:

	A rooted hydrophyte (water milfoil or mare's-tail [1])	A mesophyte (the common bean [1])	A xerophyte (the houseleek [1])
Root system			
General form of stem			
Relative amount of development of wood cells in stem			
Relative development of vessels in stem			
Development of air passages in stem			
General form of leaves			
Water storage in leaves			
Epidermis and cuticle			
Stomata			
Length of time plants can remain alive in air of room with roots in soil that is not watered			

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[1] These plants are merely suggested. Pondweed (*Potamogeton*), water weed (*Elodea*), or one of the species of *Ranunculus* with submerged, dissected leaves, will answer well as representative aquatics. There are hundreds of mesophytes from which to choose. Century plants (*Agave*), cacti, aloes, or echeverias are good examples of xerophytes.

Make a list of all the aquatic seed plants that you know, of some of the principal marsh plants, of several herbaceous and several woody mesophytes, of all the xerophytes you know, — the xerophytes arranged somewhat in the order of their capacity to resist drought conditions.

447. Ecological groups based on light relations. Plants which prepare their food by photosynthesis evidently need light as much as they do air or water; but there is great diversity in their demands as regards intensity of light. The practical forester soon becomes familiar with this fact, and the gardener and floriculturist know that while some plants, such as tulips, poppies, verbenas, and most composites, need all the sun they can get, other plants, as most ferns, lilies of the valley, spiderworts, many violets, many genera of the Parsley family and the Heath family, grow best in partial shade.

Fig. 367. Spanish moss (*Tillandsia*) growing on branches of a tree

Much reduced. Photograph by S. M. Tracy

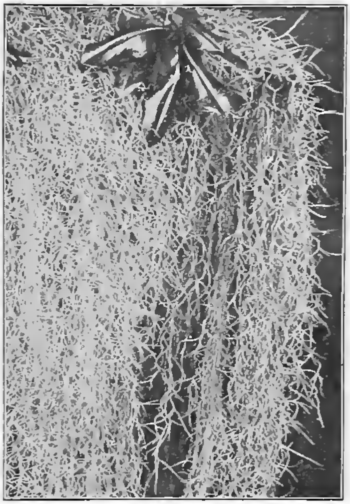

Fig. 368. Tufts of Spanish moss, with leaves of the magnolia on which it grew

Reduced. Photograph by Florida Agricultural Experiment Station

The various strata or stories of vegetation in a forest are usually arranged somewhat in the order of their light requirements, the plants most tolerant of shade at the bottom and the most intolerant species at the top. Thus in an open forest composed mainly of white pines mixed with a few other conifers and some deciduous trees, in New England, we may find some such assemblage as this: close to the ground various species of mosses, the most conspicuous being the pigeon-wheat moss (*Polytrichum*). Rising but little above the mosses are one or two species of "ground pine," or "Christmas evergreen" (*Lycopodium*, Fig. 245). Mingled with these are many herbaceous species, or very small undershrubs representing the seed plants, all shade-loving species, such as rattlesnake plantain,[1] "wild lily of the valley,"[2] chickweed, wintergreen,[3] common wood sorrel,[4] prince's pine,[5] shinleaf,[6] partridge berry,[7] and rattlesnake-weed.[8] Above these, if the woods are young, grow such larger shrubs and small trees as Juneberry,[9] blueberry,[10] and gray birch.[11] Mixed with these are young spruces and perhaps hemlocks. Only

FIG. 369. An air plant (*Tillandsia*) of the Pineapple family

Living as an epiphyte, but having numerous roots, it is intermediate in habit between the common pineapple (Fig. 283), which grows rooted in the earth, and the Spanish moss (Fig. 368), which is rootless and hangs suspended from the bark of trees. Photograph by Robert Cameron

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[1] *Goodyera.* [2] *Maianthemum.* [3] *Trientalis.* [4] *Oxalis Acetosella.* [5] *Chimaphila.* [6] *Pyrola.* [7] *Mitchella.* [8] *Hieracium.* [9] *Amelanchier.* [10] *Vaccinium vacillans.* [11] *Betula populifolia.*

the tall pines which overtop all the other trees receive the sunlight in its full intensity; under the densest shade of the pines the illumination, compared with that of the unshaded tree tops, may be only one fiftieth or less.[1]

In a forest the number and character of the strata of vegetation depend largely upon the kinds and density of the trees that compose the uppermost stratum. In an average deciduous forest such as is often found throughout the Central States the uppermost stratum consists of trees such as oaks, maple, beech, elm, hickory, and tulip (Fig. 319). In some regions one finds an almost pure beech or maple forest. The oak-maple or oak-maple-beech combination is not uncommon. If these trees grow closely crowded, the shade underneath is very dense and few shorter trees or shrubs are found. When the forest is more open a second stratum of young trees and tall shrubs is found. This stratum, in addition to the young trees, may contain the bladderwort (*Staphylea*), the hop hornbeam (*Ostrya*), the ironwood (*Carpinus*), and many others. There may be a stratum of lower shrubs immediately below the tall-shrub stratum, and this lower-shrub stratum often is characterized by the blackberry, raspberry, and the greenbrier or cat claw. The next stratum usually is characterized by many tall ferns and many kinds of flowering plants that thrive in deep shade. Below the ferns and upon the soil or decaying vegetation is the lowest stratum, which may include many kinds of toadstools and mushrooms and other fungi, mosses of many kinds, occasionally some of the leafy liverworts, and some of the soil lichens. In some forests in which there are but few strata of vegetation, during the greater part of the growing season the tall trees constitute almost the entire conspicuous flora. In early spring, however, such forests usually have a low stratum of early-flowering plants (spring beauty, bloodroot, dogtooth violet or deer's-tongue, Dutchman's-breeches, etc.), which for a brief period carpet the forest floor. These

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[1] In the pine forests of the Tyrol, Wiesner found the illumination in entire shade only one sixtieth to one ninetieth of full sunlight.

plants flower at the expense of food material that was deposited in former seasons (Sects. 34 and 69), and do most of their vegetative work before the leaves of the trees are developed so as to shade them. As the season advances and the light intensity increases, these low plants may still work by means of the diffuse light that is filtered through the tree tops.

Any local forested area will afford students interesting studies in the strata of forest vegetation.

448. Fractional part of total sunlight required by various plants.[1] The proportion of the full strength of sunlight required by any given species is not the same in different latitudes; for example, the common dandelion at Vienna (lat. 48.12°) may grow in an illumination of one twelfth, but in northern Norway (lat. 70.33°) the total light of the sun is needed to enable it to grow.

The same individual often requires different amounts of light during different stages of its development. The English ivy (*Hedera*) will not bloom with a light intensity less than two ninths of total daylight, and therefore flowers are never seen on ivies grown as house plants. But the vegetative organs continue to grow with an illumination as low as one forty-eighth.

Among the seed plants which can flourish in deep shade are many species of epiphytes and lianas. Good examples of the former are many tropical orchids; of the latter, one of the most familiar is the common frost grape (*Vitis cordifolia*), which can grow with an illumination as low as one seventieth. On the other hand, plants which live in the open and comparatively unshaded, like all the larger prairie species, such as many kinds of *Liatris*, *Coreopsis*, sunflowers, rosinweeds, some ironweeds and wormwoods, require high illuminations to thrive.

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[1] See Wiesner, Der Lichtgenuss der Pflanzen (Engelmann, Leipzig). Great caution must be used in drawing conclusions on this head, since lack of soil water and salts may easily be responsible for part of the effects attributed to scanty light supply.

449. Practical applications of the knowledge of light requirements. A few words have already been said (Sect. 370) about the importance of recognizing the difference in the light requirement of trees. The farmer and the horticulturist often have need of considering the light requirements of cultivated plants. It is not infrequently desirable to grow some kind of crop in partial shade, as in a young orchard. In such situations some of the plants which bear small fruits, as raspberries, blackberries,[1] and strawberries, will succeed fairly well. So also will common beans and broad or horse beans. Pumpkins and squashes grow well in cornfields. A good many useful grasses are tolerant of shade, and mixtures of grass seed suitable for lawns under shade trees are sold by the principal seedsmen. Some of the grasses of more or less value for pasture or hay, which grow in moderate shade, are Kentucky blue grass,[2] Canada blue grass,[3] orchard grass,[4] rough-stalked meadow grass,[5] wood meadow grass,[6] crested dog's-tail,[7] and sheep's fescue.[8]

Some crops, as sugar beets, are of inferior quality when grown in partial shade. In Austria-Hungary the beets grown in the sun were found by one observer to average rather more than three times the weight of those grown in the shade. Add to this the fact that the sun-grown beets contained about $1\frac{1}{3}$ per cent more sugar than the shade-grown ones, and the importance of full sunlight for the sugar-beet crop becomes very apparent. Certain crops depend for complete success upon a long series of days of the most brilliant sunshine.

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[1] The amount of shade which can be tolerated by plants of the same genus, natives of the same region, often differs widely. The black raspberry (*Rubus occidentalis*) has been found to flower freely but to mature hardly any fruit in a situation where the bushes were so shaded that during the earlier half of the day they received but one twelfth to one fifteenth of the total sunlight, although they had full sunlight during most of the afternoon. Mixed with these bushes were blackberries (perhaps a cultivated form of *R. allegheniensis*) which flowered and fruited abundantly.

[2] *Poa pratensis.* [3] *Poa compressa.* [4] *Dactylis glomerata.* [5] *Poa trivialis.* [6] *Poa nemoralis.* [7] *Cynosurus cristatus.* [8] *Festuca ovina.*

Corn is one of the most important of these crops, and the supremacy of the corn belt in the United States is perhaps as much due to the amount and intensity of its sunshine during the summer months as to its admirable soil.[1]

In planting many kinds of crops (corn among others), attention should be given to allowing light to enter freely between the plants; otherwise the quantity and quality of the product from the field will suffer. Fruit trees should be pruned so that the lower limbs will not be prevented from developing by the shade, and should be planted far enough apart to prevent injury to the entire tree from the same cause. The intensity of sunlight in an orchard region has much to do with the amount of pruning necessary to make apple trees bear well-developed and ripened fruit. In the northeastern states the tops of the trees should be thinned out to not more than half the thickness allowable in the Middle West. The high color of apples from Colorado and other regions of intense sunlight is due to this abundant light supply, which brings about the coloration even in trees with dense tops.

450. Plant distribution.[2] The subject of the distribution of plants on the earth's surface was at first discussed almost wholly as a group of geographical facts. While travelers for thousands of years have known something of the diversity of the vegetation of the earth, it is only recently that careful attention has been given to the factors which determine the kinds of plant inhabitants of any given region.

The vegetation of any portion of the earth is usually considered either from the *floristic* or the *ecological* point of view. In the former case the student takes into account mainly the kinds of plants — that is, the species, genera, families, and

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[1] See Warren, Elements of Agriculture, chap. vii. The Macmillan Company, New York.

[2] Within the limits of a chapter like the present one this subject can only be touched upon. Much information can be found in the larger physical geographies, in Schimper's Plant Geography on a Physiological Basis (see p. 477), and in the popular writings of naturalists like Humboldt, Darwin, J. D. Hooker, Wallace, Belt, Bates, Hudson, and others.

higher groups — with which the region is covered. In the latter case the student considers mainly the ecological groups which are present; that is, whether the plants are water or land forms, and in regard to the land plants whether they are xerophytes or mesophytes. In studying plant distribution from the floristic side a very important topic is the consideration of the history of the flora. This deals, for instance, with such questions as the investigation of the center or centers from which the plants were derived, the course which they took in migrating outward from those centers, and the time required to cover the territory which they now occupy.

451. Ecological plant geography. For most purposes the ecological characters of the principal floras of the earth are more important than their systematic relations; that is, we are especially concerned to know that arctic vegetation is scanty and of dwarf forms, that vast grassy meadows and prairies and extensive hard-wood forests, often of few species, are characteristic of temperate regions, and that tropical forests (in the rainy areas) are extremely dense, interwoven with lianas, and burdened with epiphytes. Such facts are of more general interest than the knowledge of the proportion of the floras of the different zones constituted by each family represented.

The most important unit for beginners in ecological plant geography to consider is the *association*.[1] In order to see what this term means it will be necessary to recall some of the things which most observing people already know without having studied botany. In a pond like that shown in Fig. 358 one is likely to find white pond lilies, yellow pond lilies, pickerel weed, arrowhead, pondweed (*Potamogeton*), water smartweeds, rushes, and perhaps a good many other flowering plants. Besides these there may be dozens of species of blue-green

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[1] The *plant formation* is a larger unit, made up of associations. Formations may consist of many families, genera, and species, but must comprise such vegetation forms as are able to thrive in the habitat where the formation occurs.

and green algae. Coniferous or hard-wood forests (Sect. 446) contain varied assemblages of herbs, shrubs, and trees. The plant life of the pond and that of the forest are good examples of associations. *A plant association is a set of plants, usually consisting of several genera (perhaps comprising many species), of somewhat similar aspect, living together under essentially similar conditions.* It is important to notice that even a small area may contain several associations. For instance, a rocky ledge in a meadow may have an entirely different plant population from that of the meadow around it. The aspect of an association depends largely upon the kind of vegetation forms (hydrophytes, mesophytes, or xerophytes) which the station can support. It is also influenced by other circumstances, such as, in the case of aquatics, whether the plants are wholly or only partially submerged; in the case of land plants, whether trees, shrubs, or herbs predominate.

FIG. 370. A flowerless xerophyte (the lichen *Usnea*) growing on conifers in the Maine woods

452. What determines the occurrence of vegetation forms. The ecological type of the plants which inhabit any kind of habitat depends usually on its soil (in the case of aquatics, the water), its climate, or both. If we find a region with decidedly xerophytic vegetation, this fact may be due to any one of several causes, as follows:

FIG. 371. Mangroves, halophytes with aërial roots

The young seedlings are rooting in the beach sand and the thicket is gradually pushing out toward the sea

(1) A climate with very little annual rainfall.

(2) A climate with considerable rainfall during the year but with long rainless periods.

(3) A soil or other root foothold which does not retain water, such as dry sand, bare rock surfaces, or the bark of trees.

(4) A soil which contains a good deal of water, but is *physiologically dry*,—that is, does not yield water freely for absorption by the roots.

As regards (1) and (2), it is easy to see that regions like some of the Arizona deserts, with only about a half inch of rain during the entire year, can hardly support any perennial seed plants other than extreme xerophytes. Countries like those which border portions of the Mediterranean, with a total rainfall for the year of 30 to 40 inches, but one which for four months of summer sometimes falls as low as one half inch, with a maximum daily summer temperature in the sun of 130° F. and an intensely dry atmosphere, are better suited to support xerophytes than mesophytes.

A plant under the conditions mentioned in (3) may be deluged by violent rains during much of the year and yet in a few hours after each rain be wholly cut off from any water supply. Most lichens (Figs. 190–193 and 370) and many tropical epiphytic seed plants (Fig. 20), as well as our own Spanish moss (Figs. 367 and 368), live under such conditions as these.

It is difficult at first sight to recognize what is meant by physiologically dry soils, such as are mentioned in (4). Ordinarily water cannot be absorbed from soils below a certain temperature, which varies in different kinds of plants. Hence soils in a frozen or nearly frozen condition are physiologically dry, although much water may be present in the form of ice. Soils (or waters) containing much of the humous acids derived from decaying vegetation are perhaps not physiologically dry, but the acids which they contain are injurious to most plants and it is necessary that species which are found in such situations shall be able to live without absorbing much water. Hence many marsh plants, rooted in very wet mud, have xerophytic leaves. Finally, soils containing much saline matter[1] are

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[1] As common salt, magnesium chloride, sodium carbonate, sodium sulphate, magnesium sulphate, or mixtures of these salts.

physiologically dry. On such soils the vegetation is composed of *halophytes*, or plants which tolerate a larger proportion of mineral salts in the soil than can be endured by most plants.[1] One of the best-known halophytes is the common garden asparagus, which sometimes has its growth increased by the addition of common salt to the soil in which it is growing.

FIG. 372. Plants taking possession of recently formed islands in a river

Along the bank at the right are three zones of woody plants

In many points of form and structure halophytes usually resemble ordinary xerophytes, and many of them are fleshy-stemmed or fleshy-leaved. Such plants abound in the salt marshes of the Atlantic coast and in some of the "alkali" tracts of the extreme Southwest.

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[1] For example, young seedlings of the saltwort (*Salsola Kali*, var. *tenuifolia*), a typical halophyte, live longer in a 5.5 per cent solution of common salt than most herbaceous mesophytes can in a 1.5 per cent solution. In other words, the tolerance of *Salsola* for common salt is at least four times as great as that of most herbs.

453. Competition and emigration. A little has already been said (Sect. 137) about the severe competition among plants, which often allows only one seed among many thousands to grow into a new plant. This competition frequently tends to cause plants to flourish better in new territory. Other white pines would find it almost impossible to grow up from the seed under adult trees like those of Fig. 321, but seeds blown into neighboring clearings (Fig. 322) or among young birches or other deciduous trees (Fig. 323) may promptly begin their growth into forest trees. In this way there is a constant invasion of neighboring species into any territory not already occupied by those species or by others which they cannot crowd out of the way. A newly formed island in a river (Fig. 372), the recently drained bed of a lake or a bayou, is promptly populated by the plants which crowd in from adjacent territory. The newcomers may arrive as seeds, or as cuttings,

FIG. 373. A wooded river bank invaded by a moving sand dune

In the foreground a young cottonwood is being covered by sand pieces of rootstocks, or even as entire plants washed down by the stream. Such immigration among plants is in accordance with the principle known as *following the line of least resistance;* that is, immigration occurs whenever and wherever a more densely populated area is in contact with one less densely populated, or when a set of plants of superior qualifications to occupy a given territory comes into contact with a set less well qualified.

454. Plants able to meet the conditions of their environment; exceptions. A little observation and reading is enough to convince the student that the plants of a region usually meet fairly well the requirements of its soil and climate. That is to say, wild plants occur where they do, largely because of the fact that when they migrated into the area which they now occupy they were well equipped to contend with other plants and hold their own in this environment; or because, after immigrating, they developed characteristics which enabled them to succeed. If a considerable piece of land with its flora could be transplanted bodily from the arctic regions to the most fertile part of the tropics, its vegetation would be promptly destroyed by the new climatic conditions or by the luxuriant growth which would invade it from every side. On the other hand, if a piece of ground covered with tropical vegetation were carried into arctic winter conditions, its plant life would perish of cold in a few hours.

Exceptions to the rule that plants are found growing in the places that suit them fairly well are not uncommon. A little has already been said (Sect. 434) about the extraordinary way in which some plants multiply on first being brought into territory new to them. Some of the most noteworthy instances of displacement of native plants by foreign species have occurred in New Zealand. There many large, robust plants, some of them very spiny and growing in masses impenetrable by cattle, have been replaced by European grasses and clovers. The sweetbrier destroys pastures and also drives out native shrubs; and the black locust, with its rapid growth and numerous suckers from the roots, quickly gets a footing and holds its ground to the exclusion of most other vegetation. In 1855 only 44 species of foreign plants had become naturalized in New Zealand, while in 1895 the number had increased to 500 or more. Evidently the newcomers have qualifications which enable them to succeed better than many native plants.[1]

Botanists are coming to recognize more clearly than ever before that multitudes of plants grow under conditions which are really unfavorable for them. It is thought that they do so, occurring in abundance in uncongenial stations and infrequently amid better surroundings, because the unfavorable conditions are so severe as largely to exclude the competition of other plants. For example, knotgrass,[2] knawel,[3] milk purslane,[4] and cudweed[5] do not grow in much-trodden paths because they are benefited by being trampled and by having to root themselves in hard soil, but because in such paths they are not crowded and so overshadowed by taller weeds. Seed plants which usually grow on nearly bare rocks, as on cliff sides, generally flourish better (with an equally favorable light supply) in richer and moister soil. Desert plants, as many cacti, often grow more luxuriantly under conditions of soil and climate such as suit ordinary mesophytes. The common groundsel,[6] which abounds on the clean sand of some Mediterranean beaches, blossoming and seeding with an unbranched stem only about an inch high, in fertile, fairly moist soil may grow to a height of 18 inches.

It is not safe to assume of any species that the territory or station in which it most commonly grows is the best adapted to its needs. Such a statement could only be made with assurance

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[1] On the subject of the spread of species introduced into new territory see Darwin, Origin of Species, chap. iii; Gray, essay on "The Pertinacity and Predominance of Weeds," in Scientific Papers of Asa Gray, edited by Sargent (Houghton Mifflin Company, Boston, 1889); also weed reports of the state agricultural experiment stations and of the United States Department of Agriculture.

[2] *Polygonum aviculare.* [3] *Scleranthus annuus.* [4] *Euphorbia maculata.* [5] *Gnaphalium uliginosum.* [6] *Senecio vulgaris.*

after careful endeavors to introduce the plant into all the kinds of environment in which it might have a fair chance of success. The student will find it most instructive to watch for instances of the occurrence of roadside weeds, such as knotgrass, wild peppergrass, Indian chickweed, and dog fennel, in deep, rich ground, or to plant these and similar tramp plants in good soil and observe how they succeed.

455. Plant geography of the United States. Briefly stated, the four great vegetation areas of the continuous territory of the United States[1] may be designated as follows:

(1) *The eastern and central forest region*, occupying the eastern and central portions of the country. It extends westward to an irregular boundary line, lying mostly to the east of the hundredth meridian. The easternmost portions of this boundary run considerably east of the Mississippi River, while the westernmost extend at least 500 miles west of the river.

(2) *The Plains region*, stretching westward from the forest region to the Rocky Mountain plateau.

(3) *The Rocky Mountain region*, including the Rocky Mountains, the Sierra Nevada, and the plateaus between them.

(4) *The Pacific slope*, extending from the Cascade Range and the Sierra Nevada to the Pacific coast.

It must be understood that the same species of plant may occur in several or even in all of these regions.

Compare the temperature requirements of the white pine and bald cypress (as far as shown by the maps on page 504).

Do the ranges of the two anywhere overlap? If so, where?

Consult Fig. 380 and compare the moisture requirements of the two trees (as far as shown by the maps).

Which species avoids the Appalachian highlands? What two reasons may be given for this?

In using the maps shown in Figs. 374 and 375 it should be kept in mind that they are not drawn to exactly the same scale.

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[1] That is, excluding Alaska, Porto Rico, the Hawaiian Islands, and the Philippines.

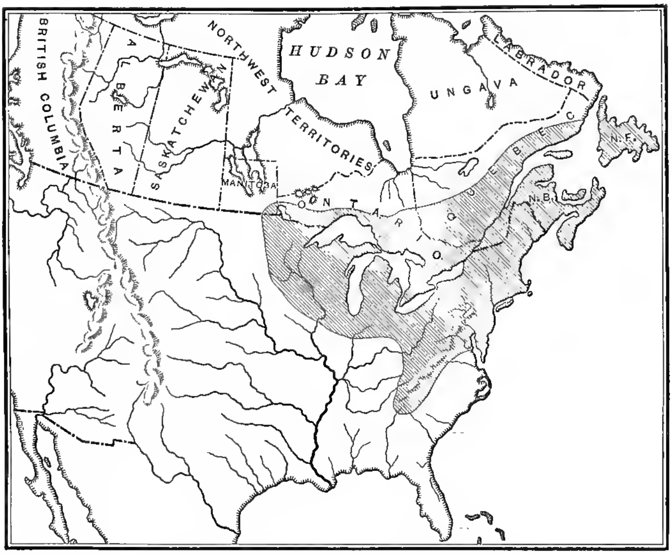

FIG. 374. Map of distribution of white pine

Modified after R. B. Hough. "Handbook of the Trees of the Northern States and Canada"

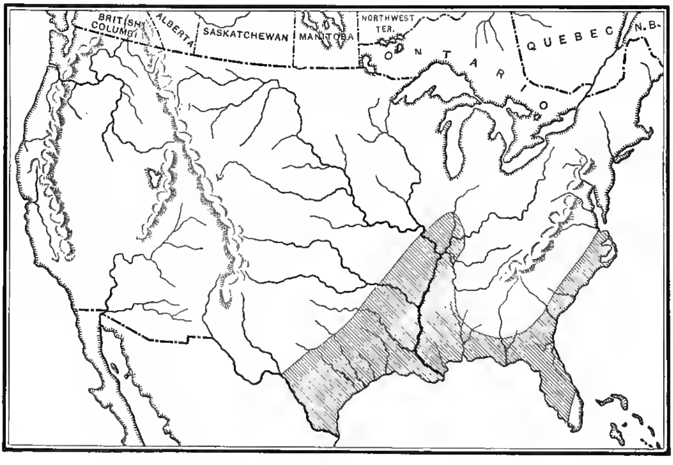

FIG. 375. Map of distribution of bald cypress

Modified after R. B. Hough

456. The eastern and central forest region. This region contains more species of useful hard woods than any similar area within the temperate zones. The oaks are the leading timber trees, but others, as the hickory, the tulip tree, and the sassafras, are of especial interest to botanists as characteristic American species. The northeasterly part of the forest region, while it contains many hard-wood genera, such as beeches, elms, and maples, is notable for its conifers. Chief among these are the pines (Fig. 321), spruces, hemlocks, and white cedars (*Thuja*). In the southerly part are several species of conifers, such as bald cypress (Fig. 19) and long-leaf pine (Fig. 260), together with such hard woods as walnuts, hickories, beeches, chestnuts, oaks, elms, magnolias, sycamores, and ashes. These are deciduous mesophytes, but there are some water-loving trees, such as the water hickory, the sweet bay, and the anise tree, in the moister parts of the South, which may fairly be ranked as hydrophytes. Some trees, as the bald cypress, may grow either as hydrophytes or mesophytes.

The forest region has always contained extensive treeless areas. The earliest settlers found "openings" in the hard-wood forests, and extensive prairies, marshes, and heaths, all nearly or quite destitute of trees. Of course the tendency under cultivation has been greatly to decrease the tree-covered area, and it is now very unusual to find bits of primeval forest like those shown in Figs. 319 and 320.

Since the forest region extends more than 1500 miles north and south, it contains plants ranging all the way from sub-arctic species, such as the dwarf herbaceous willow, saxifrages, and crowberry, to sub-tropical ones, such as palms and mahoganies.

457. The Plains region. The prairies of the Middle West merge imperceptibly into the Great Plains, which terminate, at an elevation of 5000 feet or more, in the beginnings of the Rocky Mountain system. The prairies of western Kansas, western Iowa, Minnesota, Nebraska, and South Dakota have less than 20 per cent of wooded surface, and the high plains are bare of trees except where they have been planted or occur naturally in belts along the streams. Some of the principal reasons that have been given for the treeless condition of the prairies and the plains are the frequency with which prairie fires were set by the Indians, the scanty rainfall, and the destructive effect of violent dry winter winds, acting on the trees when they can get no water from the frozen soil. Excessive evaporation, due to exposure to high winds at all seasons, seems to be a cause of prairies. Such winds are particularly fatal to seedling trees which are not yet deeply rooted. Large areas also have never been reforested since their vegetation was swept away by great geological changes in the Mississippi Basin.[1]

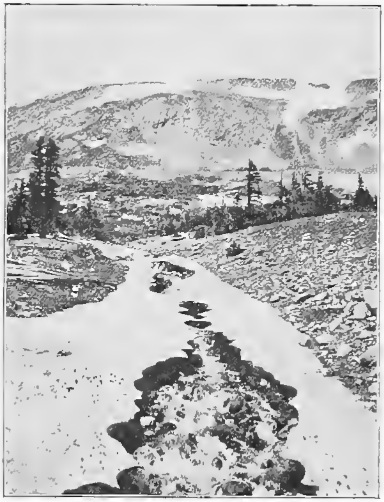
FIG. 376. Occurrence of trees above the ordinary timber line, in sheltered valleys and ravines, Rocky Mountains

The prairies in their natural condition were rather closely covered by coarse grasses, forming a very tough sod. This, when turned over by the breaking plow, was firm and durable enough to be used by the early settlers for the walls of sod houses. Among the prairie grasses are found several plants of the Pea family, such as the lead plant or shoe strings,[2] prairie clover,[3] ground plum,[4] and some others. Composites are very abundant and characteristic, among them being goldenrods and asters, the blazing star,[5] the cone flower,[6] and several species of tickseed.[7] Some sunflowers[8]

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[1] See Pound and Clements, Phytogeography of Nebraska, Vol. I, pp. 67–70.

[2] *Amorpha canescens.* [3] *Petalostemum.* [4] *Astragalus.* [5] *Liatris.* [6] *Rudbeckia.* [7] *Coreopsis.* [8] *Helianthus.*

and rosinweeds[1] are among our largest herbaceous prairie plants, reaching a height of ten or more feet and forming a striking feature in most prairie landscapes in late summer and autumn.

In their eastern portion the treeless areas of the high plains are largely covered by close mats of short xerophytic grasses known as buffalo grass[2] and grama grass.[3] Some prickly-pear cacti,[4] milkweeds,[5] and thistles[6] are also found. In early July the grasses dry up, and then hardly any vegetation remains alive aboveground except the succulent cacti.

The western portion of the high treeless plains is the beginning of the foothill region, of high, rather barren table-lands, extending from Montana to New Mexico inclusive, with an altitude in many portions of 5000 feet above sea level. Among the most characteristic woody plants of the region are several wormwoods, especially the sagebrush,[7] and (in "alkali" soils) the greasewood.[8] The sagebrush (Fig. 378) is highly xerophytic, with deep roots, small leaf area, and hairy surface.

FIG. 377. One-sided growth of trees near timber line due to severe winds from one direction. Rocky Mountains

458. The Rocky Mountain region. The Rocky Mountain region includes the most diverse formations, ranging from coniferous forest to alpine meadow. Characteristic conifers are several true spruces, the Douglas spruce,[9] and a considerable

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[1] *Silphium.* [2] *Bulbilis.* [3] *Bouteloua.* [4] *Opuntia.* [5] *Asclepias.* [6] *Cirsium.* [7] *Artemisia tridentata.* [8] *Sarcobatus vermiculatus.* [9] *Pseudotsuga.*

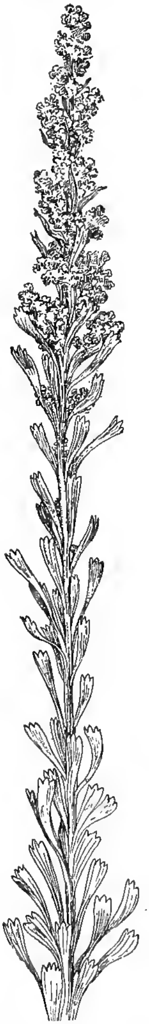

Fig. 378. A twig of sagebrush

Modified after Schimper

number of pines. The alpine flora, occurring on the mountains toward the timber line and above it, comprises many beautiful herbaceous and shrubby species. The "alkali" regions, with a highly saline soil, abound in such halophytes as the salty sage,[1] the greasewood,[2] the glasswort,[3] and the Western blite.[4] The best known of these saline areas is the Great Basin, covering an extensive area to the east of the Sierra Nevada, extending nearly to the Great Salt Lake. It is desolate, treeless, and without grass. The less saline valleys and the foothills are covered with sagebrush, while the lower and more "alkaline" valleys are tenanted by such decided halophytes as those just named.

In the southern part of the region of the Rocky Mountain system and to the southwest are found some of the principal deserts of the United States, such as the Mohave Desert, the Ralston Desert, and in southern California the Colorado Desert. In some of these the temperature for long periods in the summer ranges as high as 118° F., and the total annual rainfall may be less than an inch. Extreme xerophytes, such as cacti, a few palms, and tree yuccas (Fig. 379), abound.

459. The Pacific slope. The summer and the winter climate of the Pacific coast region differ in temperature much less than do portions of the Atlantic coast in the same latitude. In the southern part of the region the most striking difference between seasons is the contrast between their amount of rainfall.

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[1] *Atriplex.*

[2] *Sarcobatus vermiculatus.*

[3] *Salicornia.*

[4] *Suæda.*

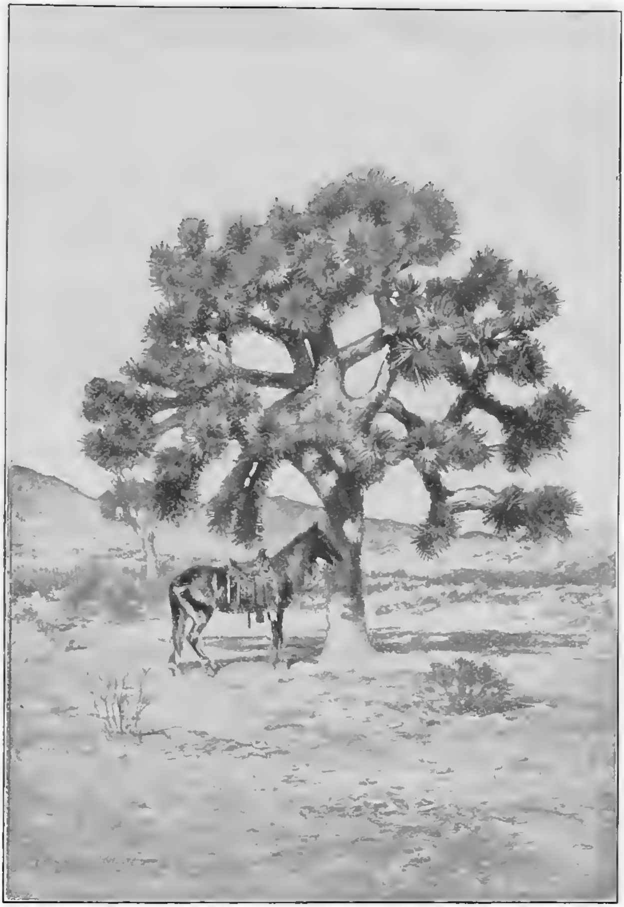

FIG. 379. Tree yucca in the Mohave Desert

Redrawn from a photograph by Coville

At Stanford University, thirty miles south of San Francisco, the rainy season usually begins in October and lasts until April. June, July, August, and September are usually rainless. At San Diego the dry season begins in April and lasts for seven months. Vegetation begins with the autumn rains

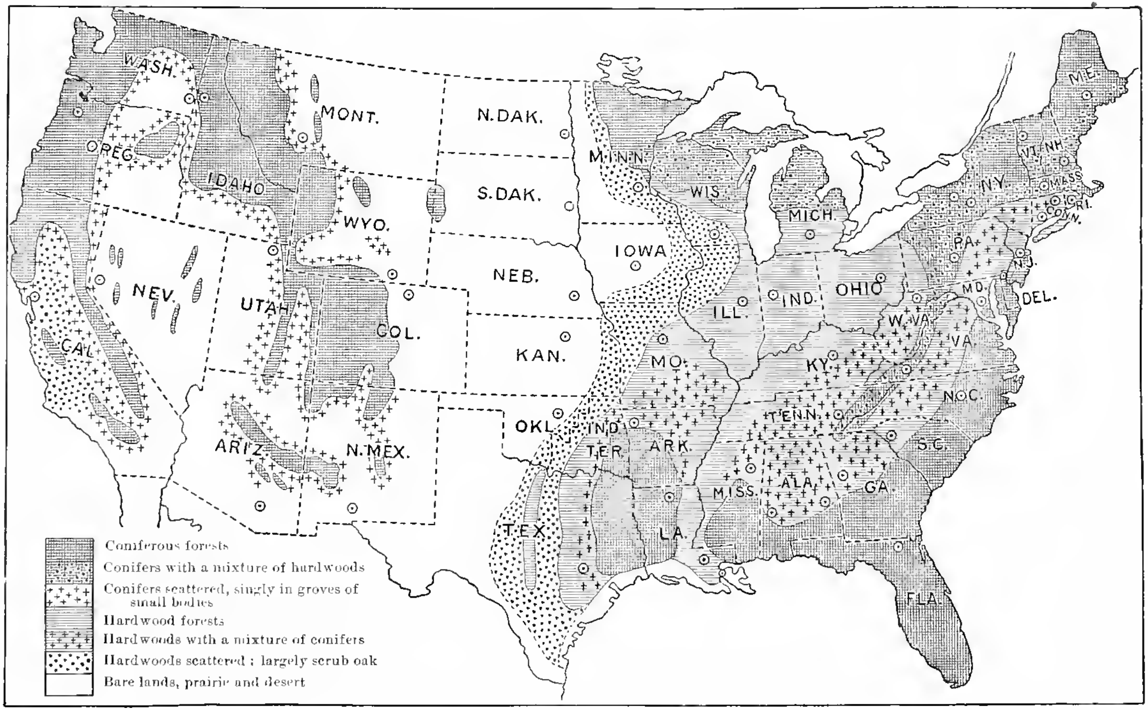

FIG. 380. General forest map of the United States. (After Roth, "First Book of Forestry")

and is merely accelerated by the coming of warm weather in the spring. Most herbaceous plants cease to grow soon after the summer drought has set in, so that the face of the country is parched and in places seems almost lifeless.

The northern portion of the Pacific slope, through the states of Washington and Oregon, is divided by the Cascade Mountains into a comparatively moist western region and a much drier (sometimes semi-desert) eastern region. This is due to the fact that the Cascade Range, running in a general north-and-south direction, causes the precipitation, in the form of rain or snow, of most of the moisture brought from the Pacific by the southwest winds. These mountains are heavily timbered, especially along their western slope, and the dense forests abound in such valuable coniferous trees as the western white pine,[1] several species of true fir,[2] and the western hemlock.[3] West of the Cascades three of the principal

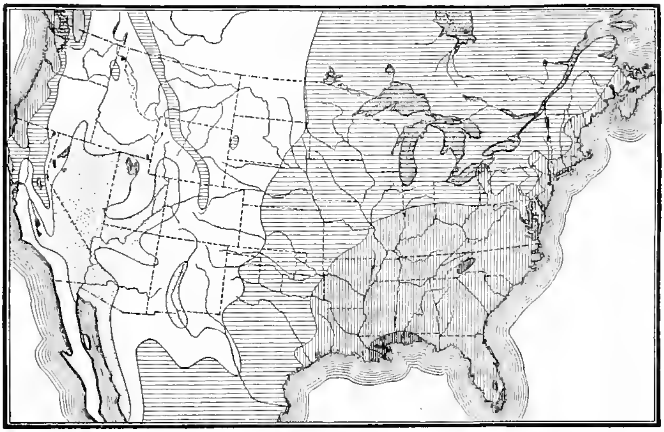

FIG. 381. Annual rainfall of the United States

Darkest shade, over 80 inches; lighter vertical lines, from 40 inches to 80 inches; horizontal lines, from 20 inches to 40 inches; blank, from 10 inches to 20 inches; dotted, less than 10 inches. After W. M. Davis, "Physical Geography"

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[1] *Pinus monticola.*

[2] *Abies.*

[3] *Tsuga heterophylla.*

conifers are the giant cedar,[1] red fir,[2] and Sitka spruce.[3] In the bottom lands of Washington, especially along rivers, there are found, besides some conifers, groves of poplar, maple, and ash. In the wettest of these lands occur dense thickets of willows, Western cornel, crab apple, and vine maple.

Much of eastern Washington has an annual rainfall of not more than ten inches, and is generally covered with sagebrush and with other semi-desert vegetation, although the soil when irrigated is extremely fertile. Southeastern Oregon is in great part a rocky, sterile plateau of volcanic origin, with vegetation consisting largely of sagebrush, dwarf pine, and juniper.

From the forty-first to the thirty-fifth parallel (beginning a little to the south of the Oregon line) the southern portion of the Pacific slope is characterized by the California evergreen conifers, the sugar pine[4] of the coast region, the yellow pine,[5] and others. Two redwoods are notable among the mountain flora, — the smaller[6] a very important source of lumber, the larger[7] (big tree or giant redwood) the greatest and most imposing of all trees (Figs. 250 and 260).

Among the characteristic members of the California flora are many xerophytic shrubs and small trees, in appearance not unlike the abundant thickets of some parts of the Mediterranean coast region. The California thickets, known as chaparral, contain many leathery-leaved evergreen dicotyledons, among them members of the Oak, the Rose, the Sumach, the Heath, the Buckthorn, and the Composite families.

On account of the long and severe dry season, southern California abounds in deep-rooted and in bulb-bearing plants, many of the latter belonging to the Lily family; and in and about the deserts are many cacti and other succulent plants, together with numerous xerophytic shrubs which are not succulent.

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[1] *Thuja plicata.* [2] *Pseudotsuga mucronata.* [3] *Picea sitchensis.* [4] *Pinus Lambertiana.* [5] *P. ponderosa.* [6] *Sequoia sempervirens.* [7] *S. Washingtoniana.*

460. Influence of rainfall on forest distribution. Plant formations in general, and forest ones among the rest, have their boundaries determined largely by the amount and seasonal distribution of the annual rainfall of the region. A careful comparison of the forest map of the United States (Fig. 380) with the rainfall map (Fig. 381) shows that the arid and semi-arid regions are treeless. By far the greater portion of the immense area lying to the west of an irregular line extending from the Red River of the North to the junction of the Pecos with the Rio Grande, has an annual rainfall ranging from twenty inches down to almost nothing. Over this great territory there are few extensive forests except those covered with xerophytic conifers, and these occur mostly in the mountains where the rainfall is somewhat greater. Our true deserts are treeless except for scattered individuals of such extreme xerophytes as the tree yucca (Fig. 379). The Pacific slope, in its northern portion, has an annual rainfall of thirty-seven inches, and is covered with such luxuriant forests as are shown in Fig. 262. The southern portion has an average annual rainfall of ten inches, and (except on the mountains) has no considerable forests but only a scanty growth of trees and xerophytic shrubs (chaparral).

APPENDIX

INFLORESCENCE

The manner in which flowers are arranged on the floral axis or flower-bearing portion of the stem is called *inflorescence.* Sometimes the flower clusters themselves are also called inflorescences.

Each flower, like a vegetative branch, usually arises from the axil of a leaf (Fig. 1, *A*), but leaves along the floral axis are often minute, sometimes even scale-like in appearance (Fig. 1, *B*; Fig. 4, *B*). All such reduced leaves are known as *bracts,* and when they arise from branches of the main axis, as in Fig. 6, *A*, they are called *bractlets.*

There are two main types of inflorescence which are distinguished by the relative development of the main axis and of the lateral axes. In the *racemose* type of inflorescence the main axis is more strongly developed than the lateral ones and overtops them, while in the *cymose* type the lateral axes extend beyond the main one. Some of the principal kinds of flower clusters are shown in the figures which follow.

CLUSTERS OF THE RACEMOSE TYPE (INDETERMINATE INFLORESCENCE)

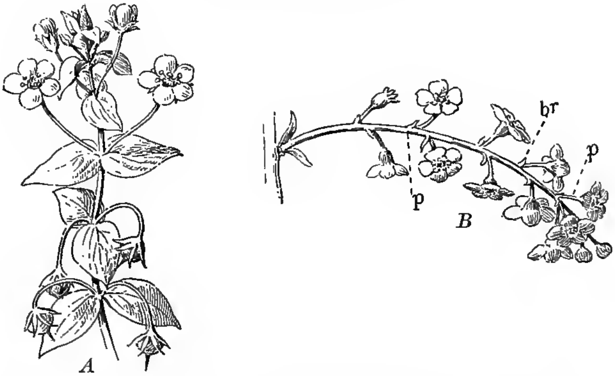

FIG. 1. *A*, axillary and solitary flowers of pimpernel; *B*, raceme of common red currant

p, peduncle; *p′*, pedicel; *br*, bract

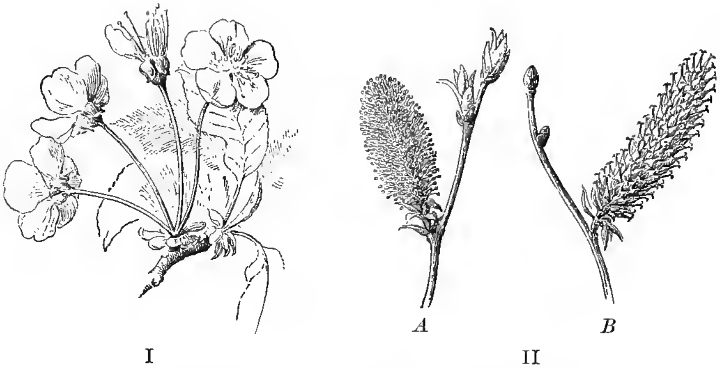

FIG. 2. I, simple umbel of cherry ; II, catkins of willow
A, staminate flowers; *B*, pistillate flowers

FIG. 3. *A*, spike of plantain ; *B*, head of red clover

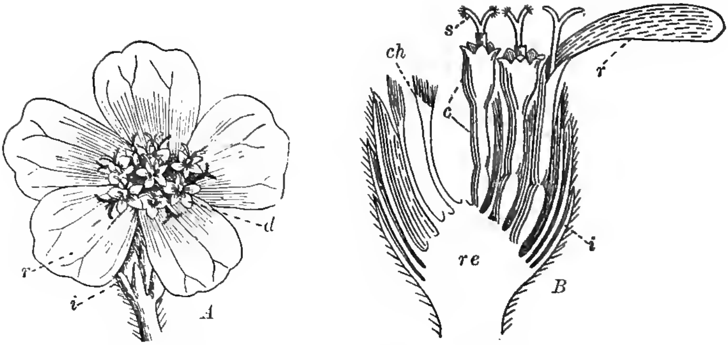

FIG. 4. Head of yarrow

A, top view (magnified); *B*, lengthwise section (magnified). *re*, receptacle; *i*, involucre; *r*, ray flowers; *d*, disk flowers; *c*, corolla; *s*, stigma; *ch*, chaff or bracts of receptacle

FIG. 5. *A*, panicle of oat; *B*, compound umbel of carrot

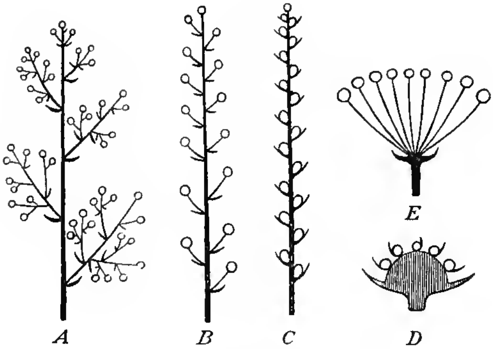

FIG. 6. Diagrams of inflorescence

A, panicle; *B*, raceme; *C*, spike; *D*, head; *E*, umbel

CLUSTERS OF THE CYMOSE TYPE (DETERMINATE INFLORESCENCE)

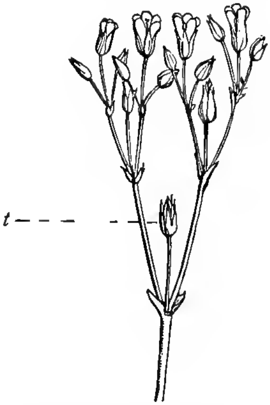

FIG. 7. Compound cyme of mouse-ear chickweed

t, the terminal (oldest) flower

SUMMARY OF PRINCIPAL KINDS OF FLOWER CLUSTERS

A. **Indeterminate inflorescence.** Order of blossoming from below upward, or from without inward

1. *Axillary flowers.* Flowers growing in the axils of ordinary leaves.
2. *Raceme.* Flowers with flower stalks, called *pedicels*, arranged along the *peduncle* or stem in the axils of special (usually pretty small) leaves called *bracts*.
3. *Corymb.* Flowers arranged as in the raceme, but with the lower pedicels so lengthened as to make the flower cluster flat or nearly so (as in the hawthorn or the yarrow).
4. *Umbel.* Flowers with pedicels of nearly equal length, all appearing to spring from a common point, like the ribs of an umbrella. An *involucre* of bracts usually surrounds the bases of the pedicels.
5. *Spike.* Flowers as in the raceme, but *sessile;* that is, without pedicels.
6. *Head.* Flowers as in the spike, but the cluster nearly globular.
7. *Panicle.* Flowers as in the raceme, but the cluster made compound by the branching of the peduncle.

B. **Determinate inflorescence.** Order of blossoming from within outward.

1. *Flower terminal.* One flower borne at the summit of the stem.
2. *Cyme.* Flowers much as in the umbel, but the innermost blossoming first.

GLOSSARY

Abortive. Imperfectly developed, as in abortive stamens.

Absorption. Act of taking in substances through the tissues.

Accessory fruits. Fruits reënforced by ripening of stem or other structures together with ordinary fruits, as in strawberry, apple, pear, quince.

Adventitious buds. Buds that spring from various parts of the root or stem, not from nodes.

Aërial roots. Roots that develop in the air.

Akene. A small, dry, one-seeded fruit in which the ovary wall adheres to the seed, as in sunflower, dandelion, and grains of common cereals.

Albuminous seeds. Seeds that, when ripe, contain endosperm.

Aleurone. Grains of definite structure containing protein food; aleurone grains are often found in a single layer of regular cells just within the seed coat.

Alternation of generations. Alternating of a sexual and a sexless generation in the life cycle of a plant.

Ament. The flower cluster of trees and shrubs, such as oak, willow, etc.

Anabolism. Building-up processes; making and assimilating food materials.

Anaërobes. Plants that cannot carry on their life processes in presence of ordinary air.

Anatropous (turned up). Applied to ovules or seeds that grow in an inverted position.

Andrœcium (male household). Stamens of a flower collectively; this name was given when stamens were thought to be male sex organs.

Anemophilous flowers (wind-loving flowers). Those whose fertilization is effected by means of the wind.

Angiosperms (inclosed seeds). One of the two groups of spermatophytes (seed plants).

Annulus (a ring). The elastic ring of cells around the sporangium in ferns.

Anther. The pollen-bearing part of the stamen.

Antheridiophores. Stalks upon which antheridia are borne.

Antheridium; pl. **antheridia.** The male sex organ in the lower groups of plants.

Antherozoid. See *Sperm.*

Antipodal (against the foot). Applied to a group of cells at the end of the embryo sac farthest from the micropyle.

Apetalous. Without petals.

Apical. At the apex or tip.

Apocarpous (without carpels). Applied to flowers in which the carpels are entirely free from one another.

Appressed. Lying flat throughout its length, as appressed bracts.

Association. An ecological unit group smaller than a plant formation, of which the latter is sometimes made up.

Awl-shaped. Narrow, tapering to a point, as awl-shaped leaves.

Awned. Having bristle-like appendages, as in heads of many kinds of wheat.

Basidium (club); pl. **basidia.** The specialized club-shaped cells on which the spores of some fungi are borne.

Bast. The phloëm portion of a fibrovascular bundle. It may be fibrous (hard bast), or composed of sieve tubes (soft bast).

Bilabiate (two-lipped). Applied to the form of corolla in certain dicotyledonous plants.

Bract (a thin plate). The small, scale-like, modified leaves which sometimes are found at the base of the flower cluster.

Calyptra (a cover). In mosses, the hood that covers the tip of the capsule.

Calyx (a cup). All the sepals, which together form the outer envelope of a flower.

Cambium. The meristem cells of a fibrovascular bundle lying between the phloëm and xylem, and having the power of division, so as to produce new phloëm and xylem.

Capitate (relating to head). (1) Rounded, as the head of the stigma of the primrose; or (2) growing in heads.

Capsule (a small box). A dry, dehiscent seed vessel (formed of more than one carpel).

Carpel (fruit). The megasporophyll; hence either a simple pistil or one of the parts of a compound pistil.

Carpellary. Relating to a carpel.

Catkins. See *Ament.*

Caulicle (a small stem). The initial stem in an embryo.

Cell. The morphological or anatomical unit of plant and animal structure.

Cellulose (pertaining to a cell). The primary substance of the cell wall.

Central cylinder. The stele, or portion of the root or stem which is inclosed by the primary cortex.

Chaff. Small dry scales usually found in connection with the seeds of plants, as in grasses and *Compositæ.*

Chalaza. The base of an ovule where integuments and nucellus are one common tissue.

Chlorophyll (green leaf). The green coloring matter of plants.

Chloroplast. One of the special bodies that contain chlorophyll.

Choripetalous (separate petals). With the petals separate, not united.

Chromatophore (color-bearing). A general term for all bodies in plants containing coloring matter.

Cilium (eyelash); pl. **cilia.** Marginal hairs; motile protoplasmic filaments, as those of sperms.

Cleistogamous. With close fertilization, occurring in flowers before they open.

Closed bundle. A fibrovascular bundle containing no cambium; growth is closed.

Cœnocyte. A number of nucleated masses of cytoplasm (cells) inclosed by a common wall.

Collateral (sides together). Side by side, as in a fibrovascular bundle in which the xylem and phloëm are side by side in a radial direction.

Columella (a small column). The persistent axis of certain spore cases, as in mosses.

Concentric (center together). Technically used of a fibrovascular bundle whose tissues are arranged so as to surround one another.

Conidiophore (conidium-bearer). Stalk upon which conidia are borne.

Conidium; pl. **conidia.** The asexual spore of some fungi, as in potato blight and grape mildew.

Conjugation (joined together). The sexual union of similar gametes.

Connate. Applied to leaves that appear united or grown together at their bases.

Connective. The portion of the stamen connecting the parts of the anther.

Cordate. Heart-shaped.

Corm. The fleshy stem or base of a stem; a bulb-like structure, as on the underground part of jack-in-the-pulpit.

Corolla (a small crown). The inner envelope of a flower within the calyx, composed of petals.

Cortex. Rind or bark.

Cortical. Relating to cortex.

Cotyledon. A primary embryo leaf borne by the hypocotyl (caulicle) of the embryo plant.

Cryptogams (hidden marriage). A term used to include thallophytes, bryophytes, and pteridophytes.

Cupule (a little cup). The gemma cup of liverworts.

Cuticle (skin). The outermost layer of epidermis, differing chemically from the remainder of the cell wall.

Cutinization. The transformation of the outer layer of the epidermis into *cutin*, a substance which is nearly waterproof and not easily penetrated by gases.

Cyclic. An arrangement of leaves or floral organs in such a way that two or more appear upon the axis at the same level, thus forming a cycle or whorl.

Cytoplasm. The jelly-like living material of the cell.

Deciduous. Applied to plants which lose their leaves at regular intervals.

Dehiscence (gaping). The opening of an organ to discharge its contents, as in case of anthers, sporangia, and capsules.

Dermatogen (skin-producer). The layer of young epidermis in growing points.

Dichogamous. With stamens and pistils not maturing together, as in many plantains.

Dichotomous (cutting in two). Forked regularly in pairs.

Dicotyledonous (cotyledons double). Having two cotyledons or seed leaves.

Dimorphism (two structures). Having two different forms. Long-styled and short-styled flowers of the same species are dimorphous.

Diœcious (two households). Having the two kinds of reproductive organs borne by separate individuals

Dorsiventral. Having the two surfaces differentiated so that one is upper and one lower.

Drupe. A stone fruit with a fleshy outer and a hard inner layer of the pericarp, as in the walnut, peach, plum, etc.

Ecology. The study of the relations between the plant and its environment, including the other living beings with which it has to do.

Egg or **oösphere.** The female gamete.

Egg apparatus. A group of three cells, consisting of the egg and two synergids, one at each side. Found in angiosperms.

Embryo. The young plantlet within the seed.

Embryo sac. The cavity within which the embryo develops.

Endodermis (within the skin). The layer of cells inclosing the fibrovascular bundle; the bundle sheath.

Endogenous (produced within). Originating from internal tissues.

Endosperm (within the seed). A tissue containing reserve materials developed within the embryo sac.

Endosperm nucleus. The nucleus of the angiosperm embryo sac from which the endosperm of the embryo sac develops.

Enzyme. One of the plant secretions which digest substances external to the plant, as in carnivorous plants, or reserve materials, as in seeds.

Epiphyte. A plant which grows upon other plants.

Fertilization. The act of uniting an egg and a sperm.

Fibrovascular bundles (fiber vessels). The strands that make up the framework of higher plants.

Filament (a thread). The stalk of the stamen that supports the anther; also the individual threads of algæ or fungi.

Filiform. Thread-like.

Fission (splitting). Cell division resulting in division into halves.

Fleshy. Thick, succulent.

Flowering glume. In grasses, the bract that subtends each flower, sometimes called lower palet.

Formation. An ecological group. It signifies a well-defined assemblage of plants characteristic of some kind of station.

Frond (a leaf). A name given to the leaf of ferns.

Fruit. The ripened ovary and its contents.

Funiculus (a slender rope). The stalk of an ovule or seed.

Gametangium (gamete vessel). The specialized organ for production of gametes.

Gamete. A reproductive cell which ordinarily becomes functional only upon union with another. As a result of this union a sexual spore is formed.

Gametophyte (gamete plant). The sexual stage of an alternating plant.

Gemma (a bud); pl. **gemmæ.** In bryophytes, many-celled buds specialized for vegetative propagation.

Generative cell. The cell within the male gametophyte of spermatophytes (usually within the microspore wall) which divides to form the two male cells.

Geotropism (turning toward the earth). The tendency of organs or portions of organs to go downward.

Glaucous (pale green, gray). Whitened with a bloom, like that on a cabbage leaf.

Glume (a husk). A chaff-like bract belonging to the inflorescence of grasses; the outer glumes subtend the spikelet; the flowering glume is the bract of the flower.

Gluten (glue). A term used for the glue-like products of plants, especially of seeds.

Grain. A seed-like fruit, like those of grasses, with pericarp grown fast to the seed; also any small, rounded body, as of starch.

Growing point. The group of meristem cells at the growing tip of an organ, from which the various tissues arise.

Guard cells. The cells (usually two) which open and close a stoma.

Gymnosperms (naked seeds). One of the two groups of spermatophytes (seed plants).

Gynæcium (female household). The pistil, or collectively the pistils, of a flower.

Halophyte. A plant which can thrive in saline soil, as that of "alkali" lands or salt marshes.

Haustorium (drinking organs); pl. **haustoria.** The absorbing organs of some parasites.

Heliotropism (turning to light). Tendency of plants to turn toward the sun.

Heterogamy (unlike gametes). The condition of plants whose pairing gametes are dissimilar.

Heterŏgamous. Pertaining to heterogamy.

Heterospory (unlike spores). The condition in plants which produce two kinds of asexual spores.

Heterosporous. Pertaining to heterospory.

Homospory (similar spores). The condition in plants which produce but one kind of asexual spore.

Homosporous. Pertaining to homospory.

Host. The plant upon or within which parasitic plants or animals develop, and from which they obtain nourishment.

Hybrid. A plant which is the offspring of an egg of one species fertilized by the pollen of another species. The term is also used for crosses between two varieties of plants.

Hydrophyte (water plant). A plant thriving only in water or marshes.

Hygroscopic (moisture seeking). Having an avidity for water.

Hymenium (a membrane). In fungi, a surface layer of interwoven filaments from which the spore-bearing filaments arise.

Hypha (a web); pl. **hyphæ.** The slender vegetative filaments of fungi which may or may not be woven into a mat (*mycelium*) or a definitely organized plant.

Hypocotyl. The short stem of an embryo seed plant.

Hypodermis (under the skin). The tissues which lie immediately beneath the epidermis and which serve to strengthen it.

Hypogynous (being under the ovary). Applied to those flowers whose stamens and floral envelopes are at the base of the ovary.

Indehiscent. Not dehiscent, or not splitting regularly.

Indusium (covering); pl. **indusia.** In ferns, a cellular outgrowth of the leaf covering the clusters of sporangia (*sori*).

Inflorescence (flowering). The arrangement of flowers; or the flowering portion of a plant.

Integument (covering). The covering of the ovule.

Intercellular. Between or among the cells.

Internode. The part of a stem between two nodes or joints.

Intine (on the inside). The inner coat of a pollen grain.

Involucre (rolled within). The leaf-like or bract-like sheath that incloses a cluster of flowers.

Irritability. The capacity which protoplasm possesses of responding to stimuli, such as light, heat, gravity, and contact with chemical reagents.

Isogamous (equal gametes). Applied to those plants whose pairing gametes are similar.

Lamina (a layer). The blade or expanded part of a leaf.

Leaf trace. The fibrovascular bundles from the leaf which blend within the stem with its fibrovascular cylinder.

Lenticel. A round, oval, or lens-shaped opening on the exterior surface of the bark.

Leucoplast (white molded). A minute colorless body within a cell. When exposed to light, leucoplasts may develop into chloroplasts.

Liana. A climbing plant.

Ligule (a small tongue). In grasses a thin appendage at the junction of leaf blade and sheath.

Medullary. Relating to the pith; medullary rays are the pith rays which radiate to the bark between the fibrovascular bundles.

Megasporangium (large spore vessel). The sporangium that produces the megaspores.

Megaspore (great or large spore). The larger one of the two kinds of asexual spores produced by certain pteridophytes and all spermatophytes.

Megasporophyll (large spore leaf). The leaf upon which the megasporangium develops.

Meristem (dividing tissue). Tissues with the cells all nearly alike and still capable of subdividing.

Mesophyll (middle leaf). The green or soft tissue of the inner part of the leaf.

Mesophytes (middle plants). Normal land plants such as grow in an average soil and under a moderate climate.

Metabolism. Chemical transformations of matter carried on by plants in the production and utilization of their food supply, and disposition of waste products.

Micropyle (small gate). The opening left by the integuments of the ovule, and which leads to the nucellus.

Microsporangium (small spore vessel). The sporangium that produces the microspore.

Microspore (small spore). The smaller spore of the two kinds produced by certain pteridophytes and all spermatophytes.

Microsporophyll (small spore leaf). The leaf upon which the microsporangium is borne.

Midrib. The central or main rib of a leaf or thallus.

Monœcious (one household). Applied to those plants upon one of which both kinds of gametes are borne. Strictly speaking, the term applies only to the gametophyte stage of plants. A monœcious seed plant bears both staminate and pistillate flowers.

Monopodial (having one foot). Said of a stem consisting of a single and continuous axis (footstalk).

Mother cell. A cell that produces new cells (usually) by internal division.

Mutualism. A symbiotic relationship in which the organisms are mutually helpful.

Mycelium (fungous growth). The filamentous vegetative growth of fungi, composed of hyphæ.

Naked. Wanting some usual covering.

Nascent. Developing or growing.

Nastic movements. Movements produced by all-round stimuli, as heat. The opening and closing of the flowers of crocuses and tulips are thermonastic movements.

Nectary. The structure in which nectar is secreted.

Nerve. A simple vein or rib.

Node (a joint). That part of a stem which normally bears leaves.

Nucellus (a little kernel). The mass of the ovule within the integuments.

Nucleolus (diminutive of nucleus). The sharply defined rounded part often seen in the nucleus.

Nucleus (a kernel). The usually roundish mass found in the protoplasm of most active cells, and differing from the rest of the protoplasm in its greater density.

Oögonium; pl. **oögonia.** The female reproductive organ of thallophytes.

Oösphere (egg sphere). The egg cell; the mass of protoplasm prepared for fertilization.

Oöspore (egg spore). The egg cell after fertilization.

Open bundle. A fibrovascular bundle which contains cambium.

Operculum (a cover or lid); pl. **opercula.** In mosses the terminal lid of the capsule, just beneath the calyptra.

Osmosis. The interchange of liquids through a membrane.

Ovary (egg-keeper). That part of the carpel in which the ovules are formed.

Ovule (an egg). The body which becomes a seed after fertilization and maturation; formerly thought to be an egg.

Palet (chaff). In grasses, the inner bract of the flower.

Palisade cells. The elongated parenchyma cells of a leaf, which stand at right angles to its surface and are often confined to the upper part of the leaf.

Palmate (pertaining to the hand). Radiating like the fingers; said of the veins or divisions of some leaves.

Panicle (a tuft). A loose and irregularly branching flower cluster, as in many grasses.

Pappus (down). The modified calyx of the composites.

Paraphysis (accompanying organs); pl. **paraphyses.** Sterile bodies, usually hairs, which are found mingled with the reproductive organs of various lower plants.

Parasite. An organism that obtains its food from the living tissues or the secretions of other organisms.

Parenchyma. Ordinary or typical cellular tissue, i.e. of thin-walled cells nearly equal in all their dimensions.

Parthenogenesis. The formation, without fertilization, of a spore which is functionally the same as a sexual spore. In general it means that the female gamete becomes a spore directly, and may grow without fertilization.

Pedicel (a little foot). The stalk upon which a structure is borne.

Peduncle (a little foot). The flower stalk.

Pentacyclic (five cycles). Applied to flowers whose four kinds of floral organs are in five cycles.

Perianth (around the flower). The floral envelopes or leaves of a flower, taken collectively; and an analogous envelope of the sporogonium of certain liverworts.

Periblem (a cloak). A name given to that part of the meristem at the growing point of the plant axis, which lies just beneath the epidermis and develops into the cortex.

Pericambium (surrounding growing tissue). In roots, the external layer of the fibrovascular cylinder.

Pericarp (around the fruit). The wall of the ovary, developed into a part of the fruit.

Perigynous (around the ovary). Applied to those flowers whose stamens and perianth arise from around the wall of the ovary.

Peristome (around the mouth). In mosses, usually bristle-like or tooth-like structures surrounding the orifice of the capsule.

Petal (a leaf). A corolla leaf.

Petiole (a little foot). The stalk of a leaf.

Phanerogamia (evident marriage). A primary division (the highest) of plants, named, from their mode of reproduction, the seed-producing plants. Phanerogam is the English equivalent.

Phloëm (the inner bark). The bark or bast portion of a fibrovascular bundle.

Photosynthesis (light construction). The name applied to the process by which chloroplasts under the influence of sunlight manufacture such carbohydrates as sugar and starch from water and carbon dioxide.

Phycocyanin (seaweed blue). A bluish coloring matter found within certain algæ.

Phyllotaxy. Leaf arrangement.

Pinna (a feather); pl. **pinnæ.** One of the primary divisions of a pinnate leaf, as in ferns.

Pinnate. Having the veins or the divisions of the leaf arranged in rows on each side of the midrib, as in black locust (*Robinia*).

Pinnule (a little feather). One of the divisions of a pinna.

Pistil (a pestle). A simple or compound carpel in spermatophytes.

Placenta; pl. **placentæ.** That portion of the ovary which bears the ovules.

Plerome (that which fills). A name given to that part of the meristem, near the growing points of the plant axis, which forms a central shaft or cylinder and develops into the axial tissues.

Plumule (a little feather). The terminal bud of the embryo above the cotyledons.

Pod. A dry, several-seeded, dehiscent fruit.

Pollen. The spores developed in the anther.

Pollen tube. The structure that develops from the wall of the microspore of spermatophytes and carries male cells to the egg.

Pollination. The transfer of pollen to the stigma.

Polypetalous (many petals). Applied to flowers that have their petals free from one another.

Prosenchyma. Tissue composed of elongated cells, with tapering ends which overlap.

Prothallium (a forerunning shoot); pl. **prothallia.** The small, usually short-lived plant which develops from the spore and bears the sex organs.

Protonema (that which is first sent out); pl. **protonemata.** In mosses, the filamentous growth which is produced by the spores, and from which the leafy moss plant is developed.

Protoplasm (that which is first formed). The living matter of cells.

Pubescent. Downy, with fine hairs.

Pyrenoid (kernel formed). Minute colorless bodies embedded in the chlorophyll structures of some lower plants.

Receptacle. That portion of an axis or pedicel (usually broadened) which forms a common support for a cluster of organs, either sex organs or sporophylls.

Respiration. The series of processes by which plants obtain energy through breaking down of protoplasm or food. Usually oxygen is used and carbon dioxide is formed as a result of the process.

Reticulated (net-like). Having a net-like appearance.

Rhizoid. Root-like; a name applied to the root-like hairs found in bryophytes and pteridophytes.

Rhizome. See *Rootstock.*

Rootstock. A horizontal, more or less thickened, root-like stem, either on the ground or underground.

Saprophyte. An organism that obtains its food from dead or decaying organisms.

Scalariform (ladder form). A name applied to ducts with piths horizontally elongated, and so placed that the intervening thickening ridges appear like the rounds of a ladder.

Scale (a flight of steps). Any thin scarious body, as a degenerated leaf, or flat hair.

Sclerenchyma. A tissue composed of cells that are thick-walled, often extremely so.

Seed. The matured ovule.

Sepal. A calyx leaf.

Seta; pl. **setæ.** A bristle, or bristle-shaped body; in mosses, the stalk of the capsule.

Sexual spore. One formed by the union of cells.

Sheath. A thin enveloping part, as of a filament, leaf, or resin duct.

Sieve cells. Cells belonging to the phloëm, and characterized by the presence of perforated plates in the wall.

Sorus (a heap); pl. **sori.** In ferns, the groups of sporangia, constituting the so-called "fruit dots"; in parasitic fungi, well-defined groups of spores, breaking through the epidermis of the host.

Sperm, or **Spermatozoid** (animal-like sperm). The male gamete.

Spermatophytes (seed plants). The highest great group of plants, of which a characteristic structure is the seed.

Spike. A flower cluster, having its flowers sessile on an elongated axis.

Spikelet (diminutive of spike). A secondary spike; in grasses, the ultimate flower cluster, consisting of one or more flowers subtended by a common pair of glumes.

Sporangium (spore vessel); pl. **sporangia.** The spore-producing structure.

Spore (seed). Originally used as the analogue of seed in flowerless plants; now applied to any one-celled or few-celled body which is separated from the parent for the purpose of reproduction, whether sexually or asexually produced; the different methods of its production are indicated by suitable prefixes.

Sporogonium (spore offspring); pl. **sporogonia.** The whole structure of the spore-bearing stage of bryophytes.

Sporophyll. A leaf that bears sporangia.

Sporophyte (spore plant). The asexual or spore-producing stage of an alternating plant.

Stamen. The microsporophyll in spermatophytes.

Stigma. That portion of the surface of a pistil (without epidermis) which receives the pollen.

Stigmatic. Relating to the stigma, or stigma-like.

Stoma (a mouth); pl. **stomata.** Epidermal structures which serve for facilitating gaseous interchanges with the external air, and for transpiration of moisture. They are often incorrectly called "breathing pores."

Strobilus. A cone-like cluster of sporophylls.

Style. The usually attenuated portion of the pistil which bears the stigma.

Succulent. Thick and fleshy.

Suspensor. A chain of cells which develops early from the oöspore, and serves to push the embryo cell deep within the embryo sac.

Symbiont. One of the organisms that has entered into a symbiotic relationship.

Symbiosis (living together). Applied to a condition in which two or more organisms are living in an intimate relationship.

Sympetalous. Having the petals apparently all united, as if grown together by their edges.

Syncarpous (carpels united). Applied to those conditions in which the carpels have united into a compound pistil.

Synergids (helpers). The two nucleated bodies which accompany the oösphere in the embryo sac, and together with it form the egg apparatus.

Testa (a shell). The outer seed coat.

Tetracyclic (four cycles). Applied to those flowers in which there are four cycles of floral organs.

Tetradynamous (four strong). Said of a stamen cluster in which there are four long and two shorter stamens.

Thalloid. Thallus-like.

Thallus (a young shoot). The body of lower plants, which exhibits no differentiation of stem, leaf, and root.

Tissue. A texture built up of mutually dependent cells of similar origin and character, as the cambium layer.

Tracheid. A long, slender cell, with closed ends and its walls thickened after the cell has attained its full size, as in the pitted cells of coniferous wood.

Transpiration. The loss of water derived from the interior of the plant body in the form of vapor. The term is not generally used with reference to plants of low organization.

Trichome (a hair). A general name for a slender outgrowth from the epidermis, usually arising from a single cell.

Turgidity. The normal swollen condition of active cells which results from the distension brought about by absorption of water.

Unisexual. Having only male or only female reproductive organs.

Vein. One of the fibrovascular bundles of leaves or of any flat organ of plants.

Venation. The mode of vein distribution.

Xerophyte. A plant capable of thriving under conditions of strongest transpiration and with scanty water supply.

Xylem (wood). The wood (inner) portion of the fibrovascular bundle.

Zoöspore (animal spore). A motile asexual spore.

Zygomorphic. Said of a flower which can be bisected by only one plane into similar halves, bilaterally symmetrical.

Zygospore (yoke spore). The spore formed by conjugation of similar gametes.

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