PLANT STUDIES

COULTER

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TWENTIETH CENTURY TEXT-BOOKS

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TWENTIETH CENTURY TEXT-BOOKS

PLANT STUDIES

AN ELEMENTARY BOTANY

BY

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UNIVERSITY OF CHICAGO

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PREFACE

This book has been prepared in response to the earnest solicitation of those schools in which there is not a sufficient allotment of time to permit the development of plant ecology and morphology, as outlined in *Plant Relations* and *Plant Structures;* and yet which are desirous of imparting instruction from both points of view. To meet this need, the essential portions of the two books referred to have been selected and combined, which, with the addition of some new matter to give it logical continuity and a degree of completeness, have been organized into this volume under the title of *Plant Studies.*

The book falls naturally into two divisions, the first fourteen chapters being dominated by Ecology, and representing the view point of *Plant Relations.* The remaining eleven chapters are dominated by Morphology, and present in much simpler form, especially in the higher groups, the ideas of *Plant Structures.* While the author believes that these two regions of the book are put in proper sequence for elementary instruction, he is very far from seeking to impose such an opinion upon teachers, who must use a sequence adapted to their own convictions and material. Hence many may prefer to begin with Chapter XV, and return to the preceding chapters later; or, what is perhaps better, they may prefer to combine the two divisions of the book much more intimately.

In any event, the book is not a laboratory guide, or a book merely for recitation, but is for reading and study in connection with laboratory and field-work. The intention is to present a connected, readable account of some of the fundamental facts of botany, and to give a certain amount of information. If it performs no other service in the schools, however, its purpose will be defeated. It is entirely too compact for any such use, for great subjects, which should involve a large amount of observation, are often merely suggested.

It is intended to serve as a supplement to three far more important factors: (1) *the teacher*, who must amplify and suggest at every point; (2) *the laboratory*, which must bring the pupil face to face with plants and their structures; (3) *field-work*, which must relate the facts observed in the laboratory to their actual place in Nature, and must bring new facts to notice which can be observed nowhere else. Taking the results obtained from these three factors, the book seeks to organize them, and to suggest explanations. It seeks to do this in two ways: (1) by means of the text, which is intended to be clear and untechnical, but compact; (2) by means of the illustrations, which must be studied as carefully as the text, as they are only second in importance to the actual material. Especially is this true in reference to the landscapes, many of which can not be made a part of experience.

My thanks are due to various members of the Department of Botany of the university for preparing and selecting illustrations. The illustrations of the first fourteen

chapters were under the general direction of Dr. Henry C. Cowles, while those of the remaining chapters were provided by Dr. Otis W. Caldwell. In this work Dr. Caldwell had the very efficient assistance of S. M. Coulter, B. A. Goldberger, J. G. Land, and A. C. Moore, whose names appear in connection with the drawings they furnished. Grateful acknowledgment should also be made to Dr. W. J. Beal, whose little book entitled *Seed Dispersal* furnished several illustrations; and to Professor George F. Atkinson, whose excellently illustrated *Elementary Botany* performed a like service. Both of these authors are credited in connection with the illustrations used from their works. The fine illustrations from Kerner and from Schimper, and from other authors, will also be recognized; but their names will all be found in the legends.

JOHN M. COULTER.

THE UNIVERSITY OF CHICAGO, *June, 1900.*

PREFACE TO THE REVISED EDITION

DURING the last four years the science of Botany has made rapid progress, both in the addition of new facts and in changed points of view. Some of this progress affects *Plant Studies*, and it is recorded in this revised edition so far as it can be without a complete rewriting of the volume. Changes will be found, therefore, in statements of fact, in points of view, in terminology, in illustrations, and also in the addition of new material.

JOHN M. COULTER.

THE UNIVERSITY OF CHICAGO, *April, 1904.*

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BOTANY

PLANT STUDIES

CHAPTER I

INTRODUCTION

1. **General relations.**—Plants form the natural covering of the earth's surface. So generally is this true that a land surface without plants seems remarkable. Not only do plants cover the land, but they abound in waters as well, both fresh and salt waters. They are wonderfully varied in size, ranging from huge trees to forms so minute that the microscope must be used to discover them. They are also exceedingly variable in form, as may be seen by comparing trees, lilies, ferns, mosses, mushrooms, lichens, and the green thready growths (*algæ*) found in water.

2. **Plant associations.**—One of the most noticeable facts in reference to plants is that they do not form a monotonous covering for the earth's surface, but that there are forests in one place, thickets in another, meadows in another, swamp growths in another, etc. In this way the general appearance of vegetation is exceedingly varied, and each appearance tells of certain conditions of living. These groups of plants living together in similar conditions, as trees and other plants in a forest, or grasses and other plants in a meadow, are known as *plant associations*. These

associations are as numerous as are the conditions of living, and it may be said that each association has its own special regulations, which admit certain plants and exclude others. The study of plant associations to determine their conditions of living is one of the chief purposes of botanical field work.

3. **Plants as living things.**—Before engaging in a study of associations, however, one must discover in a general way how the individual plant lives, for the plant covering of the earth's surface is a living one, and plants must always be thought of as living and at work. They are as much alive as are animals, and so far as mere living is concerned they live in much the same way. Nor must it be supposed that animals move and plants do not, for while more animals than plants have the power of moving from place to place, some plants have this power, and those that do not can move certain parts. The more we know of living things the more is it evident that life processes are alike in them all, whether plants or animals. In fact, there are some living things about which we are uncertain whether to regard them as plants or animals.

4. **The plant body.**—Every plant has a body, which may be alike throughout or may be made up of a number of different parts. When the green thready plants (*algæ*), so common in fresh water, are examined, the body looks like a simple thread, without any special parts; but the body of a lily is made up of such dissimilar parts as root, stem, leaf, and flower (see Figs. 75, 144, 161, 169). The plant without these special parts is said to be *simple*, the plant with them is called *complex*. The simple plant lives in the same way and does the same kind of work, so far as living is concerned, as does the complex plant. The difference is that in the case of the simple plant its whole body does every kind of work; while in the complex plant different kinds of work are done by different regions of the body, and these regions come to look unlike when different shapes are better suited to different work, as in the

case of a leaf and a root, two regions of the body doing different kinds of work.

5. **Plant organs.**—These regions of the plant body thus set apart for special purposes are called *organs.* The simplest of plants, therefore, do not have distinct organs, while the complex plants may have several kinds of organs. All plants are not either very simple or very complex, but beginning with the simplest plants one may pass to others not quite so simple, then to others more complex, and so on gradually until the most complex forms are reached. This process of becoming more and more complex is known as *differentiation,* which simply means the setting apart of different regions of the body to do different kinds of work. The advantage of this to the plant becomes plain by using the common illustration of the difference between a tribe of savages and a civilized community. The savages all do the same things, and each savage does everything. In the civilized community some of the members are farmers, others bakers, others tailors, others butchers, etc. This is what is known as "division of labor," and one great advantage it has is that every kind of work is better done. Differentiation of organs in a plant means to the plant just what division of labor means to the community; it results in more work, and better work, and new kinds of work. The very simple plant resembles the savage tribe, the complex plant resembles the civilized community. It must be understood, however, that in the case of plants the differentiation referred to is one of organs and not of individuals.

6. **Plant functions.**—Whether plants have many organs, or few organs, or no organs, it should be remembered that they are all at work, and are all doing the same essential things. Although many different kinds of work are being carried on by plants, they may all be put under two heads, *nutrition* and *reproduction.* Every plant, whether simple or complex, must care for two things: (1) its own support (nutrition), and (2) the production of other plants like

itself (reproduction). To the great work of nutrition many kinds of work contribute, and the same is true of reproduction. Nutrition and reproduction, however, are the two primary kinds of work, and it is interesting to note that the first advance in the differentiation of a simple plant body is to separate the nutritive and reproductive regions. In the complex plants there are nutritive organs and reproductive organs; by which is meant that there are distinct organs which specially contribute to the work of nutrition, and others which are specially concerned with the work of reproduction. The different kinds of work are conveniently spoken of as *functions*, each organ having one or more functions.

7. **Life-relations.**—In its nutritive and reproductive work the plant is very dependent upon its surroundings. It must receive material from the outside and get rid of waste material; and it must leave its offspring in as favorable conditions for living as possible. As a consequence, every organ holds a definite relation to something outside of itself, known as its *life-relation*. For example, green leaves are definitely related to light, many roots are related to soil, certain plants are related to abundant water, some plants are related to other plants or animals (living as parasites), etc. A plant with several organs, therefore, may hold a great variety of life-relations, and it is quite a complex problem for such a plant to adjust all of its parts properly to their necessary relations. The study of the life-relations of plants is a division of Botany known as *Ecology*, and presents to us many of the most important problems of plant life.

It must not be supposed that any plant or organ holds a perfectly simple life-relation, for it is affected by a great variety of things. A root, for instance, is affected by light, gravity, moisture, soil material, contact, etc. Every organ, therefore, must adjust itself to a very complex set of life-relations, and a plant with several organs has so many delicate adjustments to care for that it is really impossible, as yet, for us to explain why all of its parts are placed just as they are. In the beginning of the study of plants, only some of the most prominent functions and life-relations can be considered. In order to do this, it seems better to begin with single organs, and afterwards these can be put together in the construction of the whole plant.

CHAPTER II

FOLIAGE LEAVES: THE LIGHT-RELATION

8. **Definition.**—A foliage leaf is the ordinary green leaf, and is a very important organ in connection with the work of nutrition. It must not be thought that the work done by such a leaf cannot be done by green plants which have no leaves, as the algæ, for example. A leaf is simply an organ set apart to do such work better. In studying the work of a leaf, therefore, we have certain kinds of work set apart more distinctly than if they were confused with other kinds. For this reason the leaf is selected as an introduction to some of the important work carried on by plants, but it must not be forgotten that a plant does not need leaves to do this work ; they simply enable it to work more effectively.

9. **Position.**—It is easily observed that foliage leaves grow only upon stems, and that the stems which bear them always expose them to light; that is, such leaves are aerial rather than subterranean (see Figs. 1, 75, 174). Many stems grow underground, and such stems either bear no foliage leaves, or are so placed that the foliage leaves are sent above the surface, as in most ferns and many plants of the early spring (see Figs. 45, 46, 144).

10. **Color.**—Another fact to be observed is that foliage leaves have a characteristic green color, a color so universal that it has come to be associated with plants, and especially with leaves. It is also evident that this green color holds some necessary relation to light, for the leaves of plants grown in the dark, as potatoes sprouting in a cellar,

do not develop this color. Even when leaves have developed the green color they lose it if deprived of light, as is shown by the process of blanching celery, and by the effect on the color of grass if a board has lain upon it for some time. It seems plain, therefore, that the green color found in working foliage leaves depends upon light for its existence.

We conclude that at least one of the essential life-relations of a foliage leaf is what may be called the *light-relation.* This seems to explain satisfactorily why such leaves are not developed in a subterranean position, as are many stems and most roots, and why plants which produce them do not grow in the dark, as in caverns. The same green, and hence the same light-relation, is observed in other parts of the plant as well, and in plants without leaves, the only difference being that leaves display it most conspicuously. Another indication that the green color is connected with light may be obtained from the fact that it is found only in the surface region of plants. If one cuts across a living twig or into a cactus body, the green color will be seen only in the outer part of the section. The conclusion is that the leaf is a special organ for the light-relation. Plants sometimes grow in such situations that it would be unsafe for them to display leaves, or at least large leaves. In such a case the work of the leaves can be thrown upon the stem. A notable illustration of this is the cactus plant, which produces no foliage leaves, but whose stem displays the leaf color.

11. **An expanded organ.**—Another general fact in reference to the foliage leaf is that in most cases it is an expanded organ. This means that it has a great amount of surface exposed in comparison with its mass. As this form is of such common occurrence it is safe to conclude that it is in some way related to the work of the leaf, and that whatever work the leaf does demands an exposure of surface rather than thickness of body. It is but another step to say that

the amount of work an active leaf can do will depend in part upon the amount of surface it exposes.

THE LIGHT-RELATION

12. **The general relation.**—The ordinary position of the foliage leaf is more or less horizontal. This enables it to receive the direct rays of light upon its upper surface. In this way more rays of light strike the leaf surface than if it stood obliquely or on edge. It is often said that leaf blades are so directed that the flat surface is at right angles to the incident rays of light. While this may be true of horizontal leaves in a general way, the observation of almost any plant will show that it is a very general statement, to which there are numerous exceptions (see Fig. 1). Leaves must be arranged to receive as much light as possible to help in their work, but too much light will destroy the green substance (*chlorophyll*), which is essential to the work. The adjustment to light, therefore, is a delicate one, for there must be just enough

Fig. 1. The leaves of this plant (*Ficus*) are in general horizontal, but it will be seen that the lower ones are directed downward, and that the leaves become more horizontal as the stem is ascended. It will also be seen that the leaves are so broad that there are few vertical rows.

and not too much. The danger from too much light is not the same in the case of all leaves, even on the same plant, for some are more shaded than others. Leaves also have a way of protecting themselves from too intense light by their structure, rather than by a change in their position. It is evident, therefore, that the exact position which any particular leaf holds in relation to light depends upon many circumstances, and cannot be covered by a general rule, except that it seeks to get all the light it can without danger.

13. **Fixed position.**—Leaves differ very much in the power of adjusting their position to the direction of the light.

FIG. 2. The day and night positions of the leaves of a member (*Amicia*) of the pea family.—After STRASBURGER.

Most leaves when fully grown are in a fixed position and cannot change it, however unfavorable it may prove to be, except as they are blown about. Such leaves are said to have *fixed light positions.* This position is determined by the light conditions that prevailed while the leaf was growing and able to adjust itself. If these conditions continue, the resulting fixed position represents the best one that can be secured under the circumstances. The leaf may not receive the rays of light directly throughout the whole period of daylight, but its fixed position is such that it probably receives more light than it would in any other position that it could secure.

14. **Motile leaves.**—There are leaves, however, which have no fixed light position, but are so constructed that they can shift their position as the direction of the light changes. Such leaves are not in the same position in the afternoon as in the forenoon, and their night position may be very different from either (see Figs. 2, 3*a*, 3*b*, 4). Some of the common house plants show this power. In the case of the common *Oxalis* the night position of the leaves is remarkably different from the position in light. If such a plant is exposed to the light in a window and the positions of the leaves noted, and then turned half way around, so as to bring the other side to the light, the leaves may be observed to adjust themselves gradually to the changed light-relations.

FIG. 3*a*. The day position of the leaves of redbud (*Cercis*).—After ARTHUR.

FIG. 3*b*. The night position of the leaves of redbud (*Cercis*).—After ARTHUR.

15. **Compass plants.**—A striking illustration of a special light position is found in the so-called "compass plants." The best known of these plants is the rosin-weed of the prairie region. Growing in situations exposed to intense light, the leaves are turned edgewise, the flat faces being turned away from the intense rays of midday, and directed towards the rays of less intensity; that is, those of

FIG. 4. Two sensitive plants, showing the motile leaves. The plant to the left has its leaves and numerous leaflets expanded; the one to the right shows the leaflets folded together and the leaves drooping.—After KERNER.

the morning and evening (see Fig. 170). As a result, the plane of the leaf lies in a general north and south direction. It is a significant fact that when the plant grows in shaded places the leaves do not assume any such position. It seems evident, therefore, that the position has something to do with avoiding the danger of too intense light. It

FIG. 5. The common prickly lettuce (*Lactuca Scariola*), showing the leaves standing edgewise, and in a general north and south plane. —After ARTHUR and MACDOUGAL.

must not be supposed that there is any accuracy in the north or south direction, as the edgewise position seems to be the significant one. In the rosin-weed probably the north and south direction is the prevailing one; but in the prickly lettuce, a very common weed of waste grounds, and one of the most striking of the compass plants, the edgewise position is frequently assumed without any special reference to the north or south direction of the apex (see Fig. 5).

16. **Heliotropism.**—The property of leaves and of other organs of responding to light is known as *heliotropism*, light being one of the most important of those external influences to which plant organs respond (see Figs. 6, 43).

It should be understood clearly that this is but a slight glimpse

FIG. 6. These plants are growing near a window. It will be noticed that the stems bend strongly towards the light, and that the leaves face the light.

of the most obvious relations of foliage leaves to light, and that the important part which heliotropism plays, not only in connection with foliage leaves, but also in connection with other plant organs, is one of the most important and extensive subjects of plant physiology.

RELATION OF LEAVES TO ONE ANOTHER

A. *On erect stems*

In view of what has been said, it would seem that the position of foliage leaves on the stem, and their relation to one another, must be determined to some extent by the necessity of a favorable light-relation. It is apparent that the conditions of the problem are not the same for an erect as for a horizontal stem.

17. **Relation of breadth to number of vertical rows.**— Upon an erect stem it is observed that the leaves are usu-

ally arranged in a definite number of vertical rows. It is to the advantage of the plant for these leaves to shade one another as little as possible. Therefore, the narrower the leaves, the more numerous may be the vertical rows (see Figs. 7, 8); and the broader the leaves the fewer the vertical rows (see Fig. 1). A relation exists, therefore, between the breadth of leaves and the number of vertical rows, and the meaning of this becomes plain when the light-relation is considered.

Fig. 7. An Easter lily, showing narrow leaves and numerous vertical rows.

18. **Relation of length to the distance between leaves of the same row.**—The leaves in a vertical row may be close together or far apart. If they should be close together and at the same time long, it is evident that they will shade each other considerably, as the light cannot well strike in between them and reach the surface of the lower leaf. Therefore, the closer together the leaves of a vertical row, the shorter are the leaves; and the farther apart the leaves of a row, the longer may they be. Short leaves permit the light to strike between them even if they are close together on the stem; and long leaves permit the same thing only when they are far apart on the stem. A

relation is to be observed, therefore, between the length of leaves and their distance apart in the same vertical row.

The same kind of relation can be observed in reference to the breadth of leaves, for if leaves are not only short but narrow they can stand very close together. It is thus seen that the length and breadth of leaves, the number of vertical rows on the stem, and the distance between the leaves

FIG. 8. A dragon-tree, showing narrow leaves extending in all directions, and numerous vertical rows.

of any row, all have to do with the light-relation and are answers to the problem of shading.

19. **Elongation of the lower petioles.**—There is still another common arrangement by which an effective light-relation is secured by leaves which are broad and placed close together on the stem. In such a case the stalks (*petioles*) of the lower leaves become longer than those above and thus thrust their blades beyond the shadow (see Fig. 9). It may be noticed that it is very common to

find the lowest leaves of a plant the largest and with the longest petioles, even when the leaves are not very close together on the stem.

It must not be supposed that by any of these devices shading is absolutely avoided. This is often impossible and sometimes undesirable. It simply means that by these

Fig. 9. A plant (*Saintpaulia*) with the lower petioles elongated, thrusting the blades beyond the shadow of the upper leaves. A loose rosette.

arrangements the most favorable light-relation is sought by avoiding too great shading.

20. **Direction of leaves.**—Not only is the position on the stem to be observed, but the direction of leaves may result in a favorable relation to light. It is a very common thing to find a plant with a cluster of comparatively large leaves at or near the base, where they are in no danger of shading other leaves, and with the stem leaves gradually becoming

smaller and less horizontal toward the apex of the stem (see Figs. 10, 13). The common shepherd's purse and the mullein may be taken as illustrations. By this arrangement all the leaves are very completely exposed to the light.

FIG. 10. A plant (*Echeveria*) with fleshy leaves, showing large horizontal ones at base, and others becoming smaller and more directed upward as the stem is ascended.

21. **The rosette habit.**— The habit of producing a cluster or rosette of leaves at the base of the stem is called the *rosette habit.* Often this rosette of leaves at the base, frequently lying flat on the ground or on the rocks, includes the only foliage leaves the plant produces. It is evident that a rosette, in which the leaves must overlap one another more or less, is not a very favorable light arrangement, and therefore it must be that something is being provided for besides the light-relation (see Figs. 11, 12, 13). What this is will appear later, but even in this comparatively unfavorable light arrangement, there is evident adjustment to secure the most light possible under the circumstances. The lowest leaves of the rosette are the longest, and the upper (or inner) ones become gradually shorter, so that all the leaves have at least a part of the surface exposed to light. The overlapped base of such leaves is not expanded as much as the exposed apex, and hence they are mostly narrowed at the base and broad at the apex. This narrowing at the base is sometimes

carried so far that most of the part which is covered is but a stem (petiole) for the upper part (blade) which is exposed.

In many plants which do not form close rosettes a gen-

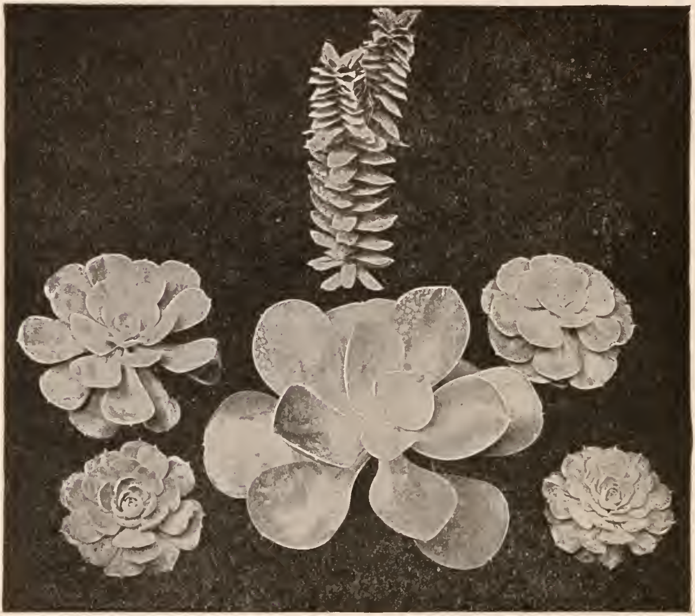

FIG. 11. A group of live-for-evers, illustrating the rosette habit and the light-relation. In the rosettes it will be observed how the leaves are fitted together and diminish in size inwards, so that excessive shading is avoided. The individual leaves also become narrower where they overlap, and are broadest where they are exposed to light. In the background is a plant showing leaves in very definite vertical rows.

eral rosette arrangement of the leaves may be observed by looking down upon them from above (see Fig. 9), as in some of the early buttercups which are so low that the large leaves would seriously shade one another, except that the lower leaves have longer petioles than the upper, and so reach beyond the shadow.

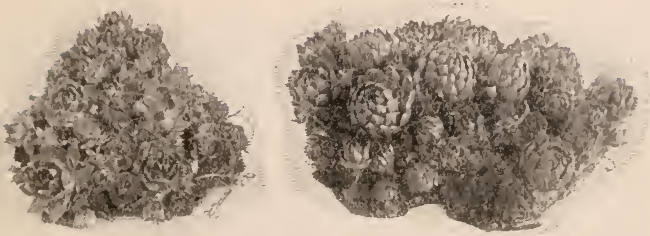

FIG. 12. Two clumps of rosettes of the house leek (*Sempervivum*), the one to the right showing the compact winter condition, the one to the left with rosettes more open after being kept indoors for several days.

22. **Branched leaves.**—Another notable feature of foliage leaves, which has something to do with the light-relation, is that on some plants the blade does not consist of one piece, but is lobed or even broken up into separate pieces. When the divisions are distinct they are called *leaflets*, and every gradation in leaves can be found, from distinct leaflets to lobed leaves, toothed leaves, and finally those whose margins are not indented at all (*entire*). This difference in leaves probably has more important reasons than the light-relation, but its significance may be observed in this connection. In those plants whose leaves are undivided, the leaves generally either diminish in size toward the top of the stem, or the lower ones develop longer petioles. In this case the general outline of the

FIG. 13. The leaves of a bellflower (*Campanula*), showing the rosette arrangement. The lower petioles are successively longer, carrying their blades beyond the shadow of the blades above. —After KERNER.

Fig. 14. A group of leaves, showing how branched leaves overtop each other without dangerous shading. It will be seen that the larger blades or less-branched leaves are towards the bottom of the group.

plant is conical, a form very common in herbs with entire or nearly entire leaves. In plants whose leaf blades are broken up into leaflets (*compound* or *branched leaves*), however, no such diminution in size toward the top of the stem is necessary (see Fig. 17), though it may frequently

FIG. 15. A plant showing much-branched leaves, which occur in great profusion without cutting off the light from one another.

occur. When a broad blade is broken up into leaflets the danger of shading is very much less, as the light can strike through between the upper leaflets and reach the leaflets below. On the lower leaves there will be splotches of light and shadow, but they will shift throughout the day, so that probably a large part of the leaf will receive light at some time during the day (see Fig. 14). The general outline of such a plant, therefore, is usually not conical, as in the other case, but cylindrical (see Figs. 4, 15, 16, 22, 45, 83, 96, 161, 174, 178 for branched leaves).

Many other factors enter into the light-relation of foliage leaves upon erect stems, but those given may suggest

Fig. 16. A cycad, showing much-branched leaves and palm-like habit.

observation in this direction, and serve to show that the arrangement of leaves in reference to light depends upon many things, and is by no means a fixed and indifferent thing. The study of any growing plant in reference to this one relation presents a multitude of problems to those who know how to observe.

B. *On horizontal stems*

23. Examples of horizontal stems, that is, stems exposed on one side to the direct light, will be found in the case of many branches of trees, stems prostrate on the ground, and

stems against a support, as the ivies. It is only necessary to notice how the leaves are adjusted to light on an erect stem, and then to bend the stem into a horizontal position or against a support, to realize how unfavorable the same arrangement would be, and how many new adjustments must be made. The leaf blades must all be brought to the light side of the stem, so far as possible, and those that belong to the lower side of the stem must be fitted into the spaces left by the leaves which belong to the upper side. This may be brought about by the twisting of the stem, the twisting of the petioles, the bending of the blade on the petiole, the lengthening of petioles, or in some other way. Every horizontal stem has its own special problems of leaf adjustment which may be observed (see Figs. 18, 50).

FIG. 17. A chrysanthemum, showing lobed leaves, the rising of the petioles to adjust the blades to light, and the general cylindrical habit.

Sometimes there is not space enough for the full development of every blade, and smaller ones are fitted into the spaces left by the larger ones (see Fig. 21). This sometimes results in what are called unequally paired leaves, where opposite leaves develop one large blade and one small one. Perhaps the most complete fitting together of leaves is found in certain ivies, where a regular layer of angular interlocking leaves is formed, the leaves fitting together like

FIG. 18. A plant (*Pellionia*) with drooping stems, showing how the leaves are all brought to the lighted side and fitted together.

the pieces of a mosaic. In fact such an arrangement is known as the *mosaic arrangement*, and involves such an amount of twisting, displacement, elongation of petioles,

FIG. 20. A spray of maple, showing the adjustment of the leaves in size and position of blades and length of petioles to secure exposure to light on a horizontal stem.—After KERNER.

etc., as to give ample evidence of the effort put forth by plants to secure a favorable light-relation for their foliage

FIG. 21. Two plants showing adjustment of leaves on a horizontal stem. The plant to the left is nightshade, in which small blades are fitted into spaces left by the large ones. The plant to the right is Selaginella, in which small leaves are distributed along the sides of the stem, and others are displayed along the upper surface.—After KERNER.

leaves (see Figs. 19, 22). In the case of ordinary shade trees every direction of branch may be found, and the resulting adjustment of leaves noted (see Fig. 20).

Looking up into a tree in full foliage, it will be noticed that the horizontal branches are comparatively bare be-

FIG. 22. A mosaic of fern (*Adiantum*) leaflets.

neath, while the leaf blades have been carried to the upper side and have assumed a mosaic arrangement.

Sprays of maidenhair fern (see Fig. 22) show a remarkable amount of adjustment of the leaflets to the light side. Another group of fern-plants, known as club-mosses, has horizontal stems clothed with numerous very small leaves. These leaves may be seen taking advantage of all the space on the lighted side (see Fig. 21).

CHAPTER III

FOLIAGE LEAVES: FUNCTION, STRUCTURE, AND PROTECTION

A. *Functions of foliage leaves*

24. **Functions in general.**—We have observed that foliage leaves are light-related organs, and that this relation is an important one is evident from the various kinds of adjustment used to secure it. We infer, therefore, that for some important function of these leaves light is necessary. It would be hasty to suppose that light is necessary for every kind of work done by a foliage leaf, for some forms of work might be carried on by the leaf that light neither helps nor hinders. Foliage leaves are not confined to one function, but are concerned in a variety of processes, all of which have to do with the great work of nutrition. Among the variety of functions which belong to foliage leaves some of the most important may be selected for mention. It will be possible to do little more than indicate these functions until the plant with all its organs is considered, but some evidence can be obtained that various processes are taking place in the foliage leaf.

25. **Photosynthesis.**—The most important function of the foliage leaf may be detected by a simple experiment. If an actively growing water plant submerged in water in a glass vessel be exposed to bright light, bubbles may be seen coming from the leaf surfaces and rising through the water (see Fig. 23). The water is merely a device by which the bubbles of gas may be seen. If the plant is very active the

bubbles are numerous. That this activity holds a definite relation to light may be proved by shading the vessel containing the plant. When the light is diminished the bubbles diminish in number, and when sufficiently darkened

Fig. 23. An experiment to illustrate the giving off of oxygen in the process of photosynthesis.

the bubbles will cease entirely. If now the vessel be again illuminated, the bubbles will reappear, and the rapidity with which the bubbles are formed will indicate in a rough way the activity of the process. That this gas being given off is mainly oxygen may be proved by collecting the bubbles (by inverting over the plants a large funnel and leading them into a test tube), and testing it in the usual way.

Some very important things are learned by this experiment. It is evident that some process is going on within the leaves that needs light and which results in giving off oxygen. It is further evident that as oxygen is eliminated, the process indicated is dealing with substances which contain more oxygen than is needed. The amount of oxygen given off may be taken as the measure of the work. The more oxygen, the more work; and, as we have observed, the more light, the more oxygen; and no light, no oxygen. Therefore, light must be essential to the work of which the elimination of oxygen is an external indication. That this process, whatever it may be, is so essentially related to light, suggests the idea that it is the special process which demands that the leaf shall be a light-related organ. If so, it is a dominating kind of work, as it chiefly determines the life-relations of foliage leaves.

The process thus indicated is known as *photosynthesis*, and the name suggests that it has to do with the arrangement of material with the help of light. It is really a process of food manufacture, by which raw materials are made into plant food. This process is an exceedingly important one, for upon it depend the lives of all plants and animals. The foliage leaves may be considered, therefore, as *special organs of photosynthesis*. They are special organs, not exclusive organs, for any green tissue, whether on stem or fruit or any part of the plant body, may do the same work. It is at once apparent, also, that during the night the process of photosynthesis is not going on, and therefore during the night oxygen is not being given off.

Another part of this process is not so easily observed, but is so closely related to the elimination of oxygen that it must be mentioned. Carbon dioxide occurs in the air to which the foliage leaves are exposed. It is given off from our lungs in breathing, and also comes off from burning wood or coal. It is a common waste product, being a combination of carbon and oxygen so intimate that the two elements are separated from one another with great difficulty. During the process of photosynthesis it has been discovered that carbon dioxide is being absorbed from the air by the leaves. As this gas is absorbed chiefly by green parts and in the light, in just the conditions in which oxygen is being given off, it is natural to connect the two, and to infer that the process of photosynthesis involves not only the green color and the light, but also the absorption of carbon dioxide and the elimination of oxygen.

When we observe that carbon dioxide is a combination of carbon and oxygen, it seems reasonable to suppose that the carbon and oxygen are separated from one another in the plant, and that the carbon is retained and the oxygen given back to the air. The process of photosynthesis may be partially defined, therefore, as the breaking up of carbon dioxide by the green parts of the plants in the presence of light, the retention of the carbon, and the elimination of the oxygen. The carbon retained is combined into real plant food, in a way to be described later. We may consider photosynthesis as the most important function of the foliage leaf, of which the absorption of carbon dioxide and the evolution of oxygen are external indications; and that light and chlorophyll are in some way essentially connected with it.

26. **Transpiration.**—One of the easiest things to observe in connection with a working leaf is the fact that it gives off moisture. A simple experiment may demonstrate this. If a glass vessel (bell jar) be inverted over a small active plant the moisture is seen to condense on the glass, and even to trickle down the sides. A still more convenient way to demonstrate this is to select a single vigorous leaf with a good petiole; pass the petiole through a perforated cardboard resting upon a tumbler containing water, and invert

a second tumbler over the blade of the leaf, which projects above the cardboard (see Fig. 24). It will be observed that moisture given off from the surface of the working leaf is condensed on the inner surface of the inverted tumbler. The cardboard is to shut off evaporation from the water in the lower tumbler.

When the amount of water given off by a single leaf is noted, some vague idea may be formed as to the amount of moisture given off by a great mass of vegetation, such as a meadow or a forest. It is evident that green plants at work are contributing a very large amount of moisture to the air in the form of water vapor, moisture which has been absorbed by some region of the plant. The foliage leaf, therefore, may be regarded as an *organ of transpiration*, not that the leaves alone are engaged in transpiration, for many parts of the plant do the same thing, but because the foliage leaves are the chief seat of transpiration.

In case the leaves are submerged, as is true of many plants, it is evident that transpiration is practically checked, for the leaves are already bathed with water, and under such circumstances water vapor is not given off. It is evident that under such circumstances leaf work must be carried on without transpiration. In some cases, as in certain grasses, fuchsias, etc., drops of water are extruded at the apex of the leaf, or at the tips of the teeth. This process is called *guttation*, and by means of it a good deal of water passes from the leaf. It is specially used by shade plants, which live in conditions that do not favor transpiration.

27. **Respiration.**—Another kind of work also may be detected in the foliage leaf, but not so easily described. In fact it escaped the general attention of botanists much longer than did photosynthesis and transpiration. It is work that goes on so long as the leaf is alive, never ceasing day or night. The external indication of it is the absorption

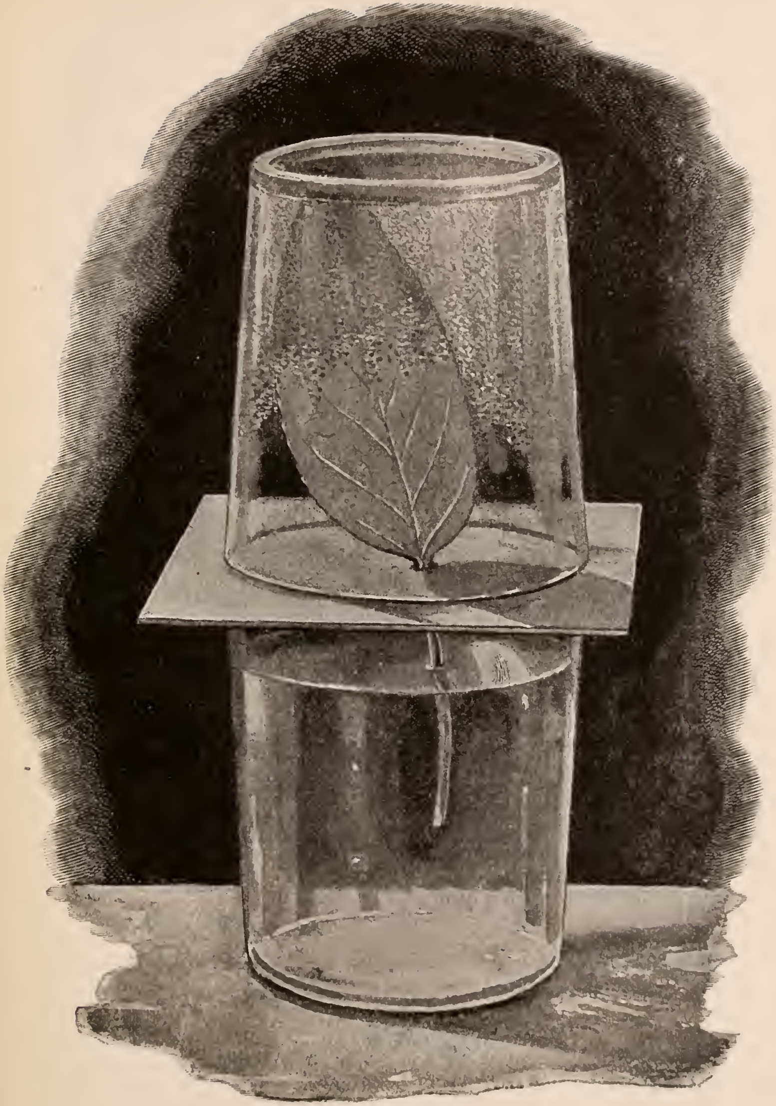

FIG. 24. Experiment illustrating transpiration.

of oxygen and the giving out of carbon dioxide. It will be noted at once that this is exactly the reverse of what takes place in photosynthesis. During the day, therefore, carbon dioxide and oxygen are both being absorbed and evolved. It will also be noted that the taking in of oxygen and the giving out of carbon dioxide is just the sort of exchange which takes place in our own respiration. In fact this process is also called *respiration* in plants. It does not depend upon light, for it goes on in the dark. It does not depend upon chlorophyll, for it goes on in plants and parts of plants which are not green. It is not peculiar to leaves, but goes on in every living part of the plant. A process which goes on without interruption in all living plants and animals must be very closely related to their living. We conclude, therefore, that while photosynthesis is peculiar to green plants, and only takes place in them when light is present, respiration is necessary to all plants in all conditions, and that when it ceases life must soon cease. The fact is, respiration supplies the energy which enables the living substance to work.

Once it was thought that plants differ from animals in the fact that plants absorb carbon dioxide and give off oxygen, while animals absorb oxygen and give off carbon dioxide. It is seen now that there is no such difference, but that respiration (absorption of oxygen and evolution of carbon dioxide) is common to both plants and animals. The difference is that green plants have the added work of photosynthesis.

We must also think of the foliage leaf, therefore, as a respiring organ, because very much of such work is done by it, but it must be remembered that respiration is going on in every living part of the plant.

This by no means completes the list of functions that might be made out for foliage leaves, but it serves to indicate both their peculiar work (photosynthesis) and the fact that they are doing other kinds of work as well.

B. *Structure of foliage leaves*

28. **Gross structure.**—It is evident that the essential part of a foliage leaf is its expanded portion or *blade*. Often the leaf is all blade (see Figs. 7, 8, 18); frequently there is a longer or shorter leaf-stalk (*petiole*) which helps to put

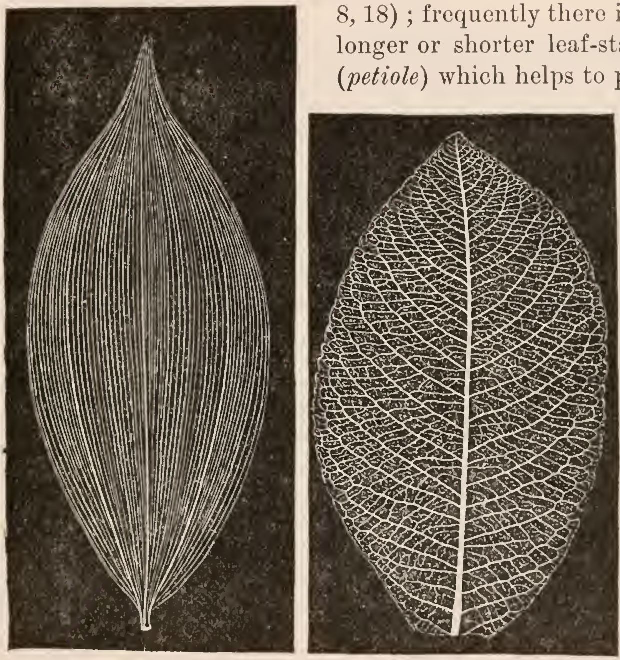

FIG. 25. Two types of leaf venation. The figure to the left is a leaf of Solomon's seal (*Polygonatum*), and shows the principal veins parallel, the very minute cross veinlets being invisible to the naked eye, being a monocotyl type. The figure to the right is a leaf of a willow, and shows netted veins, the main central vein (midrib) sending out a series of parallel branches, which are connected with one another by a network of veinlets, being a dicotyl type.—After ETTINGSHAUSEN.

the blade into better light-relation (see Figs. 1, 9, 17, 20, 26); and sometimes there are little leaf-like appendages (*stipules*) on the petiole where it joins the stem, whose function is not always clear. Upon examining the blade it is seen to consist of a green substance through which a framework of veins is variously arranged. The large veins which enter the blade send off smaller branches, and these send off still smaller ones, until the smallest veinlets are invisible, and the framework is a close network of branching veins. This is plainly shown by a "skeleton" leaf, one which has been so treated that all the green substance has disappeared, and only the network of veins remains. It will be noticed that in some leaves the veins and veinlets are very prominent, in others only the main veins are prominent, while in some it is hard to detect any veins (see Figs. 25, 26).

Fig. 26. A leaf of hawthorn, showing a short petiole, and a broad toothed blade with a conspicuous network of veins. Note the relation between the veins and the teeth.—After Strasburger.

29. Significance of leaf veins.—It is clear that the framework of veins is doing at least two things for the blade: (1) it mechanically supports the spread out green substance ; and (2) it conducts material to and from the green substance. So complete is the network of veins that this support and conduction are very perfect (see Fig. 27). It is also clear that the green substance thus supported and supplied with material is the important part of the leaf, the part that demands the light-relation. Study the various plans of the vein systems in Figs. 3, 9, 13, 18, 19, 20, 21, 25, 26, 51, 70, 73, 82, 83, 92, 161.

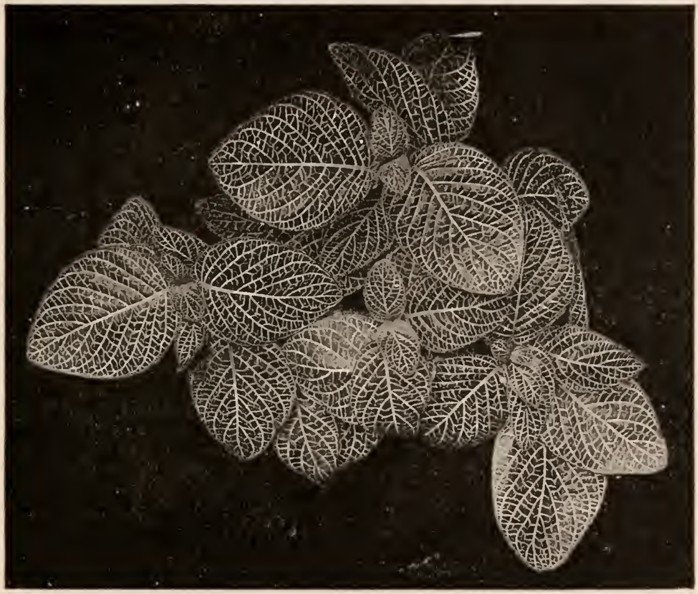

Fig. 27. A plant (*Fittonia*) whose leaves show a network of veins, and also an adjustment to one another to form a mosaic.

30. **Epidermis.**—If a thick leaf be taken, such as that of a hyacinth, it will be found possible to peel off from its surface a delicate transparent skin (*epidermis*). This epidermis completely covers the leaf, and generally shows no green color. It is a protective covering, but at the same time it must not completely shut off the green substance beneath from the outside. It is found, therefore, that three important parts of an ordinary foliage leaf are: (1)

a network of veins; (2) a green substance (*mesophyll*) in the meshes of the network; and (3) over all an epidermis.

31. **Stomata.**—If a compound microscope is used, some very important additional facts may be discovered. The thin, transparent epidermis is found to be made up of a layer of cells which fit closely together, sometimes dovetailing with each other. Curious openings in the epidermis will also be discovered, sometimes in very great numbers. Guarding each opening are two crescent-shaped cells, known as *guard*-cells, and between them a slit-like opening leads through the epidermis. The whole apparatus is known as a *stoma* (plural *stomata*), which really means "mouth," of which the guard-cells might be called the lips (see Figs. 28, 29). Sometimes stomata are found only on the under side of the leaf, sometimes only on the upper side, and sometimes on both sides.

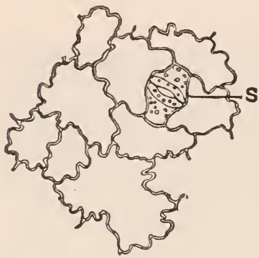

FIG. 28. Cells of the epidermis of *Maranta*, showing the interlocking walls, and a stoma (*s*) with its two guard-cells.

One important fact about stomata is that the guard-cells can change their shape, and so regulate the size of the opening. It is not certain just why the guard-cells change their shape and just what stomata do for leaves. They are often called "breathing pores," but a better name would be air pores. Stomata are not peculiar to the epidermis of foliage leaves, for they are found in the epidermis of any green part, as stems, young fruit, etc. It is evident, therefore, that they hold an important relation to green tissue which is covered by epidermis. Also, if we examine

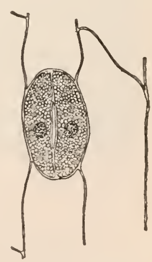

FIG. 29. A single stoma from the epidermis of a lily leaf, showing the two guard-cells full of chlorophyll, and the small slit-like opening between.

foliage leaves and other green parts of plants which live submerged in water, we find that the epidermis contains no stomata. Therefore, stomata hold a definite relation to green parts covered by epidermis only when this epidermis is exposed to the air.

It would seem that the stomata supply open passageways for material from the green tissue through the epidermis to the air, or from the air to the green tissue, or both. It will be remembered, however, that quite a number of substances are taken into the leaf and given out from it, so that it is hard to determine whether the stomata are specially for any one of these movements. For instance, the leaf gives out moisture in transpiration, oxygen in photosynthesis, and carbon dioxide in respiration; while it takes in carbon dioxide in photosynthesis, and oxygen in respiration. It is thought that stomata specially favor transpiration, and that they also much facilitate the entrance of carbon dioxide.

32. **Mesophyll.**—If a cross-section be made of an ordinary foliage leaf, such as that of a lily, the three leaf regions can be seen in their proper relation to each other. Bounding the section above and below is the layer of transparent epidermal cells, pierced here and there by stomata, marked by their peculiar guard-cells. Between the epidermal layers is the green tissue, known as the *mesophyll*, made up of cells which contain numerous small green bodies which give color to the whole leaf, and are known as *chlorophyll bodies* or *chloroplasts*.

The mesophyll cells are usually arranged differently in the upper and lower regions of the leaf. In the upper region the cells are elongated and stand upright, presenting their narrow ends to the upper leaf surface, forming the *palisade* tissue. In the lower region the cells are irregular, and so loosely arranged as to leave passageways for air between, forming the *spongy* tissue. The air spaces among the cells communicate with one another, so that a system of air chambers extends throughout the spongy mesophyll. It is into this system of air chambers that the stomata open, and so they are put into direct communication with the mesophyll or working cells. The peculiar arrangement of the upper mesophyll, to form the palisade tissue, has to do with the fact that that surface of the leaf is exposed to the direct rays of light. This light, so necessary to the mesophyll, is also dangerous for at least two reasons. If

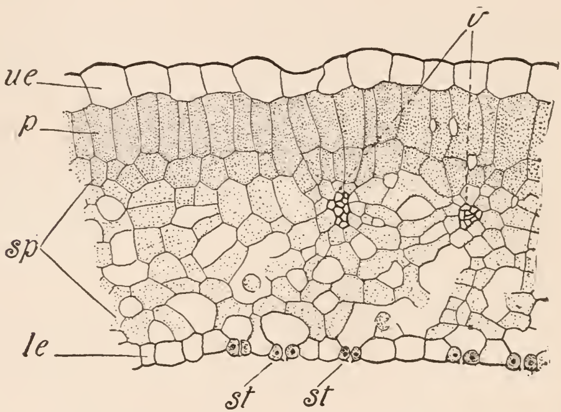

FIG. 30. A section through the leaf of lily, showing upper epidermis (*ue*), lower epidermis (*le*) with its stomata (*st*), mesophyll (dotted cells) composed of the palisade region (*p*) and the spongy region (*sp*) with air spaces among the cells, and two veins (*v*) cut across.

the light is too intense it may destroy the chlorophyll, and the heated air may dry out the cells. The narrow ends of the cells present less exposure, and the depth of the cells permits greater freedom of movement to the chloroplasts.

33. **Veins.**—In the cross-section of the leaf there will also be seen here and there, embedded in the mesophyll, the cut ends of the veinlets, made up partly of thick-walled cells, which hold the leaf in shape and conduct material to and from the mesophyll (see Fig. 30).

C. *Leaf protection*

34. **Need of protection.**—Such an important organ as the leaf, with its delicate active cells well displayed, is exposed to numerous dangers. Chief among these dangers are intense light, drought, and cold. All leaves are not exposed to these dangers. For example, plants which grow in the shade are not in danger from intense light; many water plants are not in danger from drought; and plants of the tropical lowlands are in no

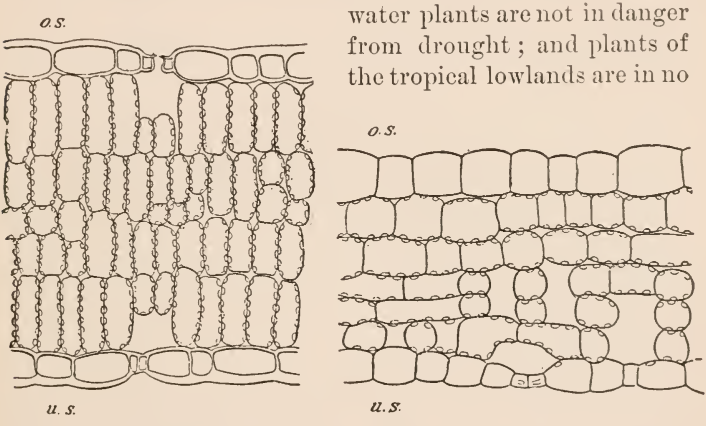

FIG. 31. Sections through leaves of the same plant, showing the effect of exposure to light upon the structure of the mesophyll. In both cases *os* indicates upper surface, and *us* under surface. In the section at the left the growing leaf was exposed to direct and intense sunlight, and, as a consequence, all of the mesophyll cells have assumed the protected or palisade position. In the section at the right the leaf was grown in the shade, and none of the mesophyll cells have organized in palisade fashion.—After STAHL.

danger from cold. The danger from all these sources is because of the large surface with no great thickness of body, and the protection against all of them is practically the same. Most of the forms of protection can be reduced to two general plans: (1) the development of protective structures between the endangered mesophyll and the air; (2) the diminution of the exposed surface.

35. **Protective structures.**—The palisade arrangement of mesophyll may be regarded as an adaptation for protection,

but it usually occurs, and does not necessarily imply extreme conditions of any kind. However, palisade tissue of unusually narrow and elongated cells, or forming two or

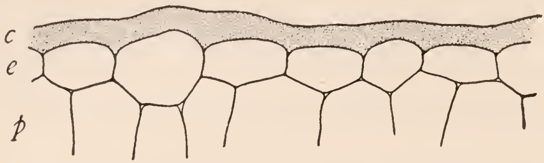

FIG. 32. Section through a portion of the leaf of the yew (*Taxus*), showing cuticle (*c*), epidermis (*e*), and the upper portion of the palisade cells (*p*).

three layers, indicates exposure to intense light or drouth, and is very characteristic of alpine and desert plants. The accompanying illustration (Fig. 31) shows in a striking way the effect of light intensity upon the structure of the mesophyll, by contrasting leaves of the same plant exposed to the extreme conditions of light and shade.

The most usual structural adaptations, however, are connected with the epidermis. The outer walls of the epidermal cells may become thickened, sometimes excessively so; the other epidermal walls may also become more or less thickened; or even what seems to be more than one epidermal layer is found protecting the mesophyll. If the outer walls of the epidermal cells continue to thicken, the outer region of the thick wall loses its structure and forms the *cuticle*, which is one of the

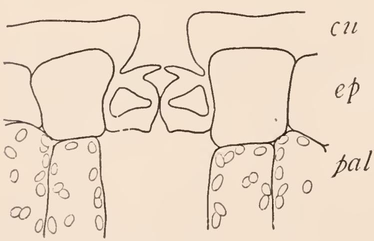

FIG. 33. Section through a portion of the leaf of carnation, showing the heavy cuticle (*cu*) formed by the outer walls of the epidermal cells (*ep*). Through the cuticle a passageway leads to the stoma, whose two guard-cells are seen lying between the two epidermal cells shown in the figure. Below the epidermal cells some of the palisade cells (*pal*) are shown containing chloroplasts, and below the stoma is seen the air chamber into which it opens.

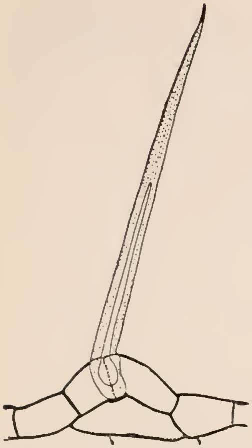

FIG. 34. A hair from the leaf of *Potentilla*. It is seen to grow out from the epidermis.

best protective substances (see Fig. 32). Sometimes this cuticle becomes so thick that the passageways through it leading down to the stomata become regular canals (see Fig. 33).

Another very common protective structure upon leaves is to be found in the great variety of hairs developed by the epidermis. These may form but a slightly downy covering, or the leaf may be covered by a woolly or felt-like mass so that the epidermis is entirely concealed. The common mullein is a good illustration of a felt-covered leaf (see Fig. 36). In cold or dry regions the hairy covering of leaves is very noticeable, often giving them a brilliant silky white or bronze look (see Figs. 34, 35). Sometimes, instead of a hair-like covering, the epidermis develops scales of various patterns, often overlapping, and forming an excellent protection (see Fig. 37). In all these cases it should be remembered that these hairs and scales may serve other purposes also, and may even be of no use whatever to the plant.

36. **Diminution of exposed surface.**— It will be impossible to give more than a few illustrations of this large subject. In very dry regions it has always been noticed that the leaves are small and

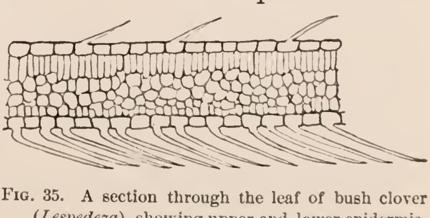

FIG. 35. A section through the leaf of bush clover (*Lespedeza*), showing upper and lower epidermis, palisade cells, and cells of the spongy region. The lower epidermis produces numerous hairs which bend sharply and lie along the leaf surface (appressed), forming a close covering

FIG. 36. A branching hair from the leaf of common mullein, showing the outline but not the many cells.

comparatively thick, although they may be very numerous (see Figs. 4, 172). In this way each leaf exposes a small surface to the drying air and intense sunlight. In our southwestern dry regions the cactus abounds, plants which have reduced their leaves so much that they are no longer used for chlorophyll work, and are not usually recognized as leaves. In their stead the globular or cylindrical or flattened stems are green and do leaf work (Figs.

FIG. 37. A scale from the leaf of *Shepherdia*. These scales overlap and form a complete covering.

FIG. 38. A group of plants from the cactus deserts, showing reduced leaf surface. At the extreme right and left are agaves, with very thick leaves. In the center are columnar cactus forms; at the right and left on the ground are small spherical cactus forms; and in the extreme background is a prickly pear cactus. Between the two columnar cactuses is a small-leaved

Fig. 39. A group of cactus forms (slender cylindrical, columnar, and globular), all of them spiny and without leaves; an agave in front; clusters of yucca flowers in the background.

38, 39, 40, **190, 191, 192, 193**). In the same regions the agaves and yuccas retain their leaves, but they become so thick that they serve as water reservoirs (see Figs. 38, 39,

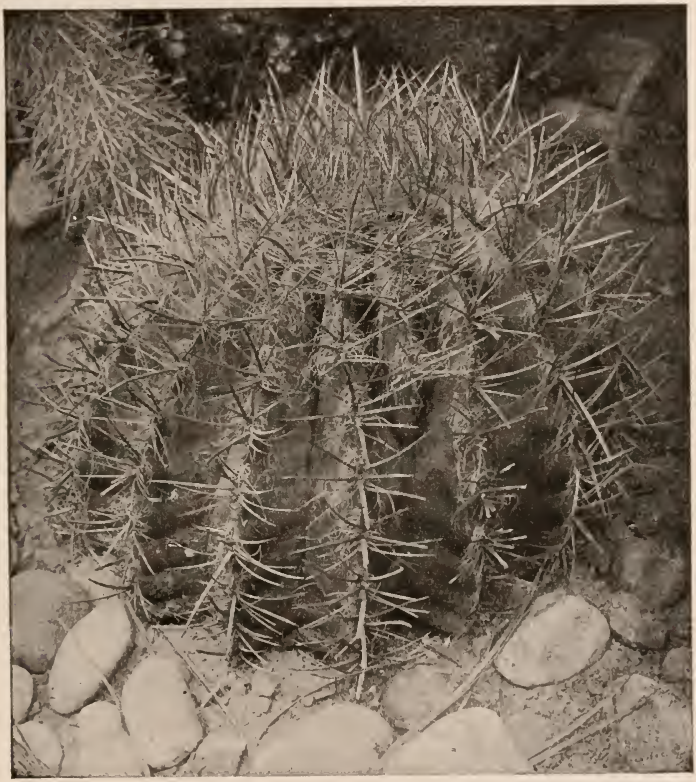

Fig. 40. A globular cactus, showing the ribbed stem, the strong spines, and the entire absence of leaves.

194). In all these cases this reduced surface is supplemented by palisade tissue, very thick epidermal walls, and an abundant cuticle.

37. **Rosette arrangement.**—The rosette arrangement of leaves is a very common method of protection used by

small plants growing in exposed situations, as bare rocks and sandy ground. The cluster of leaves, flat upon the ground, or nearly so, and more or less overlapping, is very effectively arranged for resisting intense light or drought or cold (see Figs. 11, 12, 48).

38. **Protective positions.**—In other cases, a position is assumed by the leaves which directs their flat surfaces so that they are not exposed to the most intense rays of light. The so-called "com-

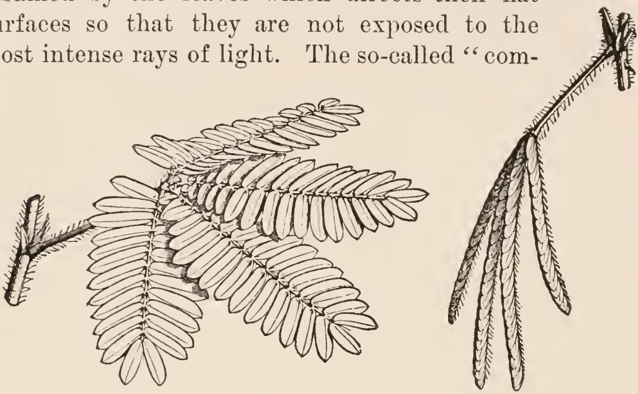

FIG. 41. A leaf of a sensitive plant in two conditions. In the figure to the left the leaf is fully expanded, with its four main divisions and numerous leaflets well spread. In the figure to the right is shown the same leaf after it has been "shocked" by a sudden touch, or by sudden heat, or in some other way. The leaflets have been thrown together forward and upward; the four main divisions have been moved together; and the main leaf-stalk has been directed sharply downward. The whole change has very much reduced the surface of exposure.—After DUCHARTRE.

pass plants," already mentioned, are illustrations of this, the leaves standing edgewise and receiving on their surface the less intense rays of light (see Figs. 5, 170). In the dry regions of Australia the leaves on many of the forest trees and shrubs have this characteristic edgewise position, known as the *profile position,* giving to the foliage a very curious appearance.

Some leaves have the power of shifting their position according to their needs, directing their flat surfaces toward the light, or more or less inclining them, according

FIG. 42. The telegraph plant (*Desmodium gyrans*). Each leaf is made up of three leaflets, a large terminal one, and a pair of small lateral ones. In the lowest figure the large leaflets are spread out in their day position ; in the central figure they are turned sharply downward in their night position. The name of the plant refers to the peculiar and constant motion of the pair of lateral leaflets, each one of which describes a curve with a jerking motion, like the second-hand of a watch, as indicated in the uppermost figure.

to the danger. Perhaps the most completely adapted leaves of this kind are those of the "sensitive plants," whose leaves respond to various external influences by changing their positions. The common sensitive plant abounds in dry regions, and may be taken as a type of such plants (see Figs. 4, 41, 171). The leaves are divided into very numerous small leaflets, sometimes very small, which stretch in pairs along the leaf branches. When drought approaches, some of the pairs of leaflets fold together, slightly reducing the surface exposure. As the drought continues, more leaflets fold together, then still others, until finally all the leaflets may be folded together, and the leaves themselves may bend against the stem. It is like a sailing vessel gradually taking in sail as a storm approaches, until finally nothing is exposed, and the vessel weathers the storm by presenting only bare poles. Sensitive plants can thus regulate the exposed surface very exactly to the need.

Fig. 43. Cotyledons of squash seedling, showing positions in light (left figure) and in darkness (right figure).—After Atkinson.

Such motile leaves not only behave in this manner at the coming of drought, but the positions of the leaflets are shifted throughout the day in reference to light, and at night a very characteristic position is assumed (see Figs. 2, 3, 42), once called a "sleeping position." One danger from night exposure may come from the radiation of heat which might chill the leaves too much; but the night position may have no such meaning. The leaflets of *Oxalis* have been referred to (see §14). Similar changes in the direction of the leaf planes at the coming of night may be observed in most of the *Leguminosæ*, even the common white clover displaying it. It can be observed that the expanded seed leaves (*cotyledons*) of many young germinating plants shift their positions at night (see Fig. 43), often assuming a vertical position which brings them in contact with one another, and also covers the stem bud (*plumule*).

Certain leaves with well-developed protective structures are able to endure the winter, as in the case of the so-called evergreens. In the case of juniper, however, the winter and summer positions of the leaves are quite different (see Fig. 44). In the winter the leaves lie close against the stem and overlap one another; while with the coming of summer conditions they become widely spreading.

FIG. 44. Two twigs of juniper, showing the ordinary summer and winter positions assumed by the leaves. The ordinary protected winter position of the leaves is shown by *A*; while in *B*, in response to summer conditions, the leaves have spread apart and have become freely exposed.—After WARMING.

39. **Protection against rain.**—It is also necessary for leaves to avoid becoming wet by rain. If the water is allowed to soak in there is danger of filling the stomata and interfering with the air exchanges. Hence it will be noticed that most leaves are able to shed water, partly by their positions, partly by their structure. In many plants the leaves are so arranged that the water runs off towards the stem and so reaches the main root system; in other plants the rain is shed outwards, as from the eaves of a house.

Some of the structures which prevent the rain from soaking in are a smooth epidermis, a cuticle layer, waxy secretions, felt-like coverings, etc. Interesting experiments may be performed with different leaves to test their power of shedding water. If a gentle spray of water is allowed to play upon different plants, it will be observed that the water glances off at once from the surfaces of some leaves, runs off more slowly from others, and may be more or less retained by others.

In this same connection it should be noticed that in most horizontal leaves the two surfaces differ more or less in appearance, the upper usually being smoother than the lower, and the stomata occurring in larger numbers, sometimes exclusively, upon the under surface. While these differences doubtless have a more important meaning than protection against wetting, they are also suggestive in this connection.

CHAPTER IV

SHOOTS

40. **General characters.**—The term shoot is used to include both stem and leaves. Among the lower plants, such as the algæ and toadstools, there is no distinct stem and leaf. In such plants the working body is spoken of as the thallus, which does the work done by both stem and leaf in the higher plants. These two kinds of work are separated in the higher plants, and the shoot is differentiated into stem and leaves.

41. **Life-relation.**—In seeking to discover the essential life-relation of the stem, it is evident that it is not necessarily a light-relation, as in the case of the foliage leaf, for many stems are subterranean. Also, in general, the stem is not an expanded organ, as is the ordinary foliage leaf. This indicates that whatever may be its essential life-relation it has little to do with exposure of surface. It becomes plain that the stem is the great leaf-bearing organ, and that its life-relation is a leaf-relation. Often stems branch, and this increases their power of producing leaves.

In classifying stems, therefore, it seems natural to use the kind of leaves they bear. From this standpoint there are three prominent kinds of stems : (1) those bearing foliage leaves ; (2) those bearing scale leaves; and (3) those bearing floral leaves. There are some peculiar forms of stems which do not bear leaves of any kind, but they need not be included in this general view.

A. *Stems bearing foliage leaves.*

42. **General character.**—As the purpose of this stem is to display foliage leaves, and as it has been discovered that the essential life-relation of foliage leaves is the light-relation, it follows that a stem of this type must be able to relate its leaves to light. It is, therefore, commonly aerial, and that it may properly display the leaves it is generally elongated, with its joints (*nodes*) bearing the leaves well separated (see Figs. 1, 4, 18, 20).

The foliage-bearing stem is generally the most conspicuous part of the plant and gives style to the whole body. One's impression of the forms of most plants is obtained from the foliage-bearing stems. Such stems have great range in size and length of life, from minute size and very short life to huge trees which may endure for centuries. Branching is also quite a feature of foliage-bearing stems; and when it occurs it is evident that the power of displaying foliage is correspondingly increased. Certain prominent types of foliage-bearing stems may be considered.

43. **The subterranean type.**—It may seem strange to include any subterranean stem with those that bear foliage, as such a stem seems to be away from any light-relation. Ordinarily subterranean stems send foliage-bearing branches above the surface, and such stems are not to be classed as foliage-bearing stems. But often the only stem possessed by the plant is subterranean, and no branches are sent to the surface. In such cases only foliage leaves appear above ground, and they come directly from the subterranean stem. The ordinary ferns furnish a conspicuous illustration of this habit, all that is seen of them above ground being the characteristic leaves, the commonly called "stem" being only the petiole of the leaf (see Figs. 45, 46, 144). Many seed plants can also be found which show the same habit, especially those which flower early in the spring. This cannot be regarded as a very favorable type of stem for

Fig. 45. A fern (*Aspidium*), showing three large branching leaves coming from a horizontal subterranean stem (rootstock); growing leaves are also shown, which are gradually unrolling. The stem, young leaves, and petioles of the large leaves are thickly covered with protecting hairs. The stem gives rise to numerous small roots from its lower surface. The figure marked 3 represents the under surface of a portion of the leaf, showing seven groups of spore cases; at 5 is represented a section through one of these groups, showing how the spore cases are attached and protected by a flap; while at 6 is represented a single spore case opening and discharging its spores, the heavy spring-like ring extending along the back and over the top.—After Wossidlo.

leaf display, and as a rule such stems do not produce many foliage leaves, but the leaves are apt to be large.

Fig. 46. A common fern, showing the underground stem (rootstock), which sends the few large foliage leaves above the surface.—After Atkinson.

The subterranean position is a good one, however, for purposes of protection against cold or drought, and when the foliage leaves are killed new ones can be put out by the protected stem. This position is also taken advantage of for comparatively safe food storage, and such stems are apt to become more or less thickened and distorted by this food deposit.

44. **The procumbent type.**—In this case the main body of the stem lies more or less prostrate, although the advancing tip is usually erect. Such stems may spread in all directions, and become interwoven into a mat or carpet. They are found especially on sterile and exposed soil,

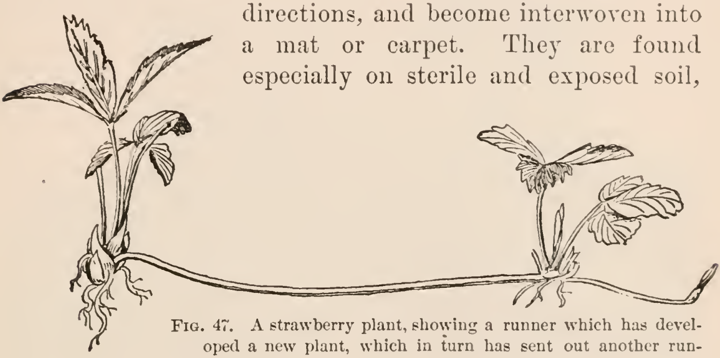

FIG. 47. A strawberry plant, showing a runner which has developed a new plant, which in turn has sent out another runner.—After SEUBERT.

and there may be an important relation between this fact and their habit, as there may not be sufficient building material for erect stems, and the erect position might result in too much exposure to light, or heat, or wind, etc. Whatever may be the cause of the procumbent habit, it has its advantages. As compared with the erect stem, there is economy of building material, for the rigid structures to enable it to stand upright are not necessary. On the other hand, such a stem loses in its power to display leaves. Instead of being free to put out its leaves in every direction, one side is against the ground, and the space for leaves is diminished at least one-half. All the leaves it bears are necessarily directed towards the free side (see Fig. 18).

We may be sure, however, that any disadvantage coming from this unfavorable position for leaf display is overbalanced by advantages in other respects. The position is certainly one of protection, and it has a further advantage in the way of migration and vegetative propagation. As the stem advances over the ground, roots strike out of the nodes into the soil. In this way fresh anchorage and new soil supplies are secured ; the old parts of the stem may

FIG. 48. Two plants of a saxifrage, showing rosette habit, and also the numerous runners sent out from the base, which strike root at tip and produce new plants. —After KERNER.

die, but the newer portions have their soil connection and continue to live. So effective is this habit for this kind of propagation that plants with erect stems often make use of it, sending out from near the base special prostrate branches, which advance over the ground and form new plants. A very familiar illustration is furnished by the strawberry plant, which sends out peculiar naked "runners" to strike root and form new plants, which then become independent plants by the dying of the runners (see Figs. 47, 48).

45. **The floating type.**—In this case the stems are sustained by water. Numerous illustrations can be found in small inland lakes and slow-moving streams (see Fig. 49). Beneath the water these stems often seem quite erect, but

FIG. 49. A submerged plant (*Ceratophyllum*) with floating stems, showing the stem joints bearing finely divided leaves.

when taken out they collapse, lacking the buoyant power of the water. Growing free and more or less upright in the water, they seem to have all the freedom of erect stems in displaying foliage leaves, and at the same time they are not called upon to build rigid structures. Economy of building material and entire freedom to display foliage would seem to be a happy combination for plants. It must be noticed, however, that another very important condition is introduced. To reach the leaf surfaces the light must pass through the water, and this diminishes its intensity so greatly that the working power of the leaves is reduced. At no very great depth of water a limit is reached, beyond which the light is no longer able to be of service to the leaves in their work. Hence it is that water plants are restricted to the surface of the water, or to shoal places; and in such places vegetation is very abundant. Water is so serious an impediment to light that very many plants bring their working leaves to the surface and float them, as seen in water lilies, thus obtaining light of undiminished intensity.

FIG. 50. A vine or liana climbing the trunk of a tree. The leaves are all adjusted to face the light and to avoid shading one another as far as possible.

46. **The climbing type.**—Climbing stems are developed especially in the tropics, where the vegetation is so dense and overshadowing that many stems have learned to climb upon the bodies of other plants, and so spread their leaves in better light (see Figs. 50, 55, 98, 199). Great woody vines fairly interlace the vegetation of tropical forests, and are known as "lianas," or "lianes." The same habit is noticeable, also, in our temperate vegetation, but it is by no means so extensively displayed as in the tropics. There are a good many forms of climbing stems. Remembering that the habit refers to one stem depending upon another for mechanical support, we may include many hedge plants in the

list of climbers. In this case the stems are too weak to stand alone, but by interlacing with one another they may keep an upright position. There are stems, also, which climb by twining about their support, as the hop vine and

FIG. 51. A cluster of smilax, showing the tendrils which enable it to climb, and also the prickles.—After KERNER.

morning glory; others which put out tendrils to grasp the support (see Figs. 51, 52), as the grapevine and star cucumber; and still others which climb by sending out suckers to act as holdfasts, as the woodbine (see Figs. 53, 54). In all these cases there is an attempt to reach towards the light without developing such structures in the stem as would enable it to stand upright.

47. **The erect type.**—This type seems altogether the best adapted for the proper display of foliage leaves. Leaves

FIG. 52. Passion-flower vines climbing supports by means of tendrils, which may be seen more or less extended or coiled. The two types of leaves upon a single stem may also be noted.

can be sent out in all directions and carried upward towards the light; but it is at the expense of developing an elaborate mechanical system to enable the stem to retain this position. There is an interesting relation between these erect bodies and zones of temperature. At high alti-

FIG. 53. Woodbine (*Ampelopsis*) in a deciduous forest. The tree trunks are almost covered by the dense masses of woodbine, whose leaves are adjusted so as to form compact mosaics. A lower stratum of vegetation is visible, composed of shrubs and tall herbs, showing that the forest is somewhat open.

tudes or latitudes the subterranean and prostrate types of foliage-bearing stems are most common; and as one passes to lower altitudes or latitudes the erect stems become more numerous and more lofty. Among stems of the erect type the tree is the most impressive, and it has developed into a great variety of forms or "habits." Any one recognizes the great difference in the habits of the pine and the elm (see Figs. 56, 57, 58, 59), and many of our

FIG. 54. A portion of a woodbine (*Ampelopsis*). The stem tendrils have attached themselves to a smooth wall by means of disk-like suckers.—After STRASBURGER.

Fig. 55. A liana in the Botanic Garden at Peradenyia, Ceylon.—After Schimper.

FIG. 56. A tree of the pine type (larch), showing the continuous central shaft and the horizontal branches, which tend to become more upright towards the top of the tree. The general outline is distinctly conical. The larch is peculiar among such trees in periodically shedding its leaves.

Fig. 57. A pine tree, showing the central shaft and also the bunching of the needle leaves toward the tips of the branches where there is the best exposure to light.

common trees may be known, even at a distance, by their characteristic habits (see Figs. 60, 61, 62). The difficulty of the mechanical problems solved by these huge bodies is very great. They maintain form and position and endure tremendous pressure and strain.

Fig. 58. An elm in its winter condition, showing the absence of a continuous central shaft, the main stem soon breaking up into branches, and giving a spreading top. On each side in the background are trees of the pine type, showing the central shaft and conical outline.

48. **Relation to light.**—As stems bearing foliage leaves hold a special relation to light, it is necessary to speak of the influence of light upon their direction, the response to

FIG. 59. An elm in foliage, showing the breaking up of the trunk into branches and the spreading top.

which is known as *heliotropism,* already referred to under foliage leaves. In the case of an erect stem the tendency is to grow towards the source of light (see Figs. 1, 64).

This has the general result of placing the leaf blades at right angles to the rays of light, and in this respect the heliotropism of the stem aids in securing a favorable leaf position (see Figs. 63, 63*a*). Prostrate stems are differently affected by the light, however, being directed transversely to the rays of light. The same is true of many foliage

FIG. 60. An oak in its winter condition, showing the wide branching. The various directions of the branches have been determined by the light-relations.

branches, as may be seen by observing almost any tree in which the lower branches are in the general transverse position. These branches generally tend to turn upwards when they are beyond the region of shading. Subterranean stems are also mostly horizontal, but they are out of the influence of light, and under the influence of gravity, the response to which is known as *geotropism*, which guides them into the transverse position. The climbing stem, like the erect one,

FIG. 61. Cottonwoods, in winter condition, on a sand dune, showing the branching habit, and the tendency to grow in groups.

grows towards the light, while floating stems may be either erect or transverse.

B. *Stems bearing scale leaves*

49. **General character.**—A scale leaf is one which does not serve as foliage, as it does not develop the necessary chlorophyll. This means that it does not need such an exposure of surface, and hence scale leaves are usually much smaller, and certainly are more inconspicuous than foliage leaves. A good illustration of scale leaves is furnished by the ordinary scaly buds of trees, in which the covering of overlapping scaly leaves is very conspicuous (see Fig. 65). As there is no development of chlorophyll in such leaves,

they do not need to be exposed to the light. Stems bearing only scale leaves, therefore, hold no necessary light-relation, and may be subterranean as well as aerial. For the same

FIG. 62. A group of weeping birches, showing the branching habit and the peculiar hanging branchlets. The trunks also show the habit of birch bark in peeling off in bands around the stem.

reason scale leaves do not need to be separated from one another, but may overlap, as in the buds referred to.

Sometimes scale leaves occur so intermixed with foliage

FIG. 63. Sunflowers with the upper part of the stem sharply bent towards the light, giving the leaves better exposure.—After SCHAFFNER.

leaves that no peculiar stem type is developed. In the pines scale leaves are found abundantly on the stems which are developed for foliage purposes. In fact, the main stem axes of pines bear only scale leaves, while short spur-like branches bear the characteristic needles, or foliage leaves, but the form of the stem is controlled by the needs of the foliage. Some very distinct types of scale-bearing stems may be noted.

50. **The bud type.**—In this case the nodes bearing the leaves remain close together, not separating, as is necessary in ordinary foliage-bearing stems, and the leaves overlap. In a stem of this character the later joints may become separated and bear foliage leaves, so that one finds scale leaves below and foliage leaves above on the same stem axis. This is always true in the case of branch buds, in which the scale leaves serve the purpose of protection, and are aerial, not because they need a light-relation, but because they are protecting young foliage leaves which do.

Fig. 63*a*. Cotyledons of castor-oil bean; the seedling to the left showing the ordinary position of the cotyledons, the one to the right showing the curvature of the stem in response to light from one side.—After Atkinson.

Sometimes the scale leaves of this bud type of stem do not serve so much for protection as for food storage, and become fleshy. Ordinary bulbs, such as those of lilies, etc.,

FIG. 64. An araucarian pine, showing the central shaft, and the regular clusters of branches spreading in every direction and bearing numerous small leaves. The lowermost branches extend downwards and are the largest, while those above become more horizontal and smaller. These differences in the size and direction of the branches secure the largest light exposure.

are of this character; and as the main purpose is food storage the most favorable position is a subterranean one (see Fig. 66). Sometimes such scale leaves become very broad and not merely overlap but enwrap one another, as in the case of the onion.

51. **The tuber type.**—The ordinary potato may be taken as an illustration (see Fig. 67). The minute scale leaves, to be found at the "eyes" of the potato, do not overlap, which means that the stem joints are farther apart than in the bud type. The whole form of the stem results from its use as a place of food storage, and hence such stems are generally subterranean. Food storage, subterranean position, and reduced scale leaves are facts which seem to follow each other naturally.

52. **The rootstock type.**—This is probably the most common form of subterranean stem. It is elongated, as are foliage stems, and hence the scale leaves are well separated. It is prominently used for food storage, and is also admirably adapted for subterranean migration (see Fig. 68). It can do for the plant, in the way of migration, what prostrate foliage-bearing stems do, and is in a more protected position. Advancing beneath the ground, it sends up a succession of branches to the surface. It is a very efficient method for the "spreading" of plants, and is extensively used by grasses in covering areas and forming turf. The persistent continuance of the worst weeds is often due to this habit (see Figs. 69, 70). It is impossible to remove all of the indefinitely branching rootstocks from the soil, and any fragments that remain are able to send up fresh crops of aerial branches.

FIG. 65. Branch buds of elm. Three buds (k) with their overlapping scales are shown, each just above the scar (b) of an old leaf.—After BEHRENS.


FIG. 66. A bulb, made up of overlapping scales, which are fleshy on account of food storage.—After GRAY.

53. **Alternation of rest and activity.**—In all of the three stem types just mentioned, it is important to note that they are associated with a remarkable alternation between rest and vigorous activity. From the branch buds the new leaves

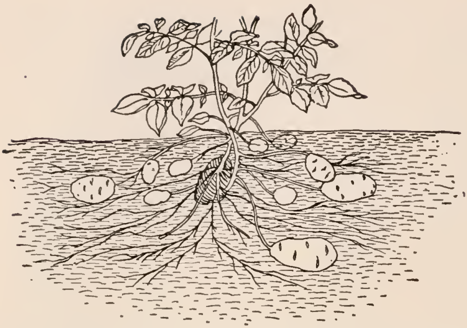

FIG. 67. A potato plant, showing the subterranean tubers.—After STRASBURGER.

emerge with great rapidity, and trees become covered with new foliage in a few days. From the subterranean stems the aerial parts come up so speedily that the surface of the ground seems to be covered suddenly with young vegetation. This sudden change from comparative rest to great activity has been well spoken of as the "awakening" of vegetation.

C. *Stems bearing floral leaves*

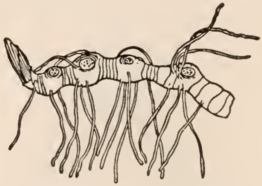

FIG. 68. The rootstock of Solomon's seal; from the under side roots are developed; and on the upper side are seen the scars which mark the positions of the successive aerial branches which bear the leaves. The advancing tip is protected by scales (forming a bud), and the positions of previous buds are indicated by groups of ring-like scars which mark the attachment of former scales. Advancing in front and dying behind such a rootstock may give rise to an indefinite succession of aerial plants.—After GRAY.

54. **The flower.**—The so-called "flowers" which certain plants produce represent another type of shoot, being stems with peculiar leaves. So attractive are flowers that they have been very much studied; and this fact has led many people to believe that flowers are the only parts of plants worth studying. Aside from the fact that a great many plants do not produce flowers, even in those that do the flowers are connected with only one of the plant processes, that of reproduction. Every one knows that flowers are exceedingly variable, and names

have been given to every kind of variation, so that their study is often not much more than learning the definitions of names. However, if we seek to discover the life-relations of flowers we find that they may be stated very simply.

55. **Life-relations.**—The flower is to produce seed. It must not only put itself into proper relation to do this, but

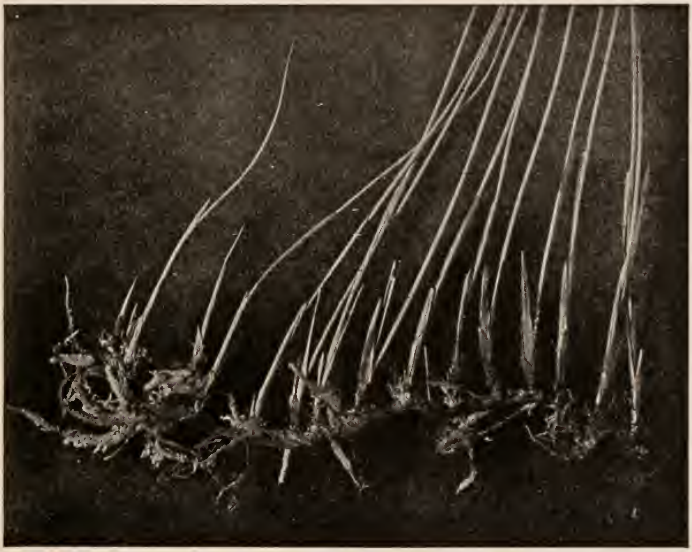

FIG. 69. The rootstock of a rush (*Juncus*), showing how it advances beneath the ground and sends above the surface a succession of branches. The breaking up of such a rootstock only results in so many separate individuals.—After COWLES.

there must also be some arrangement for putting the seeds into proper conditions for developing new plants. In the production of seed it is necessary for the flower to secure a transfer of certain yellowish, powdery bodies which it produces, known as *pollen* or *pollen-grains*, to the organ in which the seeds are produced, known as the *pistil*. This transfer is called *pollination*. One of the important things, therefore, in connection with the flower, is for it to put

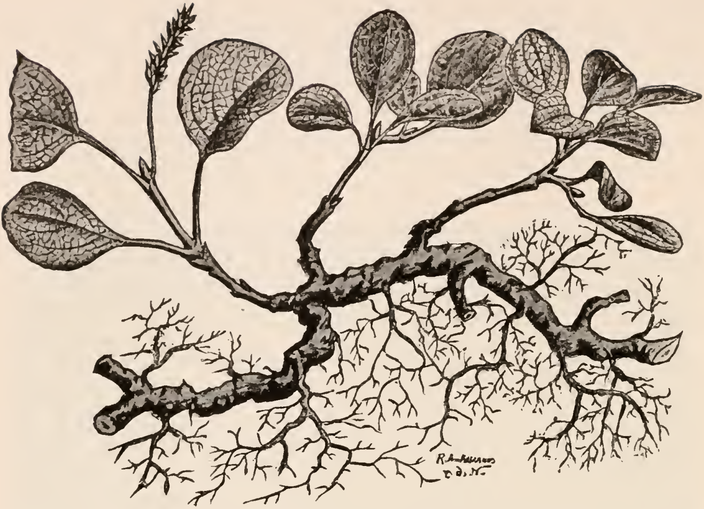

FIG. 70. An alpine willow, showing a strong rootstock developing aerial branches and roots, and capable of long life and extensive migration.—After SCHIMPER.

itself into such relations that it may secure pollination.

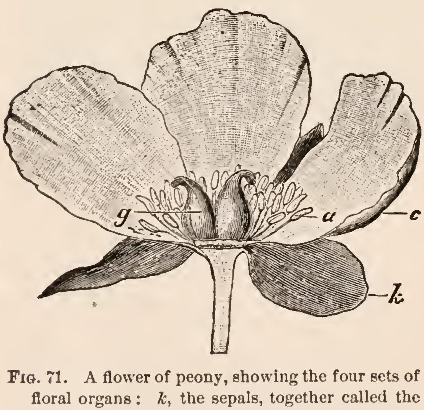

FIG. 71. A flower of peony, showing the four sets of floral organs: *k*, the sepals, together called the calyx; *c*, the petals, together called the corolla; *a*, the numerous stamens; *g*, the two carpels, which contain the ovules.—After STRASBURGER.

Besides pollination, which is necessary to the production of seeds, there must be an arrangement for seed dispersal. It is always well for seeds to be scattered, so as to be separated from one another and from the parent plant. The two great external problems in connection with the flower, therefore, are *polli-*

nation and *seed-dispersal.* It is necessary to call attention to certain peculiar features of this type of stem.

56. **Structures.**—The joints of the stem do not spread apart, so that the peculiar leaves are kept close together, usually forming a rosette-like cluster (see Fig. 71). These leaves are of four kinds : the lowest (outermost) ones (individually *sepals,* collectively *calyx*) mostly resemble small foliage leaves ; the next higher (inner) set (individually *petals,* collectively *corolla*) are usually the most conspicuous, delicate in texture and brightly colored ; the third set (*stamens*) produces the pollen ; the highest (innermost) set (*carpels*) form the pistil and produce the *ovules,* which are to become seeds. These four sets may not all be present in the same flower ; the members of the same set may be more or less blended with one another, forming tubes, urns, etc. (see Figs. 72, 73, 74) ; or the different members may be modified in the greatest variety of ways.

Another peculiarity of this type of stem is that when the

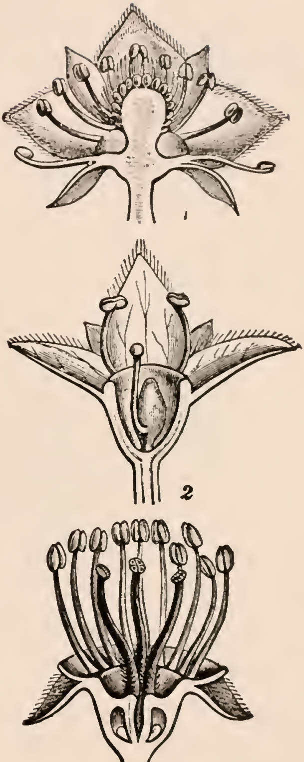

FIG. 72. A group of flowers of the rose family. The one at the top (*Potentilla*) shows three broad sepals, much smaller petals alternating with them, a group of stamens, and a large receptacle bearing numerous small carpels. The central one (*Alchemilla*) shows the tips of two small sepals, three larger petals united below, stamens arising from the rim of the urn, and a single peculiar pistil. The lowest flower (the common apple) shows the sepals, petals, stamens, and three styles, all arising from the ovary part of the pistil.—After FOCKE.

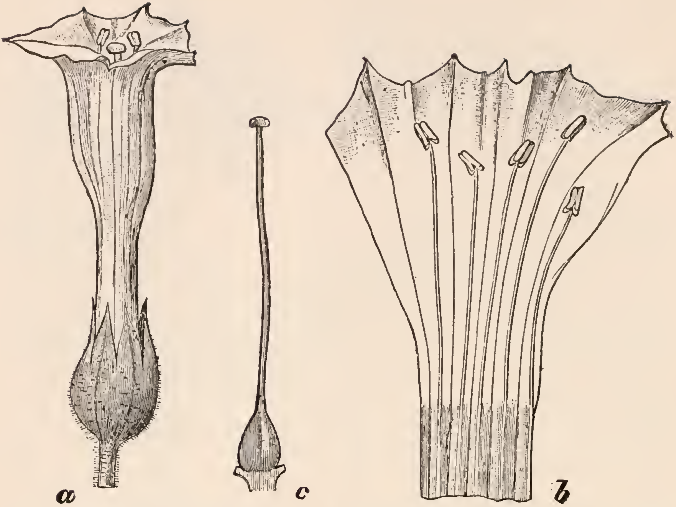

FIG. 73. A flower of the tobacco plant: *a*, a complete flower, showing the calyx with its sepals blended below, the funnelform corolla made up of united petals, and the stamens just showing at the mouth of the corolla tube; *b*, a corolla tube split open and showing the five stamens attached to it near the base; *c*, a pistil made up of two blended carpels, the bulbous base (containing the ovules) being the ovary, the long stalk-like portion the style, and the knob at the top the stigma.—After STRASBURGER.

last set of floral leaves (*carpels*) appear, the growth of the stem in length is checked and the cluster of floral leaves

FIG. 74. A group of flower forms: *a*, a flower of harebell, showing a bell-shaped corolla composed of five petals; *b*, a flower of phlox, showing a tubular corolla with its five petals distinct above and sharply spreading; *c*, a flower of dead-nettle, showing an irregular corolla with its five petals forming two lips above the funnel-form base; *d*, a flower of toad-flax, showing a two-lipped corolla, and also a spur formed by the base of the corolla; *e*, a flower of the snapdragon, showing the two lips of the corolla closed.—After GRAY.

appears to be upon the end of the stem axis. It is usual, also, for the short stem bearing the floral leaves to broaden

FIG. 75. The Star-of-Bethlehem (*Ornithogalum*), showing the loose cluster of flowers at the end of the stem. The leaves and stem arise from a bulb, which produces a cluster of roots below.—After STRASBURGER.

at the apex and form what is called a *receptacle*, upon which the close set floral leaves stand.

Although many floral stems are produced singly, it is very common for them to branch, so that the flowers appear in clusters, sometimes loose and spray-like, sometimes compact (see Figs. 75, 76, 77). For example, the common

FIG. 76. A flower cluster from a walnut tree.—After STRASBURGER.

dandelion "flower" is really a compact head of flowers. All of this branching has in view better arrangements for pollination or for seed-distribution, or for both.

The subject of pollination and seed-distribution will be considered under the head of reproduction.

STRUCTURE AND FUNCTION OF THE STEM

57. **Stem structure.**—The aerial foliage stem is the most favorable for studying stem structure, as it is not distorted by its position or by being a depository for food. If an active twig of an ordinary woody plant be cut across, it will

FIG. 77. Flower clusters of an umbellifer (*Sium*).—After STRASBURGER.

be seen that it is made up of four general regions (see Fig. 78): (1) an outer protecting layer, which may be stripped off as a thin skin, the *epidermis*; (2) within the epidermis a zone, generally green, the *cortex*; (3) an inner zone of wood or vessels, known as the *vascular region*; (4) a central *pith*.

58. **Dicotyledons and Conifers.**—Sometimes the vessels

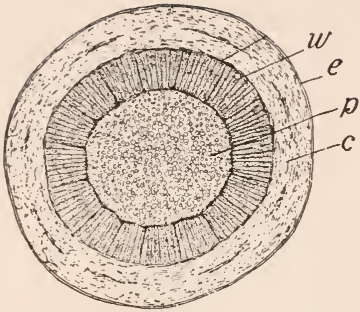

FIG. 78. Section across a young twig of box elder, showing the four stem regions: *e*, epidermis, represented by the heavy bounding line; *c*, cortex; *w*, vascular cylinder; *p*, pith.

are arranged in a hollow cylinder, just inside of the cortex, leaving what is called *pith* in the center (see Fig. 78). Sometimes the pith disappears in older stems or parts of stems and leaves the stem hollow. When the vessels are arranged in this way and the stem lives more than a year, it can increase in diameter by adding new vessels outside of the old. In the case of trees these additions appear in cross-section like a series of concentric rings, and as there is usually but one growth period during the year, they are often called *annual rings* (see Fig. 79), and the age of a tree is often estimated by counting them. This method of ascertaining the age of a tree is not absolutely certain, as there may be more than one growth period in some years. In the case of trees and shrubs the epidermis is replaced on the older parts by layers of cork, which sometimes becomes very thick and makes up the outer part of what is commonly called *bark*.

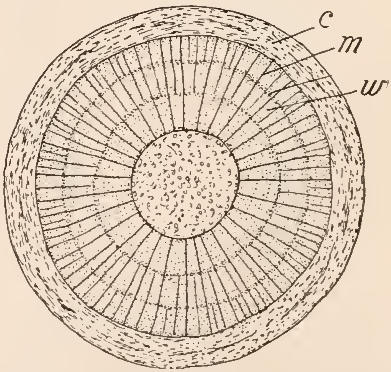

FIG. 79. Section across a twig of box elder three years old, showing three annual rings, or growth rings, in the vascular cylinder. The radiating lines (*m*) which cross the vascular region (*w*) represent the pith rays, the principal ones extending from the pith to the cortex (*c*).

Stems which increase in diameter mostly belong to the great groups called *Dicotyledons* and *Conifers*. To the former belong most of our common trees, such as maple, oak, beech, hickory, etc. (see Figs. 58, 59, 60, 61), as well as the great majority of common herbs; to the latter belong the pines, hemlocks, etc. (see Figs. 56, 57, 64, 193, 194). This annual increase in diameter enables the tree to put out an increased number of branches and hence foliage leaves each year, so that its capacity for leaf work becomes greater year after year. A reason for this is that the stem is conducting important food supplies to the leaves, and if it increases in diameter it can conduct more supplies each year and give work to more leaves.

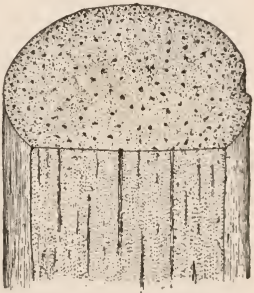

Fig. 80. A corn-stalk, showing cross-section and longitudinal section. The dots represent the scattered bundles of vessels, which in the longitudinal section are seen to be long fiber-like strands.

59. **Monocotyledons.**—In other stems, however, the vessels are arranged differently in the central region. Instead of forming a hollow cylinder enclosing a pith, they are scattered through the central region, as may be seen in the cross-section of a corn-stalk (see Fig. 80). Such stems belong mostly to a great group of plants known as *Monocotyledons*, to which belong palms, grasses, lilies, etc. For the most part such stems do not increase in diameter, hence there is no branching and no increased foliage from year to year. A palm well illustrates this habit, with its columnar, unbranching trunk, and its crown of foliage leaves, which are about the same in number from year to year (see Figs. 81, 82).

60. **Ferns.**—The same is true of the stems of most fern-plants, as the vessels of the central region are so arranged that there can be no diameter increase, though the ar-

Fig. 81. A date palm, showing the unbranched columnar trunk covered with old leaf bases, and with a cluster of huge active leaves at the top, only the lowest portions of which are shown. Two of the very heavy fruit clusters are also shown.

rangement is very different from that found in Monocotyledons. It will be noticed how similar in general appearance is the habit of the tree fern and that of the palm (see Fig. 83).

61. **Lower plants.**—In the case of moss-plants, and such algæ and fungi as develop stems, the stems are very much

FIG. 82. A palm of the palmetto type (fan palm), with low stem and a crown of large leaves.

simpler in construction, but they serve the same general purpose.

62. **Conduction by the stem.**—Aside from the work of producing leaves and furnishing mechanical support, the stem is a great conducting region of the plant. This subject will be considered in Chapter X., under the general head of "The Nutrition of Plants."

Fig. 83. A group of tropical plants. To the left of the center is a tree fern, with its slender columnar stem and crown of large leaves. The large-leaved plants to the right are bananas (monocotyledons).

CHAPTER V

ROOTS

63. **General character.**—The root is a third prominent plant organ, and it presents even a greater variety of relations than leaf or stem. In whatever relation it is found it is either an absorbent organ or a holdfast, and very often both. For such work no light-relation is necessary, as in the case of foliage leaves; and there is no leaf-relation, as in the case of stems. Roots related to the soil may be taken as an illustration.

It is evident that a soil root anchors the plant in the soil, and also absorbs water from the soil. If absorption is considered, it is further evident that the amount of it will depend in some measure upon the amount of surface which the roots expose to the soil. We have already noticed that the foliage leaf has the same problem of exposure, and it solves it by becoming an expanded organ. The question may be fairly asked, therefore, why are not roots expanded organs? The receiving of rays of light, and the absorbing of water are very different in their demands. In the former case a flat surface is demanded, in the latter tubular processes. The increase of surface in the root, therefore, is obtained not by expanding the organ, but by multiplying it. Besides, to obtain the soil water the roots must burrow in every direction, and must send out their delicate thread-like branches to come in contact with as much soil as possible. Furthermore, in soil roots absorption is not the only thing to consider, for the roots act as holdfasts and must grapple the soil. This is certainly done far more effectively by numerous thread-like processes spreading in every direction than by flat, expanded processes.

It should also be noted that as soil roots are subterranean they are used often for the storage of food, as in the case of many subterranean stems. Certain prominent root types may be noted as follows :

64. **Soil roots.**—These roots push into the ground with great energy, and their absorbing surfaces are entirely covered. Only the youngest parts of a root system absorb actively, the older parts transporting the absorbed material to the stem, and helping to grip the soil. The soil root is the most common root type, being

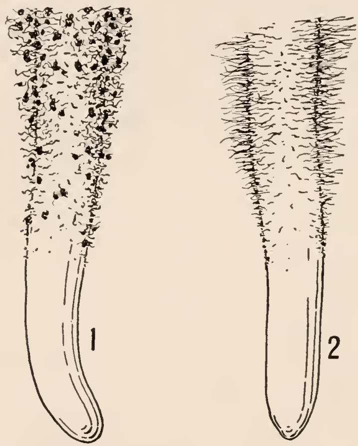

FIG. 84. Root tips of corn, showing root hairs and their position in reference to the growing tip: 1, in soil (higher up the hairs become much more abundant and longer); 2, in moist air.

used by the great majority of seed plants and fern plants, and among the moss plants the very simple root-like processes are mostly soil-related. To such roots the water of the soil presents itself either as *free water*—that is, water that can be drained away—or as films of water adhering to each soil particle, often called *water of adhesion*. To come in contact with this water, not only does the root system usually branch profusely in every direction, but the youngest branches develop abundant absorbing hairs, or *root hairs* (see Fig. 84), which crowd in among the soil particles and absorb moisture from them. By these root hairs the absorbing surface, and hence the amount of absorption, is greatly increased. Individual root hairs do not last very long, but new ones are constantly appearing just behind the advancing root tips, and the old ones are as constantly disappearing.

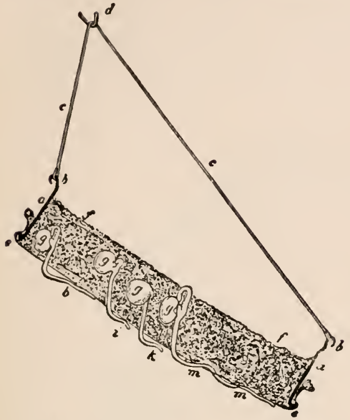

FIG. 85. Apparatus to show the influence of water (hydrotropism) upon the direction of roots. The ends (*a*) of the box have hooks for hanging, while the box proper is a cylinder or trough of wire netting and is filled with damp sawdust. In the sawdust are planted peas (*g*), whose roots (*h, i, k, m*) first descend until they emerge from the damp sawdust, but soon turn back toward it.—After SACHS.

(1) *Geotropism and hydrotropism.*—Many outside influences affect roots in the direction of their growth, and as soil roots are especially favorable for observing these influences, two prominent ones may be mentioned. The influence of gravity, or the earth influence, is very strong in directing the soil root.

FIG. 86. A raspberry plant, whose stem has been bent down to the soil and has "struck root."—After BEAL.

As is well known, when a seed germinates the tip that is to develop the root turns towards the earth, even if it has come from the seed in some other direction. This response to gravity by the plant is known as *geotropism*. Another directing influence is moisture, the response to which is

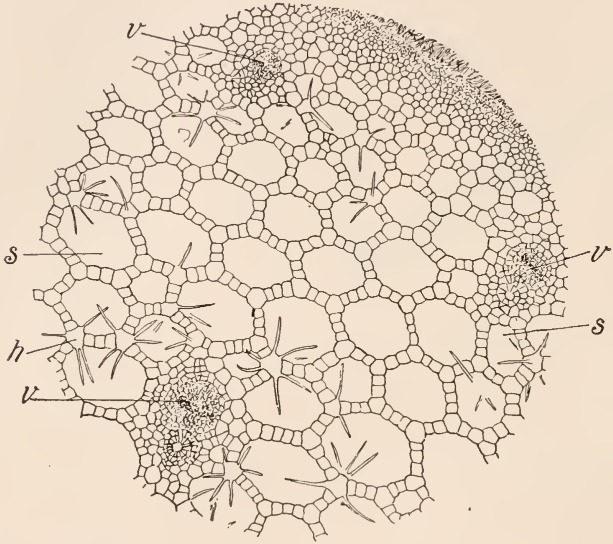

FIG. 87. A section through the leaf-stalk of a yellow pond-lily (*Nuphar*), showing the numerous conspicuous air passages (*s*) by means of which the parts under water are aerated; *h*, internal hairs projecting into the air passages; *v*, the much reduced and comparatively few vascular bundles.

known as *hydrotropism*. By means of this the root is directed towards the most favorable water supply in the soil.

Ordinarily, geotropism and hydrotropism direct the root in the same general way, and so reinforce each other; but the following experiment may be arranged, which will separate these two influences. Bore several small holes in the bottom of a box, suspended as indicated in Fig. 85, and cover the bottom and surround the box with blotting paper. Pass the root tips of several germinated seeds through the holes, so that the seeds rest on the paper, and the root tips hang through the holes. If the paper is kept moist germination will continue, but geotropism will direct the root tips downwards and hydrotropism (response to the moist paper) will direct them upwards. In this way they will pursue a devious course, now directed by one influence and now by the other.

If a root system be examined it will be found that when there is a main axis (*tap root*) it is directed steadily downwards, while the branches are directed differently. This indicates that all parts of a root system are not alike in their response to these influences. Several other influences are also concerned in directing soil roots, and the path of any root branch is a result of all of them. How variable they are may be seen by the numerous directions in which the branches travel, and the whole root system preserves the record of these numerous paths.

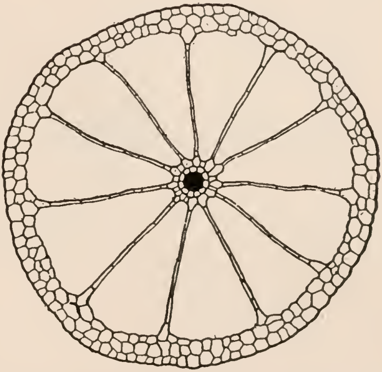

FIG. 88. A section through the stem of a waterwort (*Elatine*), showing the remarkably large and regularly arranged air passages for root aeration. The single reduced vascular bundle is central and connected with the small cortex by thin plates of cells which radiate like the spokes of a wheel.—After SCHENCK.

(2) *The pull on the stem.*—Another root property may be noted in connection with the soil root, namely the pull on the stem. When a strawberry runner strikes root at tip (see Fig. 47), the roots, after they obtain anchorage in the soil, pull the tip a little beneath the surface, as if they had gripped the soil and then slightly contracted. The same thing may be observed in the process known as

"layering," by which a stem, as a bramble, is bent down and covered with soil. The covered joints strike root, and the pulling follows (see Fig. 86). A very plain illustration of this pulling by roots can be obtained from many tuberous plants. Tubers, bulbs, rootstocks, etc., are underground structures which have been observed to bury themselves deeper and deeper in the soil. This is effected by the young

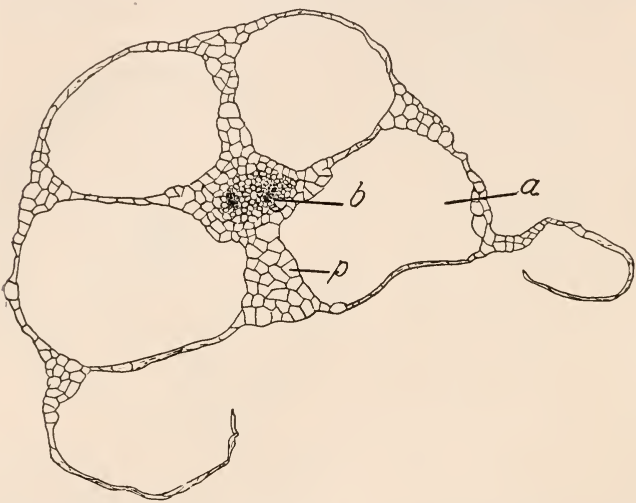

FIG. 89. Section through the leaf of a quillwort (*Isoetes*), showing the four large air chambers (*a*), the central vascular region (*b*), and the very poorly developed cortex.

roots which they continue to put forth. These roots grip the soil, then contract, and the tuber is pulled a little deeper. The compact tuber known as the Indian turnip ("Jack-in-the-pulpit") has been found to bury itself very deeply and rapidly, and this may be observed by transplanting a young and vigorous tuber into a pot of loose soil.

(3) *Soil dangers.*—In this connection certain soil dangers and the response of the roots should be noted. The soil may become poor in water or poor in certain essential materials, and this results in an extension of the root sys-

tem, as if seeking for water and the essential materials. Sometimes the root system becomes remarkably extensive, visiting a large amount of soil in order to procure the necessary supplies. Sometimes the soil is poor in heat, and root activity is interfered with. In such cases it is very common to find the leaves massed against the soil, thus slightly checking the loss of heat.

Most soil roots also need free air, and when water covers the soil the supply is cut off. In many cases there is some way by which a supply of free air may be brought down into the roots from the parts above water; sometimes by large air passages in leaves and stems (see Figs. 87, 88, 89, 90); sometimes by developing special root structures which rise above the water level, as prominently shown by the cypress in the development of *knees*. These knees are outgrowths from roots beneath the water of the cypress swamp, and rise above the water level, thus reaching the air and aerating the root system (see Fig. 91). It has been shown that if the water rises so high as to flood the knees for any length of time the trees will die, but it does not follow that this is the chief reason for their development.

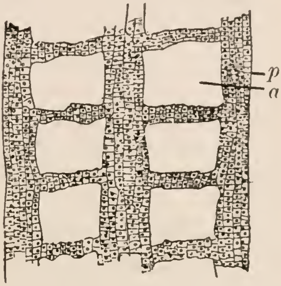

FIG. 90. Longitudinal section through a young quillwort leaf, showing that the four air chambers shown in Fig. 89 are not continuous passages, but that there are four vertical rows of prominent chambers. The plates of cells separating the chambers in a vertical row very soon become dead and full of air. In addition to the work of aeration these air chambers are very serviceable in enabling the leaves to float when they break off and carry the comparatively heavy spore cases.

65. **Water roots.**—A very different type of root is developed if it is exposed to free water, without any soil relation. If a stem is floating, clusters of whitish thread-like roots usually put out from it and dangle in the water. If the water level sinks so as to bring the tips of these roots to the mucky

FIG. 91. A cypress swamp near Clarksdale, Mississippi. In the center are two cypresses, with buttressed trunks, and surrounded by a group of conical "knees," which arise from the roots.—Photographed by O. W. CALDWELL.

FIG. 92. A tropical aroid (*Anthurium*), showing its large leaves, and bunches of aerial roots.

soil they usually do not penetrate or enter into any soil relation. Such pure water roots may be found dangling from the under surface of the common duck weeds, which often cover the surface of stagnant water with their minute, green, disk-like bodies.

Plants which ordinarily develop soil roots, if brought into proper water relations, may develop water roots. For instance, willows or other stream bank plants may be so close to the water that some of the root system enters it. In such cases the numerous clustered roots show their water

Fig. 93. An orchid, showing aerial roots.

character. Sometimes root systems developing in the soil may enter tile drains, when water roots will develop in such clusters as to choke the drain. The same bunching of water roots may be noticed when a hyacinth bulb is grown in a vessel of water.

66. **Air roots.**—In certain parts of the tropics the air is so moist that it is possible for some plants to obtain suffi-

cient moisture from this source, without any soil-relation or water-relation. Among these plants the orchids are most notable, and they may be observed in almost any greenhouse. Clinging to the trunks of trees, usually imitated in the greenhouse by nests of sticks, they send out long roots which dangle in the moist air (see Figs. 93, 94). It is necessary to have some special absorbing arrangement, and in the orchids this is usually provided by the development of a sponge-like tissue about the root known as the *velamen*, which greedily absorbs the dew or water trickling down the plant. See also Figs. 92, 95, 96, 97.

FIG. 94. An orchid, showing aerial roots and thick leaves.

67. **Clinging roots.**—These roots are developed to fasten the plant body to some support, and do no work of absorption (see Fig. 98). Very common illustrations may be obtained from the ivies, the trumpet creeper, etc. These roots cling to various supports, stone walls, tree trunks, etc., by sending minute tendril-like branches into the crevices. The sea-weeds (algæ) develop grasping structures extensively, a large majority of them being anchored to rocks or to some rigid support beneath the water, and their bodies floating free. The root-like processes by which this anchorage is secured are very prominent in many of the common marine sea-weeds (see Fig. 162).

68. **Prop roots.**—Some roots are developed to prop stems or wide-spreading branches. In swampy ground, or in tropical forests, it is very common to find the base of

Fig. 95. A staghorn fern (*Platycerium*), an aerial plant of the tropics. About it is a vine, which shows the leaves adjusted to the lighted side.

Fig. 96. Selaginella, showing dangling rhizophores and finely divided leaves.

FIG. 97. Live oaks, in the Gulf States, upon which are growing masses of long moss or black moss (*Tillandsia*), a common aerial plant.

Fig. 98. A tropical forest, showing the cord-like holdfasts developed by an epiphyte, which pass around the tree trunks like tightly bound ropes.—After Kerner.

tree trunks buttressed by such roots which extend out over and beneath the surface, and divide the area about the tree into a series of irregular chambers (see Fig. 100). Some-

Fig. 99. A screw-pine (*Pandanus*), from the Indian Ocean region, showing the prominent prop roots put out near the base.

times a stem, either inclined or with a poorly developed primary root system, puts out prop roots which support it, as in the screw-pine (see Fig. 99). A notable case is

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FIG. 100. A rubber tree, showing the trunk buttressed, and prop roots supporting the wide-spreading branches.

Fig. 101. A banyan tree, showing the great development of prop roots.—After Schimper.

that of the banyan tree, whose wide-spreading branches are supported by prop roots, which are sometimes very numerous (see Fig. 101). The immense banyans usually illustrated are especially cultivated as sacred trees, the prop roots being assisted in penetrating the soil. There is record of such a tree in Ceylon with 350 large and 3,000 small prop roots, able to cover a village of 100 huts.

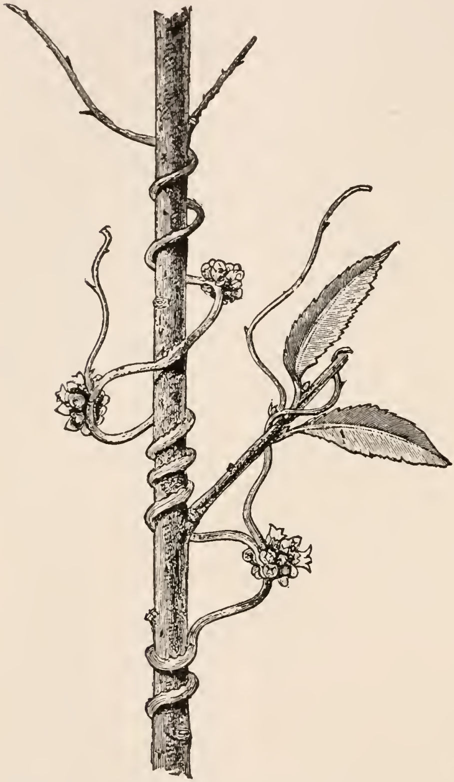


Fig. 102. A dodder plant parasitic on a willow twig. The leafless dodder twines about the willow, and sends out sucking processes which penetrate and absorb.—After Strasburger.

69. **Parasites.**—Besides the roots mentioned above, certain plants develop root-like processes which relate them to *hosts*. A host is a living plant or animal upon which some other plant or animal is living as a parasite. The parasite gets its supplies from the host, and must be related to it properly. If the parasite grows upon the surface of its host, it must penetrate the body to obtain

food supplies. Therefore, processes are developed which penetrate and absorb. The mistletoe and dodder are seed-plants which have this habit, and both have such processes (see Figs. 102, 103). This habit is much more extensively developed, however, in a low group of plants known as the fungi. Many of these parasitic fungi live upon plants and animals, common illustrations being the mildews of lilac leaves and many other plants, the rust of wheat, the smut of corn, etc.

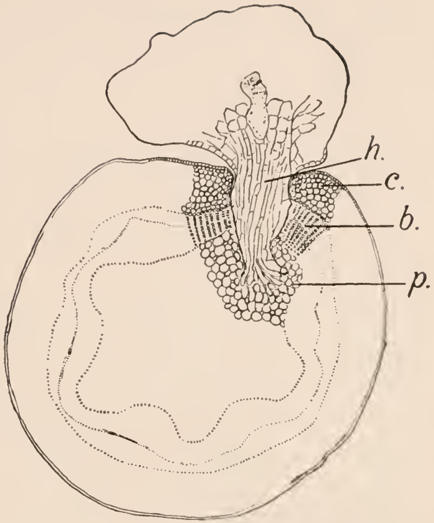


Fig. 103. A section showing the living connection between dodder and a golden rod upon which it is growing. The penetrating and absorbing organ (*h*) has passed through the cortex (*c*), the vascular zone (*b*), and is disorganizing the pith (*p*).

70. **Root structure.**—In the lowest groups of plants (algæ, fungi, and moss-plants) true roots are not formed, but very simple structures, generally hair-like (see Fig. 104). In fern-plants and seed-plants, however, the root is a complex structure, so different from the root-like pro-

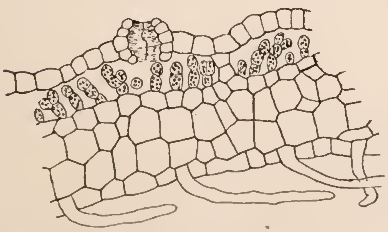


Fig. 104. Section through the thallus of a liverwort (*Marchantia*), showing the hair-like processes (rhizoids) which come from the under surface and act as roots in gripping and absorbing. In the epidermis of the upper surface a chimney-like opening is seen, leading into a chamber containing cells with chloroplasts.

cesses of the lower groups that it is regarded as the only true root. It is quite uniform in structure, consisting of a tough and fibrous central axis surrounded by a spongy region (Fig. 105). The tough axis is mostly made up of vessels, so called because they conduct material, and is called the vascular axis. The outer more spongy region is the *cortex*, which covers the vascular axis like a thick skin.

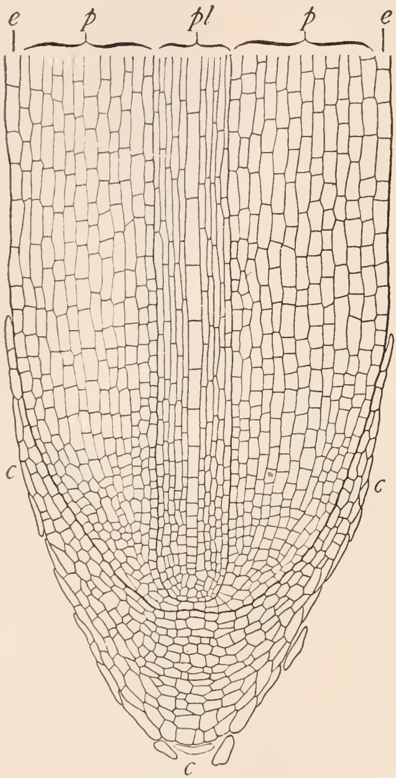


Fig. 105. A longitudinal section through the root tip of spiderwort, showing the central vascular axis (*pl*), surrounded by the cortex (*p*), outside of the cortex the epidermis (*e*) which disappears in the older parts of the root, and the prominent root-cap (*c*).

One of the peculiarities of the root is that the branches come from the vascular axis and burrow through the cortex, so that when the latter is peeled off the branches are left attached to the axis, and the cortex shows the holes through which they passed.

Another peculiarity of the root is that it elongates only by growth at the tip, and in the soil this delicate growing tip is protected by a little cap of cells, known as the *root-cap*.

CHAPTER VI

REPRODUCTIVE ORGANS

It will be remembered that nutrition and reproduction are the two great functions of plants. In discussing foliage leaves, stems, and roots, they were used as illustrations of nutritive organs, so far as their external relations are concerned. We shall now briefly study the reproductive organs from the same point of view, not describing the processes of reproduction, but some of the external relations.

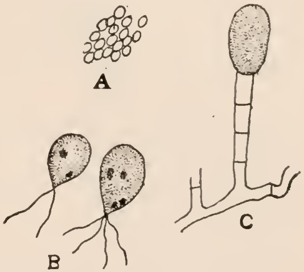


Fig. 106. A group of spores: *A*, spores from a common mold (a fungus), which are so minute and light that they are carried about by the air; *B*, two spores from a common alga (*Ulothrix*), which can swim by means of the hair-like processes; *C*, the conspicuous dotted cell is a spore developed by a common mildew (a fungus), which is carried about by currents of air.

71. **Vegetative multiplication.**—Among the very lowest plants no special organs of reproduction are developed, but most plants have them. There is a kind of reproduction by which a portion of the parent body is set apart to produce a new plant, as when a strawberry runner produces a new strawberry plant, or when a willow twig or a grape cutting is planted and produces new plants, or when a potato tuber (a subterranean stem) produces new potato plants, or when pieces of Begonia leaves are used to start new Begonias. This is known as *vegetative multiplication*, a kind of reproduction which does not use special reproductive organs.

72. **Spore reproduction.**—Besides vegetative multiplication most plants develop special reproductive bodies, known as *spores*, and this kind of reproduction is known as *spore reproduction.* These spores are very simple bodies, but have the power of producing new individuals. There are two great groups of spores, differing from each other not at all in their powers, but in the method of their production by the parent plant. One kind of spore is produced by dividing certain organs of the parent; in the other case two special bodies of the parent blend together to form the spore. Although they are both spores, for convenience we may call the first kind *spores* (see Figs. 106, 109), and the second kind *eggs* (see Fig. 107).* The two special bodies which blend together to form an egg are called *gametes* (see Figs. 107, 108, 109). These terms are necessary to any discussion of the external relations. Most plants develop both spores and eggs, but they are not always equally conspicuous. Among the algæ, both spores and eggs are prominent; among certain fungi the same is true, but many fungi are not known to produce eggs; among moss-plants the spores are prominent and abundant, but the egg is concealed and not generally noticed. What has been said

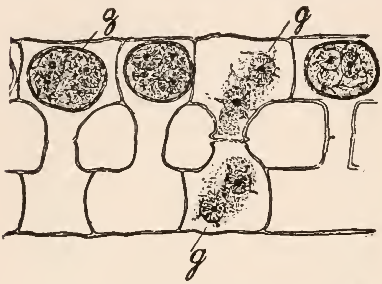


Fig. 107. Fragments of a common alga (*Spirogyra*). Portions of two threads are shown, which have been joined together by the growing of connecting tubes. In the upper thread four cells are shown, three of which contain eggs (*z*), while the cell marked *g*, and its mate of the other thread each contain a gamete, the lower one of which will pass through the tube, blend with the upper one, and form another egg.

* It is recognized that this spore is really a fertilized egg, but in the absence of any accurate simple word, the term egg is used for convenience.

of the moss-plants is still more true of the fern-plants; while among the seed-plants certain spores (*pollen grains*) are conspicuous (see Fig. 110), but the eggs can be observed only by special manipulation in the laboratory. Seeds are neither spores nor eggs, but peculiar reproductive bodies which the hidden egg has helped to produce.

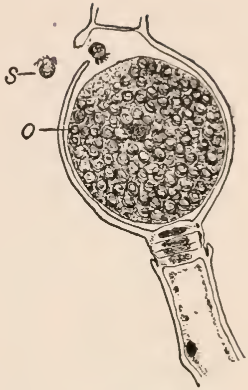


Fig. 108. A portion of the body of a common alga (*Œdogonium*), showing gametes of very unequal size and activity; a very large one (*o*) is lying in a globular cell, and a very small one is entering the cell, another similar one (*s*) being just outside. The two small gametes have hair-like processes and can swim freely. The small and large gametes unite and form an egg.

73. **Germination.** — Spores and eggs are expected to germinate; that is, to begin the development of a new plant. This germination needs certain external conditions, prominent among which are definite amounts of heat, moisture, and oxygen, and sometimes light. Conditions of germination may be observed most easily in connection with seeds. It must be understood, however, that what is called the germination of seeds is something very different from the germination of spores and eggs. In the latter cases, germination includes the very beginnings of the young plant. In the case of a seed, germination begun by an egg has been checked, and seed germination is its renewal. In other words, an egg has germinated and produced a young plant called the "embryo," and the germination of the seed simply consists in the continued growth and the escape of this embryo.

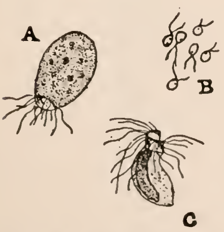


Fig. 109. A group of swimming cells: *A*, a spore of *Œdogonium* (an alga); *B*, spores of *Ulothrix* (an alga); *C*, a gamete of *Equisetum* (horse-tail or scouring rush).

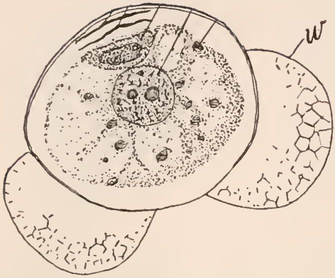


FIG. 110. A pollen grain (spore) from the pine, which develops wings (w) to assist in its transportation by currents of air.

It is evident that for the germination of seeds light is not an essential condition, for they may germinate in the light or in the dark ; but the need of heat, moisture, and oxygen is very apparent. The amount of heat required for germination varies widely with different seeds, some germinating at much lower temperatures than others. Every kind of seed, or spore, or egg has a special temperature range, below which and above which it cannot germinate. The two limits of the range may be called the lowest and highest points, but between the two there is a best point of temperature for germination. The same general fact is true in reference to the moisture supply.

74. **Dispersal of reproductive bodies.**—Among the most striking external relations, however, are those connected with the dispersal of spores, gametes, and seeds. Spores and seeds must be carried away from the parent plant, and separated from each other, out of the reach of rivalry for nutritive material ; and gametes must come together and blend to form the eggs. Conspicuous among the means of transfer are the following.

FIG. 111. A pod of fireweed (*Epilobium*) opening and exposing its plumed seeds which are transported by the wind.—After BEAL.

75. **Dispersal by locomotion.**—The common method of locomotion is by means of movable hairs (*cilia*) developed upon the reproductive body, which propel it through the water (see Fig. 109). Swimming spores are very common among the algæ, and at least one of the gametes in algæ, moss-plants, and fern-plants has the power of swimming by means of cilia.

FIG. 112. The upper figure to the left is an opening pod of fireweed discharging its plumed seeds. The lower figure represents the seed-like fruits of *Clematis* with their long tail-like plumes.—After KERNER.

76. **Dispersal by water.**—It is very common for reproductive bodies to be transported by currents of water. The spores of many water plants of all groups, not constructed for locomotion, are thus floated about. This method of transfer is also very common among seeds. Many seeds are buoyant, or become so after soaking in water, and may be carried to great distances by currents. For this reason the plants growing upon the banks or flood-plains of streams may have come from a wide area. Many seeds can even endure prolonged soaking in sea-water, and then germinate. Darwin estimated

FIG. 113. A ripe dandelion head, showing the mass of plumes, a few seed-like fruits with their plumes still attached to the receptacle, and two fallen off.—After KERNER.

that at least fourteen per cent. of the seeds of any country can retain their vitality in sea-water for twenty-eight days. At the ordinary rate of movement of ocean currents, this length of time would permit such seeds to be transported over a thousand miles, thus making possible a very great range in distribution.

77. **Dispersal of spores by air.**—This is one of the most common methods of transporting spores and seeds. In most cases spores are sufficiently small and light to be transported by the gentlest movements of air. Among the fungi this is a very common method of spore dispersal (see Fig. 106), and it is extensively used in scattering the spores of moss-plants, fern-plants (see Fig. 45), and seed-plants. Among seed-plants this is one method of pollination, the

FIG. 114. Seed-like fruits of *Senecio* with plumes for dispersal by air.—After KERNER.

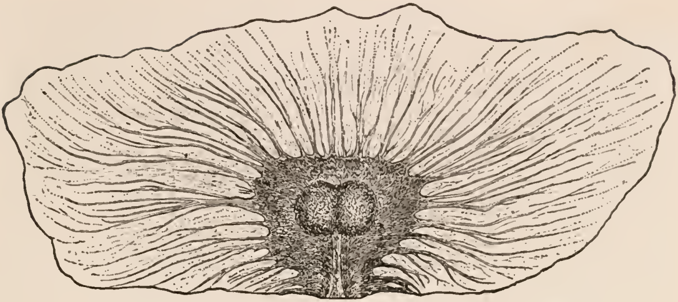


FIG. 115. A winged seed of *Bignonia*.—After STRASBURGER.

spores called pollen grains being scattered by the wind, and occasionally falling upon the right spot for germination. With such an agent of transfer the pollen must be very light and powdery, and also very abundant, for it must come down almost like rain to be certain of reaching the right places.

FIG. 116. Winged fruit of maple.—After KERNER.

Among the gymnosperms (pines, hemlocks, etc.) this is the exclusive method of pollination, and when a pine forest is shedding pollen the air is full of the spores, which may be carried to a great distance before being deposited. Occasional

FIG. 117. Winged fruit of *Ptelea*.—After KERNER.

FIG. 118. Winged fruit of *Ailanthus*.—After KERNER.

reports of "showers of sulphur" have arisen from an especially heavy fall of pollen that has been carried far from some gymnosperm forest. In the case of pines and their near relatives, the pollen spores are assisted in their dispersal through the air by developing a pair of broad wings from the outer coat of the spore (see Fig. 110). This same method of pollination—that is, carrying the pollen spores by currents of air—is also used by many monocotyledons, such as grasses; and by many dicotyledons, such as our most common forest trees (oak, hickory, chestnut, etc.).

78. **Dispersal of seeds by air.**—Many seeds are carried about in various ways by currents of air without any special adaptation. Wings and plumes of very many and often very beautiful patterns are exceedingly common in connection with seeds or seed-like fruits (see Figs. 115, 116, 117, 118, 119). Wings are developed by the fruit of maples and of ash, and by the seeds

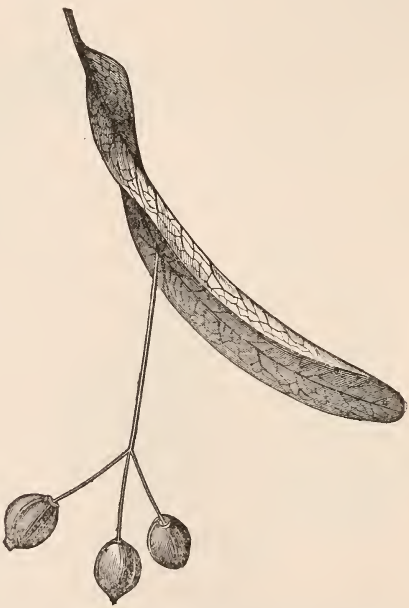


FIG. 119. Fruit of basswood (*Tilia*), showing the peculiar wing formed by a leaf.—After KERNER.

FIG. 120. A common tumbleweed (*Cycloloma*).

of pine and catalpa. Plumes and tufts of hairs are developed by the seed-like fruits of dandelion, thistle, and very many of their relatives, and by the seeds of the milkweed (see Figs. 111, 112, 113, 114). On plains, or level stretches, where winds are strong, a curious habit of seed dispersal has been developed by certain plants known as "tumbleweeds" or "field rollers." These plants are profusely branching annuals with a small root system in a

FIG. 121. The 3-valved fruit of violet discharging its seeds.—After BEAL.

Fig. 122. A fruit of witch hazel discharging its seeds.—After Beal.

light or sandy soil (see Fig. 120). When the work of the season is over, and the absorbing rootlets have shriveled, the plant is easily broken from its roots by a gust of wind, and is trundled along the surface like a light wicker ball, the ripe seed vessels dropping their seeds by the way. In case of an obstruction, such as a fence, great masses of these tumbleweeds may often be seen lodged against the windward side.

79. **Discharge of spores.**—In many plants the distribution of spores and seeds is not provided for by any of the methods just mentioned, but the vessels containing them are so constructed that they are discharged with more or less violence and are somewhat scattered.

Fig. 123. A pod of wild bean bursting, the two valves violently twisting and discharging the seeds.—After Beal.

Many spore cases, especially those of the lower plants, burst irregularly, and with sufficient violence to throw out spores. In the liverworts peculiar cells, called *elaters* or "jumpers," are formed among the spores, and when the wall of the spore case is ruptured the elaters are liberated, and by their active motion assist in discharging the spores.

In most of the true mosses the spore case opens by pushing off a lid at the apex, which exposes a delicate fringe of teeth covering the mouth of the urn-like case. These teeth bend in and out of the open spore case as they become moist or dry, and are of considerable service in the discharge of spores.

In the common ferns a heavy spring-like ring of cells encircles the delicate-walled spore case. When the wall becomes dry and comparatively brittle the spring straightens with considerable force, the delicate wall is suddenly torn, and in the recoil the spores are discharged (see Fig. 45).

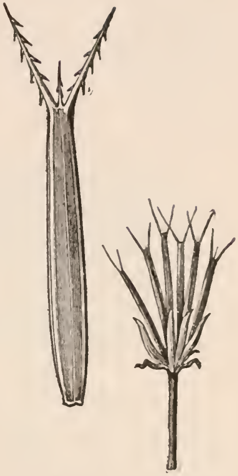


FIG. 124. Fruits of Spanish needle, showing barbed appendages for grappling. The figure to the left is one of the fruits enlarged.—After KERNER.

Even in the case of the pollen-spores of seed-plants, a special layer of the wall of the pollen-sac usually develops as a spring-like layer, which assists in opening widely the sac when the wall begins to yield along the line of breaking.

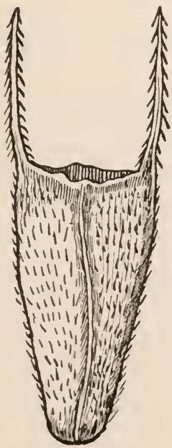


FIG. 125. A fruit of beggar ticks, showing the two barbed appendages which lay hold of animals. —After BEAL.

80. **Discharge of seeds.**—While seeds are generally carried away from the parent plant by the agency of water currents or air currents, as already noted, or by animals, in some instances there is a mechanical discharge provided for in the structure of the seed-case. In such plants as the witch hazel and violet, the walls of the seed-vessel press upon the contained seeds, so that when rupture occurs the seeds are pinched out, as a moist apple-seed is discharged by being pressed between the thumb and finger (see Figs. 121, 122). In the touch-me-not a strain is developed in the wall of the seed-vessel, so that at rupture it

suddenly curls up and throws the seeds (see Fig. 123). The squirting cucumber is so named because it becomes very much distended with water, which is finally forcibly ejected along with the mass of seed. An "artillery plant" common in cultivation discharges its seeds with considerable violence; while the detonations resulting from the explosions of the seed-vessels of *Hura crepitans*, the "monkey's dinner bell," are often remarked by travelers in tropical forests.

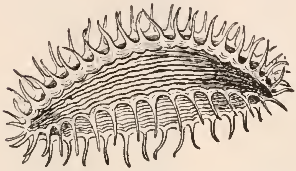


FIG. 126. The fruit of carrot, showing the grappling appendages.—After BEAL.

81. **Dispersal of seeds by animals.**—Only a few illustrations can be given of this very large subject. Water birds are great carriers of seeds which are contained in the mud clinging to their feet and legs. This mud from the borders of ponds is usually completely filled with seeds and spores of various plants. One has no conception of the number until they are actually computed. The following extract from Darwin's *Origin of Species* illustrates this point:

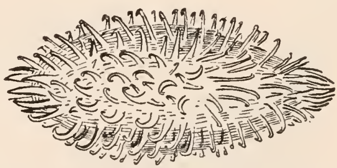


FIG. 127. The fruit of cocklebur, showing the grappling appendages.—After BEAL.

"I took, in February, three tablespoonfuls of mud from three different points beneath water, on the edge of a little pond. This mud when dried weighed only 6¾ ounces; I kept it covered up in my study for six months, pulling up and counting each plant as it grew; the plants were of many kinds, and were altogether 537 in number; and yet the viscid mud was all contained in a breakfast cup!"

Water birds are generally high and strong fliers, and the seeds and spores may thus be transported to the margins of distant ponds or lakes, and so very widely dispersed.

In many cases seeds or fruits develop grappling appendages of various kinds, which lay hold of animals brushing past, and so the seeds are dispersed. Common illustrations are Spanish needles, beggar ticks, stick seeds, burdock, etc. Study Figs. 124, 125, 126, 127, 128, 129, 130.

FIG. 128. Fruits with grappling appendages. That to the left is agrimony ; that to the right is *Galium*.—After KERNER.

In still other cases the fruit becomes pulpy, and attractive as food to certain birds or mammals. Many of the seeds (such as those of grapes) may be able to resist the attacks of the digestive fluids and escape from the alimentary tract in a condition to germinate. As if to attract the attention of fruit-eating animals, fleshy fruits usually become brightly colored when ripe, so that they are plainly seen in contrast with the foliage.

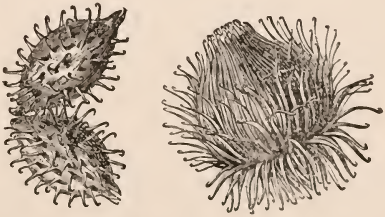


FIG. 129. Fruits with grappling appendages. The figure to the left is cocklebur ; that to the right is burdock.—After KERNER.

82. **Dispersal of pollen spores by insects.**—The transfer of pollen, the name applied to certain spores of seed-

Fig. 130. A head of fruits of burdock, showing the grappling appendages.—After Beal.

plants, is known as *pollination,* and the two chief agents of this transfer are currents of air and insects. In §77 the transfer by currents of air was noted, such plants being known as *anemophilous* plants. Such plants seldom produce what are generally recognized as true flowers. All those seed-plants which produce more or less showy flowers, however, are in some way related to the visits of insects to bring about pollination, and are known as *entomophilous* plants. This relation between insects and flowers is so important and so extensive that it will be treated in a separate chapter.

CHAPTER VII

FLOWERS AND INSECTS

83. **Insects as agents of pollination.**—The use of insects as agents of pollen transfer is very extensive, and is the prevailing method of pollination among monocotyledons and dicotyledons. All ordinary flowers, as usually recognized, are related in some way to pollination by insects, but it must not be supposed that they are always successful in securing it. This mutually helpful relation between flowers and insects is a very wonderful one, and in some cases it has become so intimate that they cannot exist without each other. Flowers have been modified in every way to be adapted to insect visits, and insects have been variously adapted to flowers.

84. **Self-pollination and cross-pollination.**—The advantage of this relation to the flower is to secure pollination. The pollen may be transferred to the carpel of its own flower, or to the carpel of some other flower. The former is known as *self-pollination*, the latter as *cross-pollination*. In the case of cross-pollination the two flowers concerned may be upon the same plant, or upon different plants, which may be quite distant from one another. It would seem that cross-pollination is the preferred method, as flowers are so commonly arranged to secure it.

85. **Advantage to insects.**—The advantage of this relation to the insect is to secure food. This the flower provides either in the form of *nectar* or *pollen ;* and insects visiting flowers may be divided roughly into the two groups of nectar-feeding insects, represented by butterflies and moths,

and pollen-feeding insects, represented by the numerous bees and wasps. When pollen is provided as food, the amount of it is far in excess of the needs of pollination. The presence of these supplies of food is made known to the insect by the display of color in connection with the flowers, by odor, or by form. It should be said that the attraction of insects by color has been doubted recently, as certain experiments have suggested that some of the common flower-visiting insects are color-blind, but remarkably keen-scented. However this may be for some insects, it seems to be sufficiently established that many insects recognize their feeding ground by the display of color.

86. **Suitable and unsuitable insects.**—It is evident that all insects desiring nectar or pollen for food are not suitable for the work of pollination. For instance, the ordinary ants are fond of such food, but as they walk from plant to plant the pollen dusted upon them is in great danger of being brushed off and lost. The most favorable insect is the flying one, that can pass from flower to flower through the air. It will be seen, therefore, that the flower must not only secure the visits of suitable insects, but must guard against the depredations of unsuitable ones.

87. **Danger of self-pollination.**—There is still another problem which insect-pollinating flowers must solve. If cross-pollination is more advantageous to the plant than self-pollination, the latter should be prevented so far as possible. As the stamens and carpels are usually close together in the same flower, the danger of self-pollination is constantly present in many flowers. In those plants which have stamen-producing flowers upon one plant and carpel-producing flowers upon another, there is no such danger.

88. **Problems of pollination.**—In most insect-pollinating flowers, therefore, there are three problems : (1) to prevent self-pollination, (2) to secure the visits of suitable insects, and (3) to ward off the visits of unsuitable insects. It must not be supposed that flowers are uniformly successful

in solving these problems. They often fail, but succeed often enough to make the effort worth while.

89. **Preventing self-pollination.**—It is evident that this danger arises only in those flowers in which the stamens and carpels are associated, but their separation in different flowers may be considered as one method of preventing self-pollination. In order to understand the various arrangements to be considered, it is necessary to explain that the carpel does not receive the pollen indifferently over its whole surface. There is one definite region organized, known as the *stigma,* upon which the pollen must be deposited if it is to do its work. Usually this is at the most projecting point of the carpel, very often at the end of a stalk-like prolongation from the *ovary* (the bulbous part of the carpel), known as the *style;* sometimes it may run down one side of the style. When the stigma is ready to receive pollen it has upon it a sweetish, sticky fluid, which holds and feeds the pollen. In this condition the stigma is said to be mature; and the pollen is mature when it is being shed, that is, ready to fall

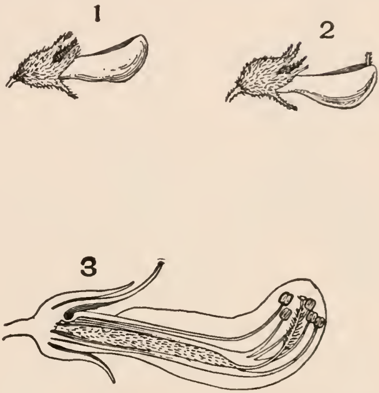


Fig. 131. Parts of the flower of rose acacia (*Robinia hispida*). In 1 the keel is shown projecting from the hairy calyx, the other more showy parts of the corolla having been removed. Within the keel are the stamens and the carpel, as seen in 3. The keel forms the natural landing place of a visiting bee, whose weight depresses the keel and causes the tip of the style to protrude, as shown in 2. This style tip bears pollen upon it, caught among the hairs, seen in 3, and as it strikes the body of the bee some pollen is brushed off. If the bee has previously visited another flower and received some pollen, it will be seen that the stigma, at the very tip of the style, striking the body first, will very probably receive some of it. The nectar pit is shown in 3, at the base of the uppermost stamen.—After Gray.

out of the pollen-sacs or to be removed from them. The devices used by flowers containing both stamens and carpels to prevent self-pollination are very numerous, but most of them may be included under the three following heads:

(1) *Position.*—In these cases the pollen and stigma are ready at the same time, but their position in reference to each other, or in reference to some conformation of the flower, makes it unlikely that the pollen will fall upon the stigma. The stigma may be placed above or beyond the pollen sacs, or the two may be separated by some mechanical obstruction, resulting in much of the irregularity of flowers.

Fig. 132. A portion of the flower of an iris, or flag. The single stamen shown is standing between the petal to the right and the petal-like style to the left. Near the top of this style the stigmatic shelf is seen extending to the right, which must receive the pollen upon its upper surface. The nectar pit is at the junction of the petal and stamen. While obtaining the nectar the insect brushes the pollen-bearing part of the stamen. and pollen is lodged upon its body. In visiting the next flower and entering the stamen chamber the stigmatic shelf is apt to be brushed.—After Gray.

In the flowers of the rose acacia and its relatives, the several stamens and the single carpel are in a cluster, enclosed in the keel of the flower. The stigma is at the summit of the style, and projects somewhat beyond the pollen-sacs shedding pollen. Also there is often a rosette of hairs, or bristles, just beneath the stigma, which acts as a barrier to the pollen (see Fig. 131).

In the iris, or common flag, each stamen is in a sort of pocket between the petal and the petal-like style, while the stigmatic surface is on the top of a flap, or shelf, which the style sends out as a roof to the pocket. With such an arrangement, it would seem impossible for the pollen to reach the stigma unaided (see Fig. 132).

In the orchids, remarkable for their strange and beautiful flowers, there are usually two pollen-sacs, and stretched between them is the stigmatic surface. In this case, however, the pollen grains are not dry and powdery, but cling together in a mass, and cannot escape from the sac without being pulled out (see Fig. 133). The same sort of pollen is developed by the milkweeds.

(2) *Consecutive maturity.*—In these cases the pollen and

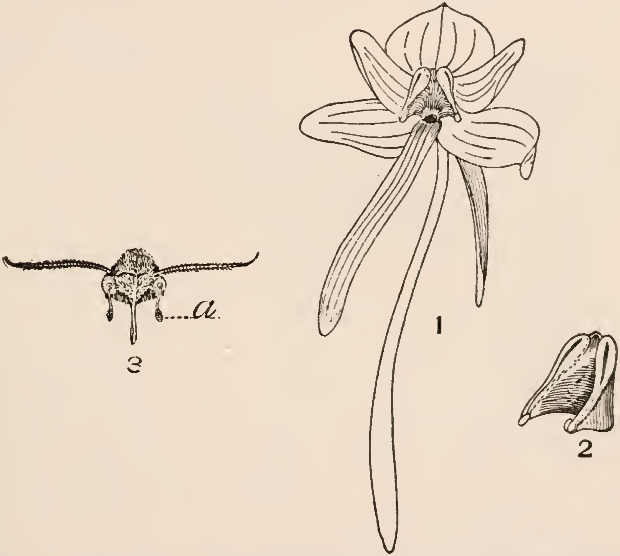


Fig. 133. A flower of an orchid (*Habenaria*). At 1 the complete flower is shown, with three sepals behind, and three petals in front, the lowest one of which has developed a long strap-shaped portion, and a still longer spur portion, the opening to which is seen at the base of the strap. At the bottom of this long spur is the nectar, which is reached by the long proboscis of a moth. The two pollen sacs of the single stamen are seen in the centre of the flower, diverging downwards, and between them stretches the stigma surface. The relation between pollen sacs and stigma surface is more clearly shown in 2. Within each pollen sac is a mass of sticky pollen, ending below in a sticky disk, which may be seen in 1 and 2. When the moth thrusts his proboscis into the nectar tube, his head is against the stigmatic surface and also against the disks. When he removes his head the disks stick fast and the pollen masses are dragged out. In 3 a pollen mass (*a*) is shown sticking to each eye of a moth. Upon visiting another flower these pollen masses are thrust against the stigmatic surface and pollination is effected.—After Gray.

stigma of the same flower are not mature at the same time. It is evident that this is a very effective method of preventing self-pollination. When the pollen is being shed the stigma is not ready to receive, or when the stigma is ready to receive the pollen is not ready to be shed. In some cases the pollen is ready first, in other cases the stigma, the former condition being called *protandry*, the latter *protogyny*. This is a very common method of preventing self-pollination, and is usually not associated with irregularity.

Fig. 134. Flowers of fireweed (*Epilobium*), showing protandry. In 1 the stamens are thrust forward, and the style is sharply turned downward and backward. In 2 the style is thrust forward, with its stigmatic branches spread. An insect in passing from 1 to 2 will almost certainly transfer pollen from the stamens of 1 to the stigmas of 2.—After Gray.

The ordinary figwort may be taken as an example of protogyny. When the flowers first open, the style, bearing the stigma at its tip, is found protruding from the urn-like flower, while the four stamens are curved down into the tube, and are not ready to shed their pollen. At some later time the style bearing the stigma wilts, and the stamens straighten up and protrude from the tube. In this way, first the receptive stigma, and afterwards the shedding pollen-sacs, occupy the same position.

Protandry is even more common, and many illustrations can be obtained. For example, the showy flowers of the common fireweed, or great willow herb, when first opened display their eight shedding stamens prominently, the style being sharply curved downward and backward, carrying the four stigma lobes well out of the way. Later, the stamens bend away, and the style straightens up and exposes its stigma lobes, now receptive (see Fig. 134).

(3) *Difference in pollen.*—In these cases there are at

least two forms of flowers, which differ from one another in the relative lengths of their stamens and styles. In the accompanying illustrations of *Houstonia* (see Fig. 135) it is to be noticed that in one flower the stamens are short and included in the tube, and the style is long and projecting, with the four stigmas exposed well above the tube. In the other flower the relative lengths are exactly reversed, the style being short and included in the tube, and the stamens long and projecting. It appears that the pollen from the short stamens is most effective upon the stigmas of the short styles, and that the pollen from the long stamens is most effective upon the stigmas of the long styles; and as short stamens and long styles, or long stamens and short styles, are associated in the same flower, the pollen must be transferred to some other flower to find its appropriate stigma. This means that there is a difference between the pollen of the short stamens and that of the long ones.

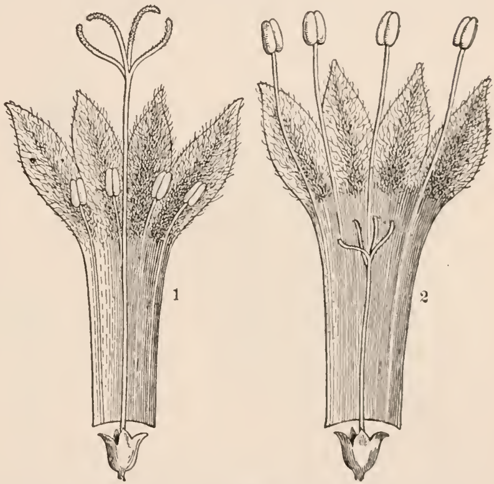


Fig. 135. Flowers of *Houstonia*, showing two forms of flowers. In 1 there are short stamens and a long style; in 2 long stamens and short style. An insect visiting 1 will receive a band of pollen about the front part of its body; upon visiting 2 this band will rub against the stigmas, and a fresh pollen band will be received upon the hinder part of the body, which, upon visiting another flower like No. 1, will brush against the stigmas.—After Gray.

In some cases there are three forms of flowers, as in one of the common loosestrifes. Each flower has stamens of two lengths, which, with the style, makes possible three combinations. One flower has short stamens, middle-length stamens, and long style; another has short stamens, middle-length style, and long stamens; the third has short style, middle-length stamens, and long stamens. In these cases also the stigmas are intended to receive pollen from stamens

Fig. 136. *Yucca* and *Pronuba*. In the lower figure to the right an opened flower shows the pendent ovary with the stigma region at its apex. The upper figure to the right shows the position of *Pronuba* when collecting pollen. The figure to the left represents a cluster of capsules of *Yucca*, which shows the perforations made by the larvæ of *Pronuba* in escaping.—After Riley and Trelease.

of their own length, and a transfer of pollen from flower to flower is necessary.

90. **Self-pollination.**—In considering these three general methods of preventing self-pollination, it must not be supposed that self-pollination is never provided for. It is provided for more extensively than was once supposed. It is found that many plants, such as violets, in addition to the usual showy, insect-pollinated flowers, produce flowers that are not at all showy, in fact do not open, and are often not prominently placed. The fact that these flowers are often closed has suggested for them the name *cleistogamous*

flowers. In these flowers self-pollination is a necessity, and is found to be very effective in producing seed.

91. **Yucca and Pronuba.**—There can be no doubt, also, that there is a great deal of self-pollination effected in flowers adapted for pollination by insects, and that the insects themselves are often responsible for it. But in the remarkable case of *Yucca* and *Pronuba* there is a definite arrangement for self-pollination by means of an insect (see Fig. 136). Yucca is a plant of the southwestern arid regions of North America, and Pronuba is a moth. The plant and the moth are very dependent upon each other. The bell-shaped flowers of Yucca hang in great terminal clusters, with six hanging stamens, and a central ovary ribbed lengthwise, and with a funnel-shaped opening at its apex, which is the stigma. The numerous ovules occur in lines beneath the furrows. During the day the small female Pronuba rests quietly within the flower, but at dusk becomes very active. She travels down the stamens, and resting on the open pollen-sac scoops out the somewhat sticky pollen with her front legs. Holding the little mass of pollen she runs to the ovary, stands astride one of the furrows, and piercing through the wall with her ovipositor, deposits an egg in an ovule. After depositing several eggs she runs to the apex of the ovary and begins to crowd the mass of pollen she has collected into the funnel-like stigma. These actions are repeated several times, until many eggs are deposited and repeated pollination has been effected. As a result of all this the flower is pollinated, and seeds are formed which develop abundant nourishment for the moth larvæ, which become mature and bore their way out through the wall of the capsule (Fig. 136).

92. **Securing cross-pollination.**—In very many ways flowers are adapted to the visits of suitable insects. In obtaining nectar or pollen as food, the visiting insect receives pollen on some part of its body which will be likely to come in contact with the stigma of the next flower visited.

FIG. 137. A clump of lady-slippers (*Cypripedium*), showing the habit of the plant and the general structure of the flower.—After GIBSON.

Illustrations of this process may be taken from the flowers already described in connection with the prevention of self-pollination.

In the flowers of the pea family, such as the rose acacia (see Fig. 131), it will be noticed that the stamens and pistil are concealed within the keel, which forms the natural landing place for the bees which are used in pollination. This keel is so inserted that the weight of the insect depresses it, and the tip of the style comes in contact with its body. Not only does the stigma strike the body, but by the glancing blow the surface of the style is rubbed against the insect, and on this style, below the stigma, the pollen has been deposited and is rubbed off against the insect. At the next flower visited the stigma is likely to strike the pollen obtained from the previous flower, and the style will deposit a new supply of pollen.

FIG. 138. Flower of *Cypripedium*, showing the flap overhanging the opening of the pouch, into which a bee is crowding its way. The small figure to the right shows a side view of the flap; that to the left a view beneath the flap, showing the two dark anthers, and between them, further down (forward), the stigma surface.—After GIBSON.

In the flower of the common flag (see Fig. 132) the nectar is deposited in a pit at the bottom of the chamber formed by each style and petal. In this chamber the stamen is found, and more or less roofing it over is the flap, or shelf, upon the upper surface of which the stigma is developed. As the insect crowds its way into this narrowing chamber, its body is dusted by the pollen, and as it visits the next flower and thrusts aside the stigmatic shelf, it is apt to deposit upon it some of the pollen previously received.

The story of pollination in connection with the orchids is still more complicated (see Fig. 133). Taking an ordinary orchid for illustration, the details are as follows. Each of the two pollen masses terminates in a sticky disk or button; between them extends the concave stigma surface, at the bottom of which is the opening into the long tube-like spur in which the nectar is found. Such a flower is adapted to the large moths, with long probosces which can reach the bottom of the tube. As the moth thrusts its proboscis into the tube, its head touches the sticky button on each side, so that when it flies away these buttons stick to its head, sometimes directly to its eyes, and the pollen masses are torn out. These masses are then carried to the next flower and are thrust against the stigma in the attempt to get the nectar.

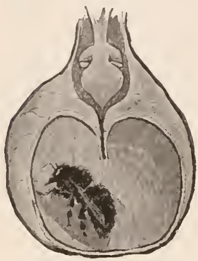


FIG. 139. A bee imprisoned in the pouch (partly cut away) of *Cypripedium*. —After GIBSON.

In the lady-slipper (*Cypripedium*), another orchid, the flowers have a conspicuous pouch (see Fig. 137), in which the nectar is secreted. A peculiar structure, like a flap, overhangs the opening of the pouch, beneath which are the two anthers, and between them the stigmatic surface (see Fig. 138). Into the pouch a bee crowds its way and becomes imprisoned (see Fig. 139). The nectar which the bee obtains is in the bottom of the pouch (see Fig. 140). When escaping, the bee moves towards the opening overhung by the flap and rubs first against the stigmatic surface (see Fig. 141), and then against the anthers, receiving pollen on its back (see Fig. 142). A visit to another flower will result in rubbing some of the pollen upon the stigma, and in receiving more pollen for another flower.

In cases of protandry, as the common figwort, flowers in the two conditions will be visited by the pollinating insect, and as the shedding stamens and receptive stigmas occupy the same relative position, the pollen from one flower will be carried to the stigma of another. It is evident that exactly the same methods prevail in the case of protogyny, as the fireweed (see Fig. 134).

FIG. 140. A bee obtaining nectar in the pouch of *Cypripedium*.—After GIBSON.

The Houstonia (see Fig. 135), in which there are stamens and styles of different lengths, is visited by insects whose bodies fill the tube and protrude above it. In visiting flowers of both kinds, one region of the body receives pollen from the short stamens, and another region from the long stamens. In this way the insect will carry about two bands of pollen, which come in contact with the corresponding stigmas. When there are three forms of flowers, as mentioned in the case of one of the loosestrifes, the insect receives three pollen bands, one for each of the three sets of stigmas.

FIG. 141. A bee escaping from the pouch of *Cypripedium*, and coming in contact with the stigma. Advancing a little further the bee will come in contact with the anthers and receive pollen.—After GIBSON.

93. **Warding off unsuitable insects.**—Prominent among

the unsuitable insects, which Kerner calls "unbidden guests," are ants, and adaptations for reducing their visits to a minimum may be taken as illustrations.

(1) *Hairs.*—A common device for turning back ants, and other creeping insects, is a barrier of hair on the stem, or in the flower cluster, or in the flower.

(2) *Glandular secretions.*—In some cases a sticky secretion is exuded from the surface of plants, which effectively stops the smaller creeping insects. In certain species of catch-fly a sticky ring girdles each joint of the stem.

FIG. 142. A bee escaping from the pouch of *Cypripedium*, and rubbing against an anther.—After GIBSON.

(3) *Isolation.*—The leaves of certain plants form water reservoirs about the stem. To ascend such a stem, therefore, a creeping insect must cross a series of such reservoirs. Teasel furnishes a common illustration, the opposite leaves being united at the base and forming a series of cups. More extensive water reservoirs are found in *Bilbergia* and *Ravenala* ("traveler's tree"), whose flower clusters are protected by reservoirs formed by the rosettes of leaves, which creeping insects cannot cross.

(4) *Latex.*—This is a milky secretion found in some plants, as in milkweeds. Caoutchouc is a latex secretion of certain tropical trees. When latex is exposed to the air it stiffens immediately, becoming sticky and finally

hard. In the flower clusters of many latex-secreting plants the epidermis of the stem is very smooth and delicate, and easily pierced by the claws of ants and other creeping insects who seek to maintain footing on the smooth surface. Wherever the epidermis is pierced the latex gushes out, and by its stiffening and hardening glues the insect fast.

(5) *Protective forms.*—In some cases the structure of the flower prevents the access of small creeping insects to the pollen or to the nectar. In the common snapdragon the two lips are firmly closed (see Fig. 74), and they can be forced apart only by some heavy insect, as the bumble-bee, alighting upon the projecting lower lip, all lighter insects being excluded. In many species of *Pentstemon,* one of the stamens does not develop pollen sacs, but lies like a bar across the mouth of the pit in which the nectar is secreted. Through the crevices left by this bar the thin proboscis of a moth or butterfly can pass, but not the whole body of a creeping insect. Very numerous adaptations of this kind may be observed in different flowers.

(6) *Protective closure.*—Certain flowers are closed at certain hours of the day, when there is the chief danger from creeping insects. For instance, the evening primroses open at dusk, after the deposit of dew, when ants are not abroad ; and at the same time they secure the visits of moths, which are night-fliers.

Numerous other adaptations to hinder the visits of unsuitable insects may be observed, but those given will serve as illustrations. In all cases it must be understood that these so-called "adaptations" have not been produced to ward off insects, but that having appeared from one cause or another they have proved to be useful in this particular.

CHAPTER VIII

AN INDIVIDUAL PLANT IN ALL OF ITS RELATIONS

FOR the purpose of summarizing the general life-relations detailed in the preceding chapters, it will be useful to apply them in the case of a single plant. Taking a common seed-plant as an illustration, and following its history from the germination of the seed, certain general facts become evident in its relations to the external world.

94. **Germination of the seed.**—The most obvious needs of the seed for germination are certain amounts of moisture and heat. In order to secure these to the best advantage, the seed is usually very definitely related to the soil, either upon it and covered by moisture and heat-retaining *debris*, or embedded in it. Along with the demand for heat and moisture is one for air (supplying oxygen), which is essential to life. The relation which germinating seeds need, therefore, is one which not only secures moisture and heat advantageously, but permits a free circulation of air.

95. **Direction of the root.**—The first part of the young plantlet to emerge from the seed is the tip of the axis which is to develop the root system. It at once shows a response to the earth influence (*geotropism*) and to the moisture influence (*hydrotropism*), for whatever the direction of emergence from the seed, a curvature is developed which directs the tip towards and finally into the soil (see Fig. 143). When the soil is penetrated the primary root may continue to grow vigorously downward, showing a strong geotropic tendency, and forming what is known as the tap-root, from which lateral roots arise, which are

much more influenced in direction by other external causes, especially the presence of moisture. As a rule, the soil is not perfectly uniform, and contact with different substances induces curvatures, and as a result of these and other causes, the root system may become very intricate, which is extremely favorable for absorbing and gripping.

96. **Direction of the stem.**—As soon as the stem tip is extricated from the seed, it shows a response to the light influence (*heliotropism*), being guided in a general way towards the light (see Fig. 143*a*). Direction towards the light, the source of the influence, is spoken of as *positive* heliotropism, as distinguished from direction away from the light, called *negative* heliotropism. If the main axis continues to develop, it continues to show this positive heliotropism strongly, but the branches may show every variation from positive to *transverse* heliotropism; that is, a direction transverse to the direction of the rays of light. In some plants certain stems, as stolons, runners, etc., show strong transverse heliotropism, while other stems, as rootstocks, etc., show a strong transverse geotropism.

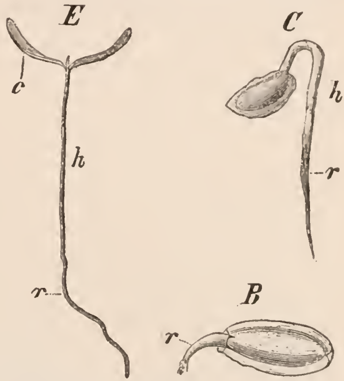


FIG. 143. Germination of the seed of arbor-vitæ (*Thuja*). *B* shows the emergence of the axis (*r*) which is to develop the root, and its turning towards the soil. *C* shows a later stage, in which the root (*r*) has been somewhat developed, and the stem of the embryo (*h*) is developing a curve preparatory to pulling out the seed leaves (cotyledons). *E* shows the young plantlet entirely free from the seed, with its root (*r*) extending into the soil, its stem (*h*) erect, and its first leaves (*c*) horizontally spread.—After STRASBURGER.

97. **Direction of foliage leaves.**—The general direction of foliage leaves on an erect stem is transversely heliotropic;

if necessary, the parts of the leaf or the stem itself twisting to allow the blade to assume this position. The danger of the leaves shading one another is reduced to a minimum by the elongation of internodes, the spiral arrangement, shortening and changing direction upwards, or lobing.

This outlines the general nutritive relations, the roots

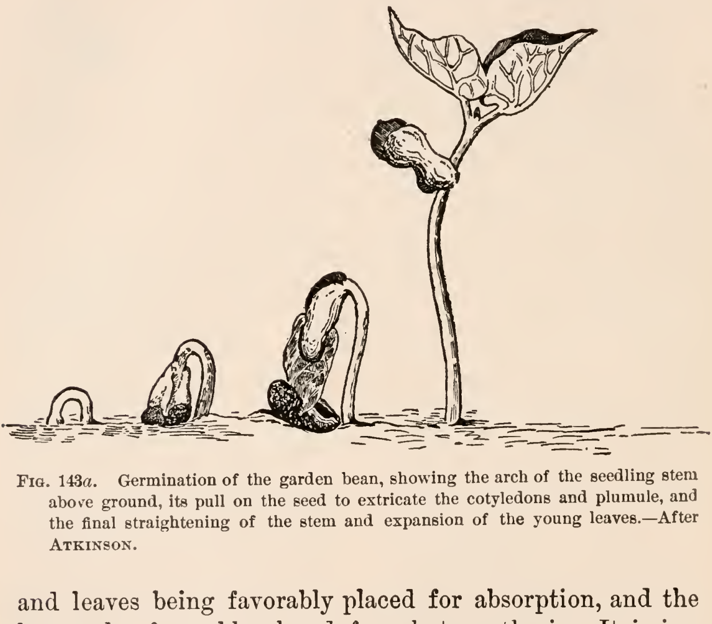


FIG. 143*a*. Germination of the garden bean, showing the arch of the seedling stem above ground, its pull on the seed to extricate the cotyledons and plumule, and the final straightening of the stem and expansion of the young leaves.—After ATKINSON.

and leaves being favorably placed for absorption, and the latter also favorably placed for photosynthesis. It is important to study the behavior of various plants in the germination of the seed, for in a comparatively short period all of the important external relations of the vegetative organs are established. Seeds should be selected which germinate rapidly, and which represent different great groups, such as squash, bean, corn, etc., and these observations should be extended as far as possible by including the observation of seedlings in nature.

98. **Placing of flowers.**—The purposes of the flower seem to be served best by exposed positions, and consequently flowers mostly appear at the extremities of stems and branches, a position evidently favorable to pollination and seed dispersal. The flowers thus exposed are very commonly massed, or, if not, the single flower is apt to be large and conspicuous. The various devices for protecting nectar and pollen against too great moisture, and the more delicate structures against chill; for securing the visits of suitable insects, and warding off unsuitable insects; and for dispersing the seeds, need not be repeated.

99. **Branch buds.**—If the plant under examination be a tree or shrub, branch buds will be observed to be developed during the growing season (see Fig. 65). This device for protecting growing tips through a season of dangerous cold is very familiar to those living in the temperate regions. The internodes do not elongate, hence the leaves overlap; they develop little or no chlorophyll, and become *scales*. The protection afforded by these overlapping scales is often increased by the development of hairs, or by the secretion of mucilage or gum.

CHAPTER IX

THE STRUGGLE FOR EXISTENCE

100. **Definition.**—The phrase "struggle for existence" has come to mean, so far as plants are concerned, that it is usually impossible for them to secure ideal relations, and that they must encounter unfavorable conditions. The proper light and heat relations may be difficult to obtain, and also the proper relations to food material. It often happens, also, that conditions once fairly favorable may become unfavorable. Also, multitudes of plants are trying to take possession of the same conditions. All this leads to the so-called "struggle," and vastly more plants fail than succeed. Before considering the organization of plant associations, it will be helpful to consider some of the possible changes in conditions, and the effect on plants.

101. **Decrease of water.**—This is probably the most common factor to fluctuate in the environment of a plant. Along the borders of streams and ponds, and in swampy places, the variation in the water is very noticeable, but the same thing is true of soils in general. However, the change chiefly referred to is that which is permanent, and which compels plants not merely to tide over a drouth, but to face a permanent decrease in the water supply.

Around the margins of ponds are very commonly seen fringes of such plants as bulrushes, cat-tail flags, reed-grasses, etc., standing in shoal water. As these plants partially decay, their bodies and the entangled silt from the land presently accumulate to such an extent that there is no more standing water, and the water supply for the bulrushes and their associates has permanently decreased below the favorable amount. In this way certain lake margins gradually encroach upon the water, and in so doing the water supply is permanently diminished for many plants. By the same process, smaller lakelets are gradually being converted into bogs, and the bogs in turn into drier ground, and these unfavorable changes in water supply are a menace to many plants.

The operations of man, also, have been very effective in diminishing the water supply for plants. Drainage, which is so extensively practiced, while it may make the water-supply more favorable for the plants which man desires, certainly makes it very unfavorable for many other plants. The clearing of forests has a similar result. The forest soil is receptive and retentive in reference to water, and is somewhat like a great sponge, steadily supplying the streams which drain it. The removal of the forest destroys much of this power. The water is not held and gradually doled out, but rushes off in a flood; hence, the streams which drain the cleared area are alternately flooded and dried up. This results in a much less total supply of water available for the use of plants.

102. **Decrease of light.**—It is very common to observe tall, rank vegetation shading lower forms, and seriously interfering with the light supply. If the rank vegetation is rather temporary, the low plants may learn to precede or follow it, and so avoid the shading; but if the over-shading vegetation is a forest growth, shading becomes permanent. In the case of deciduous trees, which drop their leaves at the close of the growing season and put out a fresh crop in the spring, there is an interval in the early spring, before the leaves are fully developed, during which low plants may secure a good exposure to light (see Fig. 144). In such places one finds an abundance of "spring flowers," but later in the season the low plants become very scarce. This effective over-shading is not common to all forests, for

FIG. 144. A common spring plant (dog-tooth violet) which grows in deciduous forests. The large mottled leaves and the conspicuous flowers are sent rapidly above the surface from the subterranean bulb (see cut in the left lower corner), where are also seen dissected out some petals and stamens and the pistil.

there are "light forests," such as the oak forest, which permit much low vegetation, as well as the shade forests, such as beech forests, which permit very little.

In the forest regions of the tropics, however, the shading is permanent, since there is no annual fall of leaves. In such conditions the climbing habit has been extensively cultivated.

103. **Change in temperature.**—In regions outside of the tropics the annual change of temperature is a very important factor in the life of plants, and they have provided for it in one way or another. In tracing the history of plants, however, back into what are called "geological times," we discover that there have been relatively permanent changes in temperature. Now and then glacial conditions prevailed, during which regions before temperate or even tropical were subjected to arctic conditions. It is very evident that such permanent changes of temperature must have had an immense influence upon plant life.

104. **Change in soil composition.**—One of the most extensive agencies in changing the compositions of soils in certain regions has been the movement of glaciers of continental extent, which have deposited soil material over very extensive areas. Areas within reach of occasional floods, also, may have the soil much changed in character by the new deposits. Shifting dunes are billow-like masses of sand, developed and kept in motion by strong prevailing winds, and often encroach upon other areas. Besides these changes in the character of soil by natural agencies, the various operations of man have been influential. Clearing, draining, fertilizing, all change the character of the soil, both in its chemical composition and its physical properties.

105. **Devastating animals.**—The ravages of animals form an important factor in the life of many plants. For example, grazing animals are wholesale destroyers of vegetation, and may seriously affect the plant life of an area. The various leaf feeders among insects have frequently done a vast

amount of damage to plants. Many burrowing animals attack subterranean parts of plants, and interfere seriously with their occupation of an area.

Various protective adaptations against such attacks have been pointed out, but this subject probably has been much exaggerated. The occurrence of hairs, prickles, thorns, and spiny growths upon many plants may discourage the attacks of animals, but it would be rash to assume that these protections have been developed because of the danger of such attacks. One of the families of plants most completely protected in this way is the great cactus family, chiefly inhabiting the arid regions of southwestern United States and Mexico. In such a region succulent vegetation is at a premium, and it is doubtless true that the armor of thorns and bristles reduces the amount of destruction.

In addition to armor, the acrid or bitter secretions of certain plants or certain parts of plants would have a tendency to ward off the attacks of animals.

106. **Plant rivalry.**—It is evident that there must be rivalry among plants in occupying an area, and that those plants which can most nearly utilize identical conditions will be the most intense rivals. For example, a great many young oaks may start up over an area, and it is evident that the individuals must come into sharp competition with one another, and that but few of them succeed in establishing themselves permanently. This is rivalry between individuals of the same kind ; but some other kind of trees, as the beech, may come into competition with the oak, and another form of rivalry will appear.

As a consequence of plant rivalry, the different plants which finally succeed in taking possession of an area are apt to be dissimilar, and a plant association is usually made up of plants which represent widely different regions of the plant kingdom. It is sometimes said that any well-developed plant association is an epitome of the plant kingdom.

A familiar illustration of plant rivalry may be observed in the case of what are called "weeds." Every one is familiar with the fact that if cultivated ground is neglected these undesirable plants will invade it vigorously and seriously affect the development of plants under cultivation.

107. **Adaptation.**—When the changes mentioned above occur in the environment of plants to such an extent as to make the conditions for living very unfavorable, one of three things is likely to occur, adaptation, migration, or destruction.

The change in conditions may come slowly enough, and certain plants may be able to endure it long enough to adjust themselves to it. Such an adjustment may involve changes in structure, and probably no plants are plastic enough to adjust themselves to extreme and sudden changes which are to be comparatively permanent. There are plants, such as the common cress, which may be called amphibious, which can live in the water or out of it without change of structure, but this is endurance rather than adaptation. Many plants, however, can pass slowly into different conditions, such as drier soil, denser shade, etc., and corresponding changes in their structure may be noted. Very often, however, such plants are given no opportunity to adjust themselves to the new conditions, as the area is apt to be invaded by plants already better adapted. While adaptation may be regarded as a real result of changed conditions, it would seem to be by no means the common one.

108. **Migration.**—This is a very common result of changed conditions. Plants migrate as truly as animals, though, of course, their migration is from generation to generation. It is evident, however, that migration cannot be universal, for barriers of various kinds may forbid it. In general, these barriers represent unfavorable conditions for living. If a plant area with good soil is surrounded by a sterile area, the latter would form an efficient barrier to migration from the former. Plants of the lowlands could not cross mountains to escape from unfavorable conditions.

To make migration possible, therefore, it is necessary for the conditions to be favorable for the migrating plants in some direction. In the case of bulrushes, cat-tail flags, etc., growing in the shoal water of a lake margin, the building up of soil about them results in unfavorable conditions. As a consequence, they migrate further into the lake. If the lake happens to be a small one, the filling up process may finally obliterate it, and a time will come when such forms as bulrushes and flags will find it impossible to migrate.

In glacial times very many arctic plants migrated southward, especially along the mountain systems, and many alpine plants moved to lower ground. When warmer conditions returned, many plants that had been driven south returned towards the north, and the arctic and alpine plants retreated to the north and up the mountains. The history of plants is full of migrations, compelled by changed conditions and permitted in various directions. It must be remembered, also, that migrations often result in changes of structure.

109. **Destruction.**—Probably this is by far the most common result of greatly changed conditions. Even if plants adapt themselves to changed conditions, or migrate, their structure may be so changed that they will seem like quite different plants. In this way old forms gradually disappear and new ones take their places.

CHAPTER X

THE NUTRITION OF PLANTS

110. **Physiology.**—In the previous chapters plants have been considered in reference to their surroundings. It was observed that various organs of nutrition hold certain life-relations, but it is essential to discover what these relations mean to the life of the plant. The study of plants from the standpoint of their life-relations has been called *Ecology*; the study of the life-processes of plants is called *Physiology*. These two points of view may be illustrated by comparing them to two points of view for the study of man. Man may be studied in reference to his relation to his fellow-men and to the character of the country in which he lives; or his bodily processes may be studied, such as digestion, circulation, respiration, etc. The former corresponds to Ecology, the latter is Physiology.

All of the ecological relations that have been mentioned find their meaning in the physiology of the plant, for life-relations have in view life-processes. The subject of plant physiology is a very complex one, and it would be impossible in an elementary work to present more than a few very general facts. Certain facts in reference to plant movements, an important physiological subject, have been mentioned in connection with life-relations, but it seems necessary to make some special mention of nutrition.

111. **Significance of chlorophyll.**—Probably the most important fact to observe in reference to the nutrition of plants is that some plants are green or have green parts, while others, such as toadstools, do not show this green

color. It has been stated that this green color is due to the presence of a coloring matter known as *chlorophyll* (see §12). The two groups may be spoken of, therefore, as (1) *green plants* and (2) *plants without chlorophyll.* The presence of chlorophyll makes it possible for the plants containing it to manufacture their own food out of such materials as water, soil material, and gases. For this reason, green plants may be entirely independent of all other living things, so far as their food supply is concerned.

Plants without chlorophyll, however, are unable to manufacture food out of such materials, and must obtain it already manufactured in the bodies of other plants or animals. For this reason, they are dependent upon other living things for their food supply, just as are animals. It is evident that plants without chlorophyll may obtain this food supply either from the living bodies of plants and animals, in which case they are called *parasites*, or they may obtain it from the substances derived from the bodies of plants and animals, in which case they are called *saprophytes.* For example, the rust which attacks the wheat, and is found upon the leaves and stems of the living plant, is a parasite; while the mould which often develops on stale bread is a saprophyte. Some plants without chlorophyll can live either as parasites or saprophytes, while others are always one or the other. By far the largest number of parasites and saprophytes belong to the group of low plants called fungi, and when fungi are referred to, it must be understood that it means the greatest group of plants without chlorophyll.

112. **Photosynthesis.**—The nutritive processes in green plants are the same as in other plants, and in addition there is in green plants the peculiar process known as *photosynthesis* (see §25). In plants with foliage leaves, these are the chief organs for this work. It must be remembered, however, that leaves are not necessary for photosynthesis, for plants without leaves, such as algæ, perform it. The

essential thing is green tissue exposed to light, but in this brief account an ordinary leafy plant growing in the soil will be considered.

As the leaves are the active structures in the work of photosynthesis, the raw materials necessary must be brought to them. In a general way, these materials are carbon dioxide and water. The gas exists diffused through the atmosphere, and so is in contact with the leaves. It also occurs dissolved in the water of the soil, but the gas used is absorbed from the air by the leaves. The supply of water, on the other hand, in soil-related plants, is obtained from the soil. The root system absorbs this water, which then ascends the stem and is distributed to the leaves.

(1) *Ascent of water.*—The water does not move upwards through all parts of the stem, but is restricted to a certain definite region. This region is easily recognized as the woody part of stems. Sometimes separate strands of wood, looking like fibers, may be seen running lengthwise through the stem ; sometimes the fibrous strands are packed so close together that they form a compact woody mass, as in shrubs and trees. In the case of most trees new wood is made each year, through which the water moves. Hence the very common distinction is made between *sap-wood,* through which the water is moving, and *heart-wood,* which the water current has abandoned. Just how the water ascends through these woody fibers, especially in tall trees, is a matter of much discussion, and cannot be regarded as definitely known. In any event, it should be remembered that these woody fibers are not like the open veins and arteries of animal bodies, and no "circulation" is possible. These same woody strands are seen branching throughout the leaves, forming the so-called vein system, and it is evident, therefore, that they form a continuous route from roots to leaves.

It is easy to demonstrate the ascent of water in the stem, and the path it takes, by a simple experiment. If an active stem be cut and plunged into water stained with an aniline color called eosin,* the ascending water will stain its pathway. After some time sections through the stem will show that the water has traveled upwards through it, and the stain will point out the region of the stem used in the movement.

In general, therefore, the carbon dioxide is absorbed directly from the air by the leaves, and the water is absorbed by the root from the soil, and moves upwards through the stem into the leaves. An interesting fact about these raw materials is that they are very common waste products. They are waste products because in most life-processes they cannot be taken to pieces and used. The fact that they can be used in photosynthesis shows that it is a very remarkable life process.

Fig. 145. Some mesophyll cells from the leaf of *Fittonia*, showing chloroplasts.

(2) *Chloroplasts.*—Having obtained some knowledge of the raw materials used in photosynthesis, and their sources, it is necessary to consider the plant machinery arranged for the work. In the working leaf cells it is discovered that the color is due to the presence of very small green bodies, known as chlorophyll bodies or *chloroplasts* (see Fig. 145). These consist of the living substance, known as protoplasm, and the green stain called chlorophyll; therefore, each chloroplast is a living body (*plastid*) stained green. It is in these chloroplasts that the work of photosynthesis is done. In order that they may work it is necessary for them to obtain a supply of energy from some outside source, and the source used in nature is sunlight. The green stain (chlorophyll) seems to be used in absorbing the necessary energy from sunlight, and the

* The commoner grades of red ink are usually solutions of eosin.

plastid uses this energy in the work of photosynthesis. It is evident, therefore, that photosynthesis goes on only in the sunlight, and is suspended entirely at night. It is found that any intense light can be used as a substitute for sunlight, and plants have been observed to carry on the work of photosynthesis in the presence of electric light.

(3) *Result of photosynthesis.*—The result of this work can be stated only in a very general way. Carbon dioxide is composed of two elements, carbon and oxygen, in the proportion one part of carbon to two parts of oxygen. Water is also composed of two elements, hydrogen and oxygen. In photosynthesis the elements composing these substances are separated from one another, and recombined in a new way. In the process a certain amount of oxygen is liberated, just as much as was in the carbon dioxide, and a new substance is formed, known as a carbohydrate. The oxygen set free escapes from the plant, and may be regarded as waste product in the process of photosynthesis. It will be remembered that the external changes in this process are the absorption of carbon dioxide and the giving off of oxygen (see §25).

(4) *Carbohydrates and proteids.* — The carbohydrate formed is an organic substance; that is, a substance made in nature only by life processes. It is the same kind of substance as sugar or starch, and all are known as carbohydrates; that is, substances composed of carbon, and of hydrogen and oxygen in the same proportion as in water. The work of photosynthesis, therefore, is to form carbohydrates. The carbohydrates, such as sugar and starch, represent but one type of food material. Proteids represent another prominent type, substances which contain carbon, hydrogen, and oxygen, as do carbohydrates, but which also contain other elements, notably nitrogen, sulphur, and phosphorus. The white of an egg may be taken as an example of proteids. They seem to be made from the carbo-

hydrates, the nitrogen, sulphur, and other necessary additional elements being obtained from soil substances dissolved in the water which is absorbed and conveyed to the leaves.

113. **Transpiration.**—The water which is absorbed by the roots and passes to the leaves is much more abundant than is needed in the process of photosynthesis. It should be remembered that the water is not only used as a raw material for food manufacture, but also acts as a solvent of the soil materials that are passing into the plant. The water in excess of the small amount used in food manufacture is given off from the plant in the form of water vapor, the process being already referred to as *transpiration* (see §26).

114. **Digestion.**—Carbohydrates and proteids may be regarded as prominent types of plant food which green plants are able to manufacture. These foods are transported through the plant to regions where work is going on, and if there is a greater supply of food than is needed for the working regions, the excess is stored up in some part of the plant. As a rule, green plants are able to manufacture much more food than they use, and it is upon this excess that other plants and animals live. In the transfer of foods through the plant certain changes are often necessary. For example, starch is insoluble, and hence cannot be carried about in solution. It is necessary to transform it into sugar, which is soluble. These changes, made to facilitate the transfer of foods, represent *digestion*.

115. **Assimilation.**—When food in some form has reached a working region, it is organized into the living substance of the plant, known as *protoplasm*, and the protoplasm builds the plant structure. This process of organizing the food into the living substance is known as *assimilation*.

116. **Respiration.**—The formation of foods, their digestion and assimilation are all preparatory to the process of respiration, which may be called the use of assimilated food. The whole working power of the plant depends

upon respiration, which means the absorption of oxygen by the protoplasm, the breaking down of protoplasm, and the giving off of carbon dioxide and water as wastes. The im-

Fig. 146. The common Northern pitcher plant. The hollow leaves, each with a hood and a wing, form a rosette, from the center of which arise the flower stalks.—After Kerner.

portance of this process may be realized when it is remembered that there is the same need in our own living, as it is essential for us also to "breathe in" oxygen, and as a result we "breathe out" carbon dioxide and water. This breaking down or "oxidizing" of protoplasm releases the power by which the work of the plant is carried on (see §27).

117. **Summary of life-processes.**—To summarize the nutritive life-processes in green plants, therefore, *photosynthesis* manufactures carbohydrates, the materials used being carbon dioxide and water, the work being done by the chloroplast with the aid of light; the *manufacture of proteids* uses these carbohydrates, and also substances containing nitrogen, sulphur, etc.; *digestion* puts the insoluble carbohydrates and the proteids into a soluble form for transfer through the plant; *assimilation* converts this food material into the living substance of the plant, protoplasm; *respiration* is the oxidizing of the protoplasm which enables the plant to work, oxygen being absorbed, and carbon dioxide and water vapor being given off in the process.

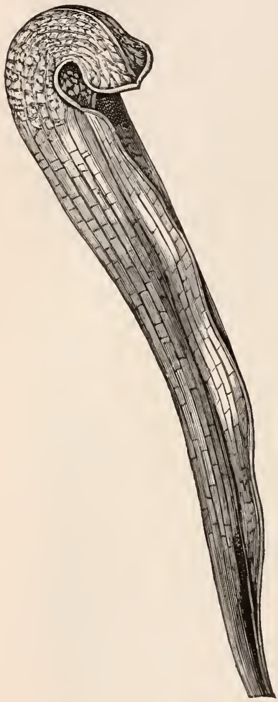


Fig. 147. The Southern pitcher plant, showing the funnelform and winged pitcher, and the overarching hood with translucent spots.—After Kerner.

118. **Plants without chlorophyll.**—Remembering the life-processes described under green plants, it is evident that plants without chlorophyll cannot do the work of photosynthesis. This means that they cannot manufacture carbohydrates, and that they must depend upon other plants or animals for this important food. Mushrooms, puff-balls, moulds, mildews, rusts, dodder, corpse plants, beech drops, etc., may be taken as illustrations of such plants.

119. **Saprophytes.**—In the case of saprophytes dead bodies or body products are attacked, and sooner or later all organic matter is attacked and decomposed by them. The decomposition is a result of the nutritive processes of plants without chlorophyll, and were it not for them "the whole surface of the earth would be covered with a thick deposit of the animal and plant remains of the past thousands of years."

The green plants, therefore, are the manufacturers of organic material, producing far more than they can use, while the plants without chlorophyll are the destroyers of organic material. The chief destroyers are the Bacteria and ordinary Fungi, but some of the higher plants have also adopted this method of obtaining food. Many ordinary green plants have the saprophytic habit of absorbing organic material from rich humus soil; and such plants as the broom rapes are parasitic, attaching their subterranean parts to those of other plants, becoming "root parasites."

120. **Parasites.**—Certain plants without chlorophyll are not content to obtain organic material from dead bodies, but attack living ones. As in the case of saprophytes, the vast majority of plants which have formed this habit are Bacteria and ordinary Fungi. Parasites are not only modified in structure in consequence of the absence of chlorophyll, but they have developed means of penetrating their hosts. Many of them have also cultivated a very selective habit, restricting themselves to certain plants or animals, or even to certain organs.

The parasitic habit has also been developed by some of the higher plants, sometimes completely, sometimes partially. Dodder, for example, is completely parasitic at maturity (Fig. 148), while mistletoe is only partially so, doing chlorophyll work and also absorbing from the tree into which it has sent its haustoria.

That saprophytism and parasitism are both habits gradually acquired is inferred from the number of green plants which have developed them more or less, as a supplement to the food which they manufacture. The less chlorophyll is used the less is it developed, and a green plant which is obtaining the larger amount of its food in a saprophytic or parasitic way is on the way to losing all of its chlorophyll and becoming a complete saprophyte or parasite.

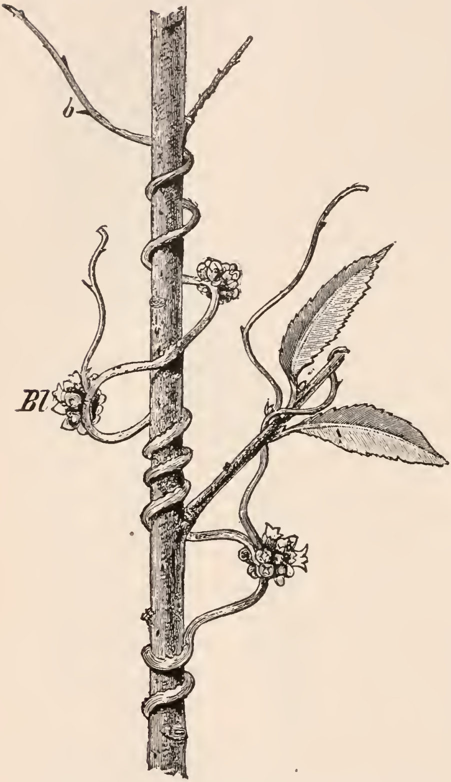


FIG. 148. A dodder plant parasitic on a willow twig. The leafless dodder twines about the willow, and sends out sucking processes which penetrate and absorb.—After STRASBURGER.

Certain of the lower Algæ are in the habit of living in the body cavities of higher plants, finding in such situations the moisture and protection which they need. They may thus have brought within their reach some of the organic products of the higher plant. If they can use some of these, as is very likely, a partially parasitic habit is begun, which may lead to loss of chlorophyll and complete parasitism.

121. Symbionts.—*Symbiosis* means "living together," and two organisms thus related are called *symbionts*. In its broadest sense symbiosis includes any sort of dependence between living organisms, from the vine and the tree upon which it climbs, to the alga and fungus so intimately associated in a Lichen as to seem a single plant. In a narrower sense it includes only cases in which there is an intimate organic relation between the symbionts. This would include parasitism, the parasite and host being the symbionts, and the organic relation certainly being intimate. In a still narrower sense symbiosis includes only those cases in which the symbionts are mutually helpful. This fact, however, is very difficult to determine, and opinions often vary widely as to the mutual advantage in certain cases. However large a set of phenomena may be included under the term symbiosis, we use it here in this narrowest sense, which is often distinguished as *mutualism*.

(1) *Lichens.*—A Lichen is a complex made up of a fungus and an alga living together. It is certain that the fungus cannot live without the alga, but the alga can live without the fungus. Hence it seems plain that this relation is not one of mutual helpfulness, but that the fungus is living upon the alga as any other parasite lives upon its host (see §194).

(2) *Mycorhiza.*—The name means "root-fungus," and refers to an association which exists between certain Fungi of the soil and roots of higher plants. It was formerly thought that mycorhiza occurred only in connection with a limited number of higher plants, such as orchids, heaths, oaks, etc., but more recent study indicates that probably the large majority of vascular plants (that is, plants with true roots) possess it, the water plants being excepted (Figs. 149, 150). It has been found that the humus soil of forests is in large part "a living mass of innumerable filamentous fungi." It is clearly of advantage to roots to relate themselves to this great network of filaments, which are already in the best relations for absorption, and those plants which are unable to do this are at a disadvantage in the competition for the nutrient materials of the forest soil. It is doubtful whether many vascular green plants

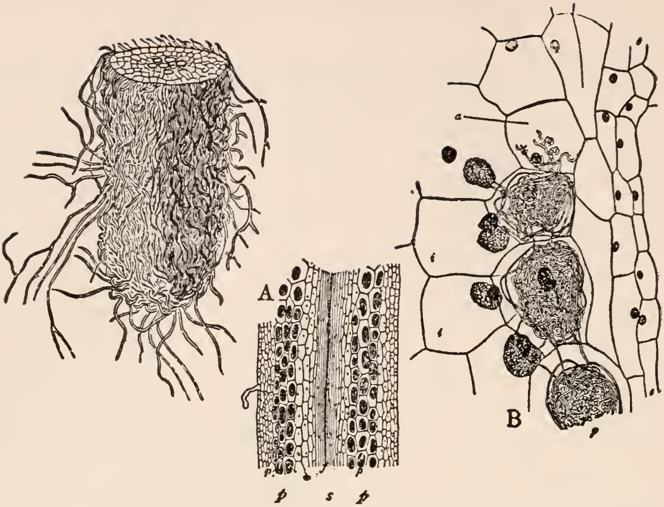


FIG. 149. Mycorhiza: to the left is the tip of a rootlet of beech enmeshed by the fungus; *A*, diagram of longitudinal section of an orchid root, showing the cells of the cortex (p) filled with hyphæ; *B*, part of longitudinal section of orchid root much enlarged, showing epidermis (e), outermost cells of the cortex (p) filled with hyphal threads, which are sending branches into the adjacent cortical cells (a, i). —After FRANK.

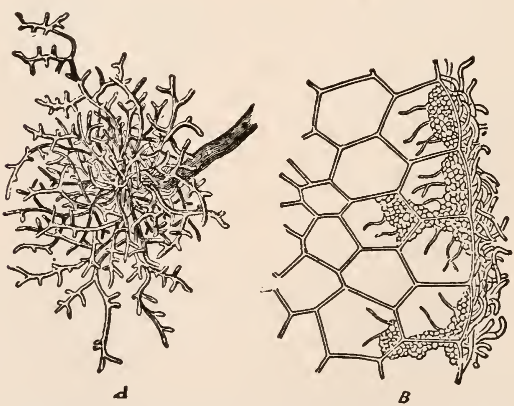


FIG. 150. Mycorhiza: *A*, rootlets of white poplar forming mycorrhiza; *B*, enlarged section of single rootlets, showing the hyphæ penetrating the cells.—After KERNER.

can absorb enough for their needs from the soil without this assistance, and, if so, the fungus becomes of vital importance in the nutrition of such plants. In the case of some of these plants it seems that the soil fungus is not merely passing into their bodies the soil water with its dissolved salts, but is contributing to them organized food, thus diminishing the amount of necessary food manufacture. The delicate branching filaments (hyphæ) of the fungus wrap the rootlets with a mesh of hyphæ and penetrate into the cells, and it is evident that the fungus obtains food from the rootlet as a parasite.

Fig. 151. Root-tubercles on *Vicia Faba*.—After Noll.

(3) *Root-tubercles.*—On the roots of many legume plants, as clovers, peas, beans, etc., little wart-like outgrowths are frequently found, known as "root-tubercles" (Fig. 151). It is found that these tubercles are caused by certain Bacteria, which penetrate the roots and induce these excrescent growths. The tubercles are found to swarm with Bacteria, which are doubtless obtaining food from the roots of the host. At the same time, these Bacteria have the peculiar power of laying hold of the free nitrogen of the air circulating in the soil, and of supplying it to the host plant in some usable form. Ordinarily plants can not use free nitrogen, although it occurs in the air in such abundance, and this power of these soil Bacteria is peculiarly interesting.

This habit of clover and its allies explains why they are useful in what is called "restoring the soil." After ordinary crops have exhausted the soil of its nitrogen-containing salts, and it has become comparatively sterile, clover is able to grow by obtaining nitrogen from the air through the root-tubercles. If the crop of clover be "plowed under," nitrogen-containing materials which the clover has organized will be contributed to the soil, which is thus restored to a condition which will support the ordinary crops again. This indicates the significance of a very ordinary "rotation of crops."

(4) *Ant-plants, etc.*—In symbiosis one of the symbionts may be an animal. Certain fresh-water polyps and sponges become green on account of Algæ which they harbor within their bodies (Fig. 152). Like the Lichen-fungus, these animals are benefited by the presence of the Algæ, which in turn find a congenial situation for living. By some this would also be regarded as a case of helotism, the animal enslaving the alga.

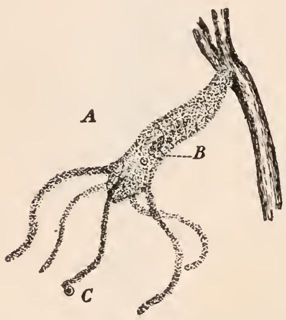


Fig. 152. A fresh-water polyp (*Hydra*) attached to a twig and containing algæ (*C*), which may be seen through the transparent body wall (*B*).—Goldberger.

Very definite arrangements are made by certain plants for harboring ants, which in turn guard them against the attack of leaf-cutting insects and other foes. These plants are called *Myrmecophytes*, which means "ant-plants," or *myrmecophilous plants*, which means "plants loving ants." These plants are mainly in the tropics, and in stem cavities, in hollow thorns, or elsewhere, they provide dwelling places for tribes of warlike ants (Fig. 153). In addition to these dwelling places they provide special kinds of food for the ants.

(5) *Flowers and insects.*—A very interesting and important case of symbiosis is that existing between flowers and insects. The flowers furnish food to the insects, and the

latter are used by the flowers as agents of pollination. An account of this relationship, with illustrations, was given in

Fig. 153. An ant plant (*Hydnophytum*) from South Java, in which an excrescent growth provides a habitation for ants.—After Schimper.

Chapter VII, but it should be associated with other illustrations of symbiosis.

This association of insects and flowers is sometimes so intimate that they have come to depend absolutely upon one another. Especially among the orchids is it true that special flowers and insects are adapted so exactly to one another, that if one disappears the other becomes extinct also.

FIG. 154. The Californian pitcher plant (*Darlingtonia*), showing twisted and winged pitcher, the overarching hood with translucent spots, and the fish-tail appendage to the hood which is attractive to flying insects.—After KERNER.

122. **"Carnivorous" plants.**—This name has been given to plants which have developed the curious habit of capturing insects and using them for food, and perhaps they had better be called "insectivorous plants." They are green plants and, therefore, can manufacture carbohydrates. But they live in soil poor in nitrogen compounds, and hence proteid formation is interfered with. The bodies of captured insects supplement the proteid supply, and the plants have come to depend upon them. Many, if not all, of these carnivorous plants secrete a digestive substance which acts upon the bodies of the captured insects very much as the digestive substances of the alimentary canal act upon proteids

swallowed by animals. Some common illustrations are as follows:

(1) *Pitcher plants.*—In these plants the leaves form tubes, or urns, of various forms, which contain water, and to which insects are attracted and drowned (see Fig. 146). A pitcher plant common throughout the Southern States may be taken as a type (see Fig. 147). The leaves are shaped like slender, hollow cones, and rise in a tuft from the swampy ground. The mouth of this conical urn is overarched and shaded by a hood, in which are translucent spots, like small windows. Around the mouth of the urn are glands, which secrete a sweet liquid (*nectar*), and nectar drops form a trail down the outside of the urn. Inside, just below the rim of the urn, is a glazed zone, so smooth that insects cannot walk upon it. Below the glazed zone is another zone, thickly set with stiff, downward-pointing hairs, and below this is the liquid in the bottom of the urn.

Fig. 155. A sun-dew, showing rosette habit of the insect-catching leaves.

If a fly is attracted by the nectar drops upon this curious leaf, it naturally follows the trail up to the rim of the urn, where the nectar is abundant. If it attempts to descend within the urn, it slips on the glazed zone, and falls into the water, and if it attempts to escape by crawling up the sides of the urn, the thicket of downward-pointing hairs prevents. If it seeks to fly away from the rim, it flies towards the translucent spots in the hood, which look like the way of escape, as the direction of entrance is in the shadow of the hood. Pounding against the hood, the fly falls into the tube. This Southern pitcher plant is known

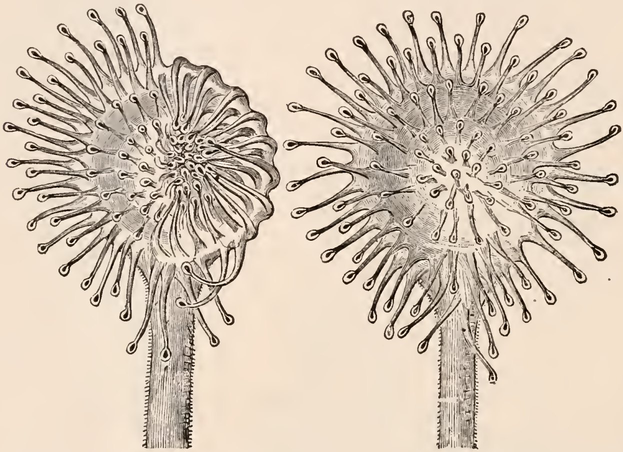


FIG. 156. Two leaves of a sun-dew. The one to the right has its glandular hairs fully expanded; the one to the left shows half of the hairs bending inward, in the position assumed when an insect has been captured.—After KERNER.

as a great fly-catcher, and the urns are often well supplied with the decaying bodies of these insects.

A much larger Californian pitcher plant has still more elaborate contrivances for attracting insects (see Fig. 154).

(2) *Drosera.*—The droseras are commonly known as "sun-dews," and grow in swampy regions, the leaves forming small rosettes on the ground (see Fig. 155). In one form the leaf blade is round, and the margin is beset by prominent bristle-like hairs, each with a globular gland at its tip (see Fig. 156). Shorter gland-bearing hairs are

scattered also over the inner surface of the blade. These glands excrete a clear, sticky fluid, which hangs to them in drops like dew-drops. If a small insect becomes entangled

FIG. 157. Plants of *Dionæa*, showing the rosette habit of the leaves with terminal traps, and the erect flowering stem.—After KERNER.

in the sticky drop, the hair begins to curve inward, and presently presses its victim down upon the surface of the blade. In the case of larger insects, several of the marginal hairs may join together in holding it, or the whole blade may become more or less rolled inward.

(3) *Dionæa.*—This is one of the most famous and remarkable of fly-catching plants (see Fig. 157). It is found in sandy swamps near Wilmington, North Carolina. The leaf blade is constructed like a steel trap, the two halves snapping together, and the marginal bristles interlocking like the teeth of a trap (see Fig. 158). A few sensitive hairs, like feelers, are developed on the leaf surface, and when one of these is touched by a small flying or hovering insect, the trap snaps shut and the insect is caught. Only after digestion does the trap open again.

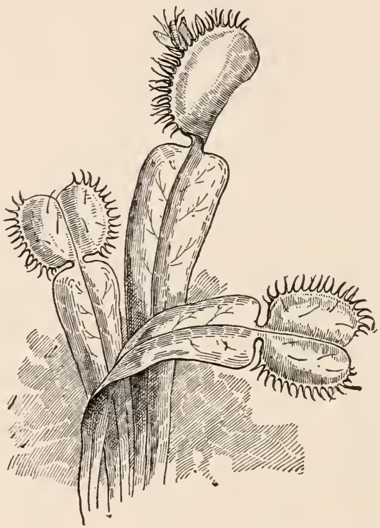


FIG. 158. Three leaves of *Dionæa*, showing the details of the trap in the leaves to right and left, and the central trap in the act of capturing an insect.

There are certain green plants, not called carnivorous plants, which show the same general habit of supplementing their food supply, and so reducing the necessity of food manufacture. The mistletoe is a green plant, growing upon certain trees, from which it obtains some food, supplementing that which it is able to manufacture.

CHAPTER XI

PLANT ASSOCIATIONS: ECOLOGICAL FACTORS

123. Definition of plant association.—From the previous chapters it has been learned that every complex plant is a combination of organs, and that each organ is related in some special way to its environment. It follows, therefore, that the whole plant, made up of organs, holds a very complex relation with its environment. The stem demands certain things, the root other things, and the leaves still others. To satisfy all of these demands, so far as possible, the whole plant is delicately adjusted.

The earth's surface presents very diverse conditions in reference to plant life, and as plants are grouped according to these conditions, this leads to definite associations of plants, those adapted to the same general conditions being apt to live together. Such an assemblage of plants living together in similar conditions is a *plant association*, the conditions forbidding other plants. It must not be understood that all plants affecting the same conditions will be found living together. For example, a meadow of a certain type will not contain all the kinds of grasses associated with that type. Certain grasses will be found in one meadow, and other grasses will be found in other meadows of the same type.

The rivalry of closely related plants living in the same association is apt to be intense, on account of their similar demands, and unrelated plants are able to live together with the least rivalry. A plant association, therefore, may contain a wide representation of the plant kingdom, from plants of low rank to those of high rank.

Before considering some of the common associations, it is necessary to note some of the conditions which determine plant associations. Those things in the environment of the plant which influence the organization of an association are known as *ecological factors*.

124. **Water.**—Water is certainly one of the most important conditions in the environment of a plant, and has great influence in determining the organization of associations. If all plants are considered, it will be noted that the amount of water to which they are exposed is exceedingly variable. At one extreme are those plants which are completely submerged; at the other extreme are those plants of arid regions which can obtain very little water; and between these extremes there is every gradation in the amount of available water. Among the most striking adaptations of plants are those for living in the presence of a great amount of water, and those for guarding against its lack.

One of the first things to consider in connection with any plant association is the amount of water supply. It is not merely a question of its total annual amount, but of its distribution through the year. Is it supplied somewhat uniformly, or is there alternating flood and drouth? The nature of the water supply is also important. Are there surface channels or subterranean channels, or does the whole supply come in the form of rain and snow which fall upon the area?

Another important fact to consider in connection with the water supply has to do with the structure of the soil. There is what may be called a water level in soils, and it is important to note the depth of this level beneath the surface. In some soils it is very near the surface; in others, such as sandy soils, it may be some distance beneath the surface.

Not only do the amount of water and the depth of the water level help to determine plant associations, but also the substances which the water contains. Two areas may have the same amount of water and the same water level, but if the substances dissolved in the water differ in certain particulars, two entirely distinct associations may result.

125. **Heat.**—The general temperature of an area is important to consider, but it is evident that differences of temperature are not so local as differences in the water supply, and therefore this factor is not so important in the organization of the plant associations of any given neighborhood as is the water factor. Even in the distribution of plants over the surface of the earth, however, the water factor is probably more important than the heat factor. The range of temperature which the plant kingdom, as a whole, can endure during active work may be stated in a general way as from 0° to 50° C.; that is, from the freezing point of water to 122° Fahr. There are certain plants which can work at higher temperatures, notably certain algæ growing in hot springs, but they may be regarded as exceptions. It must be remembered that the range of temperature given is for plants actively at work, and does not include the temperature which many plants are able to endure in a specially protected but very inactive condition. For example, many plants of the temperate regions endure a winter temperature which is frequently lower than the freezing point of water, but it is a question of endurance and not of work.

It must not be supposed that all plants can work equally well throughout the whole range of temperature given, for they differ widely in this regard. Tropical plants, for instance, accustomed to a certain limited range of high temperature, cannot work continuously at the lower temperatures. For each kind of plant there is what may be called a zero point, below which it is not in the habit of working.

While it is important to note the general temperature of an area throughout the year, it is also necessary to note its distribution. Two regions may have presumably the same amount of heat through the year, but if in the one case it is uniformly distributed, and in the other great extremes of temperature occur, the same plants will not be found in both. It is, perhaps, most important to note the temperature during certain critical periods in the life of plants, such as the flowering period of seed-plants.

Although the temperature problem may be comparatively uniform over any given area, the effect of it may be noted in the succession of plants through the growing season. In our temperate regions the spring plants and summer plants and autumn plants differ decidedly from one another. It is evident that the spring plants can endure greater cold than the summer plants, and the succession of flowers will indicate somewhat these relations of temperature.

It should be remarked, also, that not only is the temperature of the air to be noted, but also that of the soil. These two temperatures may differ by several degrees, and the soil temperature especially affects root activity, and hence is a very important factor to discover.

At this point it is possible to call attention to the effect of the combination of ecological factors. For instance, in reference to the occurrence of plants in any association, the water factor and the heat factor cannot be considered each by itself, but must be taken in combination. For example, if in a given area there is a combination of maximum heat and minimum water, the result will be a desert, and only certain specially adapted plants can exist. It is evident that the great heat increases the transpiration, and transpiration when the supply of water is very meager is peculiarly dangerous. Plants which exist in such conditions, therefore, must be specially adapted for controlling transpiration. On the other hand, if in any area the combination is maximum heat and maximum water, the result will be the most luxuriant vegetation on the earth, such as grows in the rainy tropics. It is evident that the possible combinations of the water and heat factors may be very numerous, and that it is such combinations that chiefly affect plant associations.

126. **Soil.**—The soil factor is not merely important to consider in connection with those plants directly related to the soil, but is a factor for all plants, as it determines the substances which the water contains. There are two things to be considered in connection with the soil, namely, its chemical composition and its physical properties. Perhaps the physical properties are more important from the standpoint of soil-related plants than the chemical composition, although both the chemical and physical nature of the soil are so bound up together that they need not be considered separately here. The physical properties of the soil, which are important to plants, are chiefly those which relate to the water supply. It is always important to determine how receptive a soil is. Does it take in water easily or not? It is also necessary to determine how retentive it is; it may receive water readily, but it may not retain it.

For convenience in ordinary field work with plants, soils may be divided roughly into six classes: (1) *rock,* which means solid uncrumbled rock, upon which certain plants are able to grow; (2) *sand,* which has small water capacity, that is, it may receive water readily enough, but does not retain it; (3) *lime soil;* (4) *clay,* which has great water capacity; (5) *humus,* which is rich in the products of plant and animal decay; (6) *salt soil,* in which the water contains certain salts, and is generally spoken of as alkaline. These divisions in a rough way indicate both the structure of the soil and its chemical composition. Not only should the kinds of soil on an area be determined, but their depth is an important consideration. It is very common to find one of these soils overlying another one, and this relation between the two will have a very important effect. For instance, if a sand soil is found lying over a clay soil, the result will be that the sand soil will retain far more water than it would alone. If a humus soil in one area overlies a sand soil, and in another area overlies a clay soil, the humus will differ very much in the two cases in reference to water.

The soil cover should also be considered. The common soil covers are snow, fallen leaves, and living plants. It will be noticed that all these covers tend to diminish the loss of heat from the soil, as well as the access of heat to the soil. In other words, a good soil cover will very much diminish the extremes of temperature. All this tends to increase the retention of water.

127. **Light.**—It is known that light is essential for the peculiar work of green plants. However, all green plants cannot have an equal amount of light, and some have learned to live with a less amount than others. While no sharp line can be drawn between green plants which use intense light, and those which use less intense light, we still recognize in a general way what are called *light plants* and *shade plants*. We know that certain plants are chiefly found in situations where they can be exposed freely to light, and that other plants, as a rule, are found in shady situations.

Starting with this idea, we find that plants grow in strata. In a forest association, for example, the tall trees represent the highest stratum; below this there may be a stratum of shrubs, then tall herbs, then low herbs, then forms like mosses and lichens growing close to the ground. In any plant association it is important to note the number of these strata. It may be that the highest stratum shades so densely that many of the other strata are not represented at all. An illustration of this can be obtained from a dense beech forest.

128. **Wind.**—It is generally known that wind has a drying effect, and, therefore, it increases the transpiration of plants and tends to impoverish them in water. This factor is especially conspicuous in regions where there are prevailing winds, such as near the sea-coast, around the great lakes, and on the prairies and plains. In all such regions

the plants have been compelled to adapt themselves to this loss of water; and in some regions the prevailing winds are so constant and violent that the force of the wind itself has influenced the appearance of the vegetation, giving what is called a characteristic physiognomy to the area.

These five factors have been selected from a much larger number that might be enumerated, but they may be regarded as among the most important ones. It will be noticed that these factors may be combined in all sorts of ways, so that an almost endless series of combinations seems to be possible. This will give some idea as to the possible number of plant associations, for they may be as numerous as are the combinations of these factors.

129. **The great groups of associations.**—It is possible to reduce the very numerous associations to three or four great groups. For convenience, the water factor is chiefly used for this classification. It results in a convenient classification, but one that is certainly more or less artificial. The selection of any one factor from among the many for the purpose of classification never results in a very natural classification when the combination of factors determines the group. However, for general purposes, the usual classification on the basis of water supply will be used. On this basis there are three great groups of associations, as follows:

(1) *Hydrophytes.*—The name means "water plants," and suggests that such associations are at that extreme of the water supply where it is very abundant. Such plants may grow in the water, or in very wet soil, but in any event they are exposed to a large amount of water.

(2) *Xerophytes.*—The name means "drouth plants," and suggests the other extreme of the water supply. True xerophytes are exposed to dry soil and dry atmosphere.

(3) *Mesophytes.*—Between the two extremes of the water supply there is a great middle region of medium water supply, and plants which occupy it are known as

mesophytes, the plants of medium conditions. It is evident that mesophytes gradually pass into hydrophytes on the one side, and into xerophytes on the other; but it is also evident that mesophyte associations have the greatest range of water supply, extending from a large amount of water to a very small amount.

It should be understood that these three groups of associations, which are distinguished from one another by the amount of the water supply, are artificial groups rather than natural ones, for they bring together unrelated associations, and often separate those that are closely related. For example, a swampy meadow is put among hydrophyte associations by this classification; and it may shade into an ordinary meadow, which belongs among the mesophytes. Probably the largest fact which may be used in grouping plant associations is that certain associations are so situated that they seek for the most part to reduce transpiration, and that others are so situated that they seek for the most part to increase transpiration.

However, the factors which determine associations are so numerous that they cannot be presented in an elementary book, and the simpler artificial grouping given above will serve to introduce the associations to observation.

CHAPTER XII

HYDROPHYTE ASSOCIATIONS

130. **General character.**—Hydrophytes are related to abundant water, either throughout their whole structure or in part of their structure. It is a well-known fact that hydrophytes are among the most cosmopolitan of plants, and hydrophyte associations in one part of the world look very much like hydrophyte associations in any other region. It is probable that the abundant water makes the conditions more uniform.

It is evident that for those plants, or plant parts, which are submerged, the water affects the heat factor by diminishing the extremes. It also affects the light factor, in so far as the light must pass through the water to reach the chlorophyll-containing parts, as light is diminished in intensity by passing through the water. Before considering a few hydrophyte associations, it is necessary to note the prominent hydrophyte adaptations.

131. **Adaptations.**—In order that the illustration may be as simple as possible, a complex plant completely exposed to water is selected, for it is evident that the relations of a swamp plant, with its roots in water and its stem and leaves exposed to air, are complicated. A number of adaptations may be noted in connection with the submerged or floating plant.

(1) *Thin-walled epidermis.*—In the case of the soil-related plants, the water supply comes mainly from the soil, and the root system is constructed to absorb it. In the case of the water plant under consideration, however, the

whole plant body is exposed to the water supply, and therefore absorption may take place through the whole surface rather than at any particular region such as the root. In order that this may be done, however, it is necessary for the epidermis to have thin walls, which is usually not the case in epidermis exposed to the air, where a certain amount of protection is needed in the way of thickening.

(2) *Roots much reduced or wanting.*—It must be evident that if water is being absorbed by the whole free surface of the plant, there is not so much need for a special root region for absorption. Therefore, in such water plants the root system may be much reduced, or may even disappear entirely. It is often retained, however, to act as a holdfast, rather than as an absorbent organ, for most water plants anchor themselves to some support.

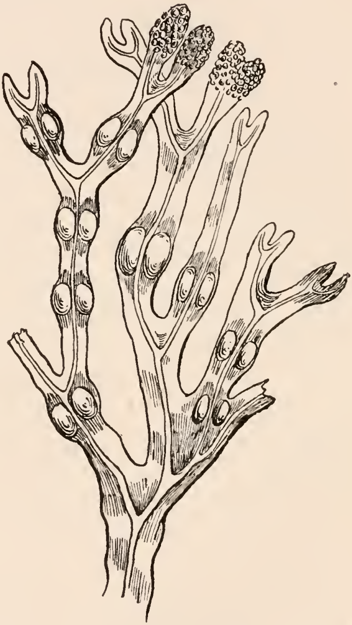


Fig. 159. Fragment of a common seaweed (*Fucus*), showing the body with forking branching and bladder-like air cavities.—After Luerssen.

(3) *Reduction of water-conducting tissues.*—In the ordinary soil-related plants, not only is an absorbing root system necessary, but also a conducting system, to carry the water absorbed from the roots to the leaves and elsewhere. It has already been noted that this conducting system takes the form of woody strands. It is evident that if water is being absorbed by the whole surface of the plant, the

work of conduction is not so extensive or definite, and therefore in such water plants the woody bundles are not so prominently developed as in land plants.

(4) *Reduction of mechanical tissues.*—In the case of ordinary land plants, certain firm tissues are developed so

Fig. 160. Gulfweed (*Sargassum*), showing the thallus differentiated into stem-like and leaf-like portions, and also the bladder-like floats.—After Bennett and Murray.

that the plant may maintain its form. These supporting tissues reach their culmination in such forms as trees, where massive bodies are able to stand upright. It is evident that in the water there is no such need for rigid supporting tissues, as the buoyant power of water helps to support the plant. This fact may be illustrated by taking out of water submerged plants which seem to be upright, with all their parts properly spread out. When removed they collapse, not being able to support themselves in any way.

(5) *Development of air cavities.*—The presence of air in the bodies of water plants is necessary for two reasons: (1),

FIG. 161. Bladderwort, showing the numerous bladders which float the plant, the finely divided water leaves, and the erect flowering stems. The bladders are also effective "insect traps," *Utricularia* being one of the "carnivorous plants." —After KERNER.

to aerate the plant; (2), to increase its buoyancy. In most complex water plants there must be some arrangement for the distribution of air containing oxygen. This usually takes the form of air chambers and passageways in the body of the plant (see Figs. 87, 88, 89, 90). Of course such air chambers increase the buoyancy of the body. Sometimes, however, a special buoyancy is provided for by the development of regular floats, which are bladder-like bodies (see Figs. 159, 160). These floats are very common among certain of the seaweeds, and are found among higher plants, as the utricularias or bladderworts, which

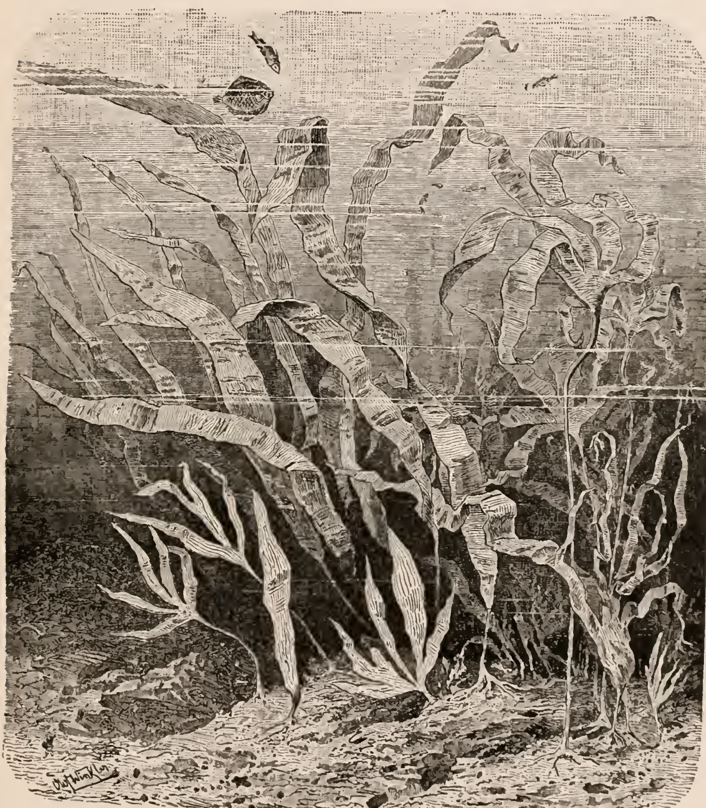


FIG. 162. A group of marine seaweeds (*Laminarias*). Note the various habits of the plant body and the root-like holdfasts.—After KERNER.

have received their name from the numerous bladders developed in connection with their bodies (see Fig. 161), and which are also put to additional uses.

132. **Associations.**—The hydrophyte associations may be put into two great divisions:

1. *True hydrophytes*, in which the contents and temperature of the water are favorable to plant activity. Among such associations may be mentioned the following: (1) Free-swimming associations, in which the plants are entirely sustained by water, as the "pond associations," composed of algæ, duckweeds, etc., which float in stagnant or slow-moving waters.

(2) Pondweed associations, in which the plants are anchored, but their bodies are submerged or floating. Here belong the "rock associations," consisting of plants anchored to some firm support under water, as the algæ; and the "loose-soil associations," which imbed their roots in the mucky soil of the bottom (Fig. 163), the water lilies and pickerel weeds being conspicuous illustrations.

(3) Swamp associations, in which the plants are rooted in water, or in soil rich in water, but the leaf-bearing stems rise above the surface. The conspicuous swamp associations are "reed swamps," characterized by bulrushes, cattails, and reed-grasses (Figs. 164, 167); "swamp-moors," the ordinary swamps, marshes, bogs, etc., and dominated by coarse sedges and grasses (Fig. 163); and "swamp-thickets," consisting of willows, alders, birches, etc.

2. *Xerophytic hydrophytes*, in which the contents and temperature of the water are unfavorable to plant activity, and the structures of the plants are adapted to reduce transpiration. This results in such xerophytic structures as are displayed by the true xerophytes (see §144). Here belong the "sphagnum moors" (Fig. 191), in which sphagnum moss predominates, and is accompanied by numerous peculiar orchids, heaths, carnivorous plants, etc.; "swamp-forests," where tamarack, spruce, pine, etc., are the prevailing trees; "mangrove swamps," of the flat tropical sea-coasts; and "salt marshes," the extensive meadow-like expanses of coarse sedges and grasses near the sea-coast.

FIG. 163. A series of plant associations, showing transition from hydrophyte to mesophyte associations as follows: Lily pond, sedges at margin of water, grading into swamp grasses farther back, then a shrub association, and in the background a tree association. — From photograph by W. J. Lewis.

Fig. 164. An artificial lily pond. Broad, floating leaves of at least two kinds can be seen. The larger, with upturned edge, making the leaf like a great platter, is the great Amazon water lily (*Victoria regia*); the smaller floating leaves are those of the ordinary water lily (*Nymphæa*). The group in the center, with leaf blades raised above the water and cupped, is the lotus (*Nelumbium*). There seems to be some relation between density of growth and the rising of the leaf blades above the water, as may be seen often in the common water lily.

FIG. 165.—A group of pondweeds. The stems are sustained in an erect position by the water, and the narrow leaves are exposed to a light whose intensity is diminished by passing through the water.—After KERNER.

Fig. 166. Eel grass (*Vallisneria*), a common pondweed plant. The plants are anchored and the foliage is submerged. The carpel-bearing flowers are carried to the surface on long stalks which allow a variable depth of water. The stamen-bearing flowers remain submerged, as indicated near the lower left corner, the flowers breaking away and rising to the surface, where they float and effect pollination.—After Kerner.

FIG. 167. A reed swamp, fringing the low shore of a lake or a sluggish stream. The plants are tall and wand-like, and all are monocotyls. Three types are prominent, the reed grasses (the tallest), the cat-tails (at the right), and the bulrushes (a group standing out in deeper water near the middle of the fringing growth). The plant in the foreground at the extreme right is the arrow-leaf (*Sagittaria*), recognized by its characteristic leaves.—After KERNER.

CHAPTER XIII

XEROPHYTE ASSOCIATIONS

133. **General character.**—Strongly contrasted with the hydrophytes are the xerophytes, which are adapted to dry air and soil. The xerophytic conditions may be regarded in general as drouth conditions. It is not necessary for the air and soil to be dry throughout the year to develop xerophytic conditions. These conditions may be put under three heads: (1) *possible drouth,* in which a season of drouth may occur at irregular intervals, or in some seasons may not occur at all; (2) *periodic drouth,* in which there is a drouth period as definite as the winter period in certain regions; (3) *perennial drouth,* in which the dry conditions are constant, and the region is distinctly an arid or desert region.

However xerophytic conditions may occur, the problem of the plant is always one of water supply, and many striking structures have been developed to answer it. Plants in such conditions must provide, therefore, for two things: (1) collection and retention of water, and (2) prevention of its loss. It is evident that in these drouth conditions the loss of water through transpiration (see §26) tends to be much increased. This tendency in the presence of a very meager water supply is a menace to the life of the plant, for it is impossible to stop transpiration entirely, as it must take place so long as the plant is alive. The adaptations on the part of the plant, therefore, are directed towards the regulation of transpiration, that it may occur sufficiently for the life-processes, but that it may not be wasteful to the point of danger.

The regulation of transpiration may be accomplished in two general ways. It will be remembered that the amount of transpiration holds some relation to the amount of leaf exposure or exposure of green tissue. Therefore, if the amount of leaf exposure be diminished, the total amount of transpiration will be reduced. Another general way for regulating transpiration is to protect the exposed surface in some way so that the water does not escape so easily. In a word, therefore, the general method is to reduce the extent of exposed surface or to protect it. It must be understood that plants do not differ from each other in adopting one or the other of these methods, for both are very commonly used by the same plant.

Adaptations

134. **Complete desiccation.**—Some plants have a very remarkable power of completely drying up during the drouth period, and then reviving upon the return of moisture. This power is strikingly illustrated among the lichens and mosses, some of which can become so dry that they may be crumbled into powder, but revive when moisture reaches them. A group of club mosses, popularly known as "resurrection plants," illustrates this same power. The dried up nest-like bodies of these plants are common in the markets, and when they are placed in a bowl of water they expand and may renew their activity. In such cases it can hardly be said that there is any special effort on the part of the plant to resist drouth, for it seems to yield completely to the dry conditions and loses its moisture. The power of reviving, after being completely dried out, is an offset, however, for protective structures.

135. **Periodic reduction of surface.**—In regions of periodic

drouth it is very common for plants to diminish the exposed surface in a very decided way. In such cases there is what may be called a periodic surface decrease. For example, annual plants remarkably diminish their exposed surface at the period of drouth by being represented only by well-protected seeds. The whole exposed surface of the plant, root, stem, and leaves, has disappeared, and the seed preserves the plant through the drouth.

Little less remarkable is the so-called geophilous habit. In this case the whole of the plant surface exposed to the air disappears, and only underground parts, such as bulbs, tubers, etc., persist (see Figs. 45, 46, 66, 67, 68, 69, 70, 75, 144, 168, 169). At the re-

FIG. 168. The bloodroot (*Sanguinaria*), showing the subterranean rootstock sending leaves and flower above the surface.—After ATKINSON.

FIG. 169. The spring beauty (*Claytonia*), showing subterranean tuber-like stem sending leaf and flower-bearing stem above the surface.—After ATKINSON.

turn of the moist season these underground parts develop new exposed surfaces. In such cases it may be said that at the coming of the drouth the plant seeks a subterranean retreat.

A little less decrease of exposed surface is shown by the deciduous habit. It is known that certain trees and shrubs, whose bodies remain exposed to the drouth, shed their leaves and thus very greatly reduce the amount of exposure; with the return of moisture, new leaves are put forth. It will be remarked, in this connection, that the same habits serve just as well to bridge over a period of cold as a period of drouth, and perhaps they are more familiar in connection with the cold period than in connection with the drouth period.

136. **Temporary reduction of surface.**—While the habits above have to do with regular drouth

periods, there are other habits by which a temporary reduction of surface may be secured. For instance, at the approach of a period of drouth, it is very easy to observe certain leaves rolling up in various ways. As a leaf becomes rolled up, it is evident that its exposed surface is reduced. The behavior of grass leaves, under such circumstances, is very easily noted. A comparison of the grass blades upon a well-watered lawn with those upon a dried-up lawn will show that in the former case the leaves are flat, and in the latter more or less rolled up. The same habit is also very easily observed in connection with the larger-leaved mosses, which are very apt to encounter drouth periods.

137. **Fixed light position.**—In general, when leaves have reached maturity, they are unable to change their position in reference to light, having obtained what is known as a fixed light position. During the growth of the leaf, however, there may be changes in direction so that the fixed light position will depend upon the light direction during growth. The position finally attained is an expression of the attempt to secure sufficient, but not too much light (see §13). The most noteworthy fixed positions of leaves are those which have been developed in intense light. A very common position in such cases is the profile position, in which the leaf apex or margin is directed upwards, and the two surfaces are more freely exposed to the morning and evening rays—that is, the rays of low intensity—than to those of midday.

Illustrations of leaves with one edge directed upwards can be obtained from the so-called compass plants. Probably most common among these are the rosin-weed of the prairie region, and the prickly lettuce, which is an introduced plant very common in waste ground (see Fig. 170). Such plants received their popular name from the fact that many of the leaves, when edgewise, point approximately north and south, but this direction is very indefinite. It is evident that such a position avoids exposure of the leaf surface to the noon rays, but obtains for these same surfaces the morning and evening rays. If these plants are developed in the shade, the "compass" habit does not

FIG. 170. Two compass plants. The two figures to the left represent the same plant (*Silphium*) viewed from the east and from the south. The two figures to the right represent the same relative positions of the leaves of *Lactuca*.—After KERNER.

appear (see §15). The profile position is a very common one for the leaves of Australian plants, a fact which gives much of the vegetation a peculiar appearance. All these positions are serviceable in diminishing the loss of water, which would occur with exposure to more intense light.

138. **Motile leaves.**—Although in most plants the mature

leaves are in a fixed position, there are certain ones whose leaves are able to perform movements according to the need. Mention has been made already of such forms as *Oxalis* (see §14), whose leaves change their position readily in reference to light. Motile leaves have been developed most extensively among the *Leguminosæ,* the family to which

FIG. 171. Two twigs of a sensitive plant. The one to the left shows the numerous small leaflets in their expanded position ; the one to the right shows the greatly reduced surface, the leaflets folded together, the main leaf branches having approached one another, and the main leaf-stalk having bent sharply downwards. —After STRASBURGER.

belong peas, etc. In this family are the so-called "sensitive plants," which have received their popular name from their sensitive response to light as well as to other influences (see Fig. 171). The acacia and mimosa forms are the most notable sensitive plants, and are especially developed in arid regions. The leaves are usually very large, but are so much branched that each leaf is composed of very numerous small leaflets. Each leaflet has the power of independent motion, or the whole leaf may move. If there is danger from exposure to drouth, some of the leaflets will be observed to fold together; in case

FIG. 172. A heath plant (*Erica*), showing low, bushy growth and small leaves.

the danger is prolonged, more leaflets will fold together; and if the danger persists, the surface of exposure will be still further reduced, until the whole plant may have its leaves completely folded up. In this way the amount of reduction of the exposed surface may be accurately regulated to suit the need (see §38).

139. **Reduced leaves.**—In regions that are rather permanently dry, it is observed that the plants in general produce smaller leaves than in other regions (see Fig. 173). That this holds a direct relation to the dry conditions is

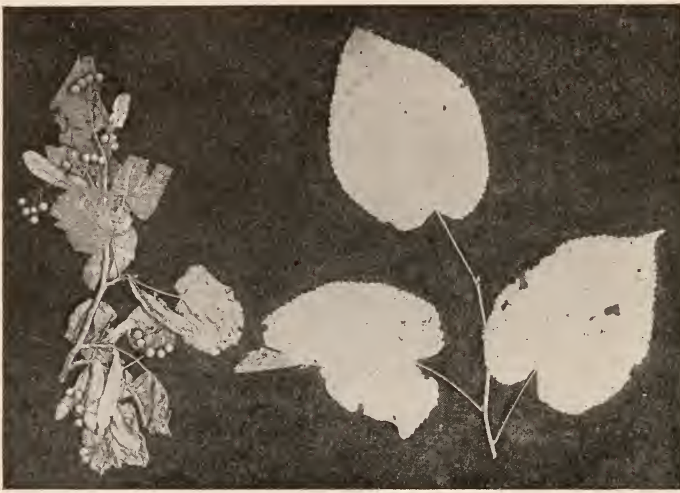


Fig. 173. Leaves from the common basswood (*Tilia*), showing the effect of environment; those at the right being from a tree growing in a river bottom (mesophyte conditions); those at the left being from a tree growing upon a dune, where it is exposed to intense light, heat, cold, and wind. Not only are the former larger, but they are much thinner. The leaves from the dune tree are strikingly smaller, much thicker, and more compact.—After Cowles.

evident from the fact that the same plant often produces smaller leaves in xerophytic conditions than in moist conditions. One of the most striking features of an arid region is the absence of large, showy leaves (see Fig. 172). These reduced leaves are of various forms, such as the needle leaves of pines, or the thread-like leaves of certain sedges and grasses, or the narrow leaves with inrolled margins such as is common in many heath plants. The

FIG. 174. Two species of *Achillea* on different soils. The one to the left was grown in drier conditions and shows an abundant development of hairs.—After SCHIMPER.

extreme of leaf reduction has been reached by the cactus plants, whose leaves, so far as foliage is concerned, have disappeared entirely, and the leaf work is done by the surface of the globular, cylindrical, or flattened stems (see §36).

140. **Hairy coverings.**—A covering of hairs is an effective sun screen, and it is very common to find plants of xerophyte regions characteristically hairy (see §35). The hairs are dead structures, and within them there is air. This causes them to reflect the light, and hence to appear white or nearly so. This reflection of light by the hairs diminishes the amount which reaches the working region of the plant (see Fig. 174).

Fig. 175. Two plants of a common scouring rush (*Equisetum*), showing the effect of environment; the long, unbranched one having grown in normal mesophyte conditions; the short, bushy branching, more slender form having grown on the dunes (xerophyte conditions).—After Cowles.

141. **Body habit.**—Besides the various devices for diminishing exposure or leaf surface, and hence loss of water, enumerated above, the whole habit of the plant may emphasize the same purpose. In dry regions it is to be observed that dwarf growths prevail, so that the plant as a whole does not present such an exposure to the dry air as in regions of greater moisture (see Fig. 175). Also the pros-

trate or creeping habit is a much less exposed one in such regions than the erect habit. In the same manner, the very characteristic rosette habit, with its cluster of overlapping leaves close against the ground, tends to diminish loss of water through transpiration.

One of the most common results of xerophytic conditions upon body habit is the development of thorns and spiny

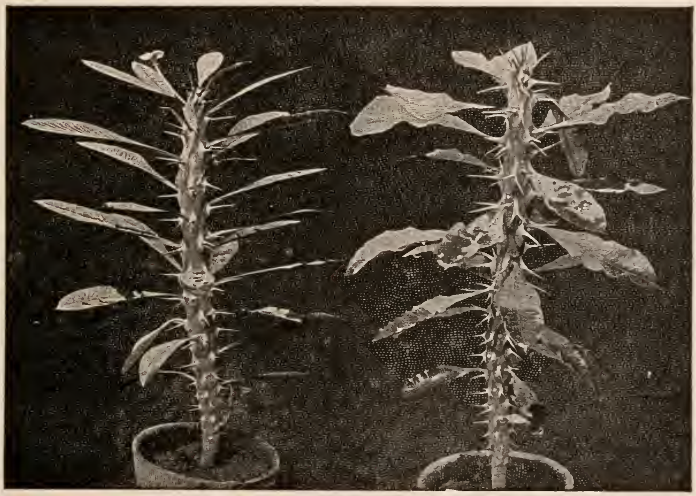


FIG. 176. Young plants of *Euphorbia splendens*, showing a development of thorns characteristic of the plants of dry regions.

processes. As a consequence, the vegetation of dry regions is characteristically spiny. In many cases these spiny processes can be made to develop into ordinary stems or leaves in the presence of more favorable water conditions. It is probable, therefore, that such structures represent reductions in the growth of certain regions, caused by the unfavorable conditions. Incidentally these thorns and spiny processes are probably of great service as a protection to plants in regions where vegetation is peculiarly exposed to the ravages of animals (see §105). Examine Figs. 176, 177, 178, 179, 180, 181.

142. **Anatomical adaptations.**—It is in connection with the xerophytes that some of the most striking anatomical adaptations have been developed. In such conditions the epidermis is apt to be covered by layers of cuticle, which are developed by the walls of the epidermal cells, and being constantly formed beneath, the cuticle may become very thick. This forms a very efficient protective covering, and has a tendency to diminish the loss of water (see §35). It is also to be observed that among xerophytes there is a strong development of palisade tissue. The working cells of the leaves next to the exposed surface are elongated, and are directed endwise to the surface. In this way only the ends of the elongated cells are exposed, and as such cells stand very closely together, there is no drying air between them. In some cases there may be more than one of these palisade rows (see §32). It has been observed that the chloroplasts in these palisade cells are able to assume various positions in

Fig. 177. Two plants of common gorse or furze (*Ulex*), showing the effect of environment : *b* is a plant grown in moist conditions; *a* is a plant grown in dry conditions, the leaves and branches having been almost entirely developed as thorns.—After Lothelier.

FIG. 178. A branch of *Cytisus*, showing the reduced leaves and thorny branches.—After KERNER.

the cell, so that when the light is very intense they move to the more shaded depths of the cell, and when it becomes less intense they move to the more external regions of the cell (see Fig. 182). The stomata, or air pores, which are developed in the epidermis, are also great regulators of transpiration, as has been mentioned already (see §31).

143. Water reservoirs.—In xerophytes attention must be given not only to the regulation of transpiration, but also to the storage of water, as it is received at rare intervals. It is very common to find a certain region of the plant body given over to this work, forming what is known as water tissue. In many leaves this water tissue may be distinguished from the ordinary working cells by being a group of colorless cells (see Fig. 183). In plants of the drier regions leaves may become thick and fleshy through acting as water reservoirs, as in the case of the agave, sedums, etc. Fleshy or "succulent" leaves are regarded as adaptations of prime impor-

FIG. 179. A leaf of tragacanth, showing the reduced leaflets and the thorn-like tip.—After KERNER.

tance in xerophytic conditions. In the cactus plants the peculiar stems have become great reservoirs of moisture. The globular body may be taken to represent the most complete answer to this general problem, as it is the form of body by which the least amount of surface may be exposed and the greatest amount of water storage secured. In the case of fleshy leaves and fleshy bodies it has long been noticed that they not only contain water, but also have a great power of retaining it. Plant collectors have found much difficulty in drying these fleshy forms, some of which seem to be able to retain their moisture indefinitely, even in the driest conditions.

Fig. 180. A fragment of barberry, showing the thorns.—After Kerner.

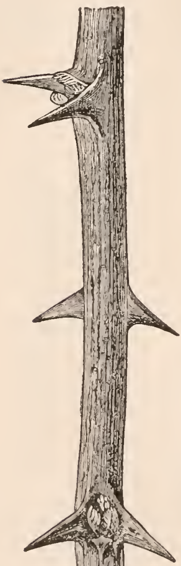


Fig. 181. Twig of common locust, showing the thorns.—After Kerner.

144. **Xerophytic structure.**—The adaptations given above are generally found in plants growing in drouth conditions, and they all imply an effort to diminish transpiration. It must not be supposed, however, that only plants living in drouth conditions show these adaptations. Such adaptations result in what is known as the xerophytic structure, and such a structure may appear even in plants growing in hydrophyte conditions. For example, the bulrush grows in shallow water, and is a prominent member of one of the hydrophyte associations (see §132); and yet it has a remarkably xerophytic structure. This is probably due to the fact that although it

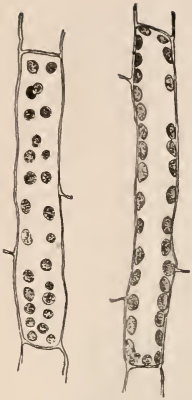


FIG. 182. Cells from the leaf of a quillwort (*Isoetes*). The light is striking the cells from the direction of one looking at the illustration. If it be somewhat diffuse the chloroplasts distribute themselves through the shallow cell, as in the cell to the left. If the light be intense, the chloroplasts move to the wall and assume positions less exposed, as in the cell to the right.

stands in the water its stem is exposed to a heat which is often intense.

The ordinary prairie (see §146) is included among mesophyte associations on account of the rich, well-watered soil; and yet many of the plants are very xerophytic in structure, probably on account of the prevailing dry winds.

The ordinary sphagnum-bog (see §132), or "peat-bog," is included among hydrophyte associations. It has an abundance of water, and is not exposed to blazing heat, as in the case of the bulrushes, or to drying wind, as in the case of prairie plants; and yet its plants show a xerophytic structure. The cause for this has not yet been determined, although several suggestions have been made.

It is evident, therefore, that xerophytic structures are not necessarily confined to xerophytic situations. It is probably true that all associations which show xerophytic structures belong together more naturally than do the associations which are grouped according to the water supply.

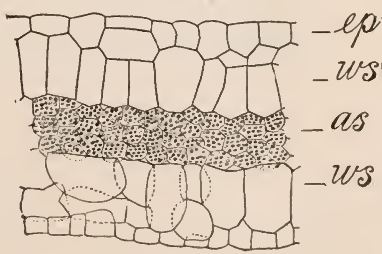


FIG. 183. A section through a *Begonia* leaf, showing the epidermis (*ep*) above and below, the water-storage tissue (*ws*) above and below, and the central chlorophyll region (*as*).

Associations

No attempt will be made to classify these very numerous associations, but a few prominent illustrations will be given. Some of the prominent associations are as follows: "rock associations," composed of plants living upon exposed rock surfaces, etc., notably lichens and mosses (Fig. 184); "sand associations," including beaches, dunes (Fig. 185), etc.; "shrubby heaths," characterized by heath plants; "plains," the great areas with dry air developed in the interiors of continents (Fig. 186); "cactus deserts," still more arid areas of the Mexican region, where the cactus, agave, etc., have learned to live

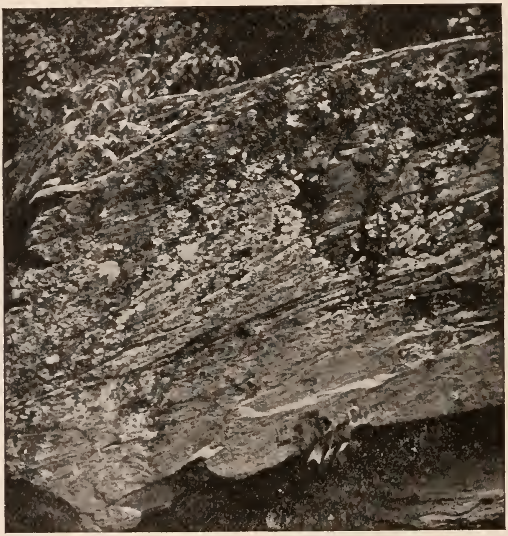


Fig. 184. A rock covered with lichens.

(Fig. 190); "tropical deserts," where xerophytic conditions reach their extreme in the combination of maximum heat and minimum water; "xerophyte thickets," the most impenetrable of all thicket-growths, represented by the "chaparral" of the southwest (Fig. 187), and the "bush" of Africa and Australia; "xerophyte forests," also notably coniferous. (See Figs. 192, 193.)

FIG. 185. A dune encroaching upon various plant associations. In the foreground it is encroaching upon a swamp containing bulrushes. Farther back the encroachment is upon a mixed pine and oak forest. Behind the forest an area of swamp pools is being invaded, and still farther in the background is another mixed forest area. In this particular case it will be noticed that the dune front is convex towards the swamp areas and concave towards the forest areas.—After COWLES.

Fig. 186. A plain, showing the general level character, and the dominant coarse grasses, herbs, and low shrubs (generally sage brush). The cottonwood in the foreground, and others dimly indicated in the background, generally indicate spots of greater moisture or a stream.

FIG. 189. Two plants of the giant cactus. Note the fluted, clumsy branching, leafless bodies growing from the rocky, sterile soil characteristic of cactus deserts. Certain dry-ground grasses and low, shrubby plants with small leaves may be seen in the foreground.

FIG. 190. A cactus desert, showing the very rough, rocky soil, with occasional clumps of globular cactus forms.—After SCHIMPER.

FIG. 191.—Peat bog, showing heath-covered islands (dark) in a general sedgy swamp (light).

FIG. 192.—A xerophyte conifer forest in the Cumberland Mountains of Tennessee. The table mountain pines find footholds in crevices of the rocks.

FIG. 193. A grove of Southern pines, with a growth of palmetto palms in the foreground.—After SCHIMPER.

CHAPTER XIV

MESOPHYTE ASSOCIATIONS

145. **General characters.**—Mesophytes make up the common vegetation of temperate regions, the vegetation most commonly met and studied. The conditions of moisture are medium, precipitation is in general evenly distributed, and the soil is rich in humus. The conditions are not extreme, and therefore special adaptations, such as are necessary for xerophyte or hydrophyte conditions, do not appear. This may be regarded as the normal plant condition. It is certainly the arable condition, and most adapted to the plants which men seek to cultivate. When for purposes of cultivation xerophyte areas are irrigated, or hydrophyte areas are drained, it is simply to bring them into mesophyte conditions.

In looking over a mesophyte area and contrasting it with a xerophyte area, one of the first things evident is that the former is far richer in leaf forms. It is in the mesophyte conditions that foliage leaves show their remarkable diversity. In hydrophyte and xerophyte areas they are apt to be more or less monotonous in form. Another contrast is found in the dense growth over mesophyte areas, much more so than in xerophyte regions, and even more dense than in hydrophyte areas.

Among the mesophyte associations must be included not merely the natural ones, but those new associations which have been formed under the influence of man, and which do not appear among xerophyte and hydrophyte associations.

These new associations have been formed by the introduction of weeds and culture plants.

146. **The two groups of associations.**—Two very prominent types of associations are included here under the mesophytes, although they are probably as distinct from one another as are the mesophyte and xerophyte associations. One group is composed of low vegetation, notably the common grasses and herbs; the other is a higher woody vegetation, composed of shrubs and trees. The most characteristic types under each one of these divisions are noted as follows.

Among the mesophyte grass and herb associations are the "arctic and alpine carpets," so characteristic of high latitudes and altitudes where the conditions forbid trees, shrubs, or even tall herbs; "meadows," areas dominated by grasses (Fig. 197), the prairies being the greatest meadows, where grasses and flowering herbs are richly displayed (Fig. 198); "pastures," drier and more open than meadows.

Among the woody mesophyte associations are the "thickets," composed of willow, alder, birch, hazel, etc., either pure or forming a jungle of mixed shrubs, brambles, and tall herbs; "deciduous forests," the glory of the temperate regions, rich in forms and foliage display, with annual fall of leaves, and exhibiting the remarkable phenomenon of autumnal coloration (Figs. 194–196); "rainy tropical forests," in the region of trade winds, heavy rainfalls, and great heat, where the world's vegetation reaches its climax, and where in a saturated atmosphere gigantic jungles are developed, composed of trees of various heights, shrubs of all sizes, tall and low herbs, all bound together in an inextricable tangle by great vines or lianas, and covered by a luxuriant growth of numerous epiphytes (Fig. 199).

Fig. 195.—A chestnut forest in the mountains of Tennessee; an almost pure forest of large trees.

FIG. 196.—River bottom forest; a mixed forest (basswood, elm, etc.) with

Fig. 197. A natural meadow, developed from a flood plain; the trees in the center are on a fragment of the original upland which was not eroded by the stream.

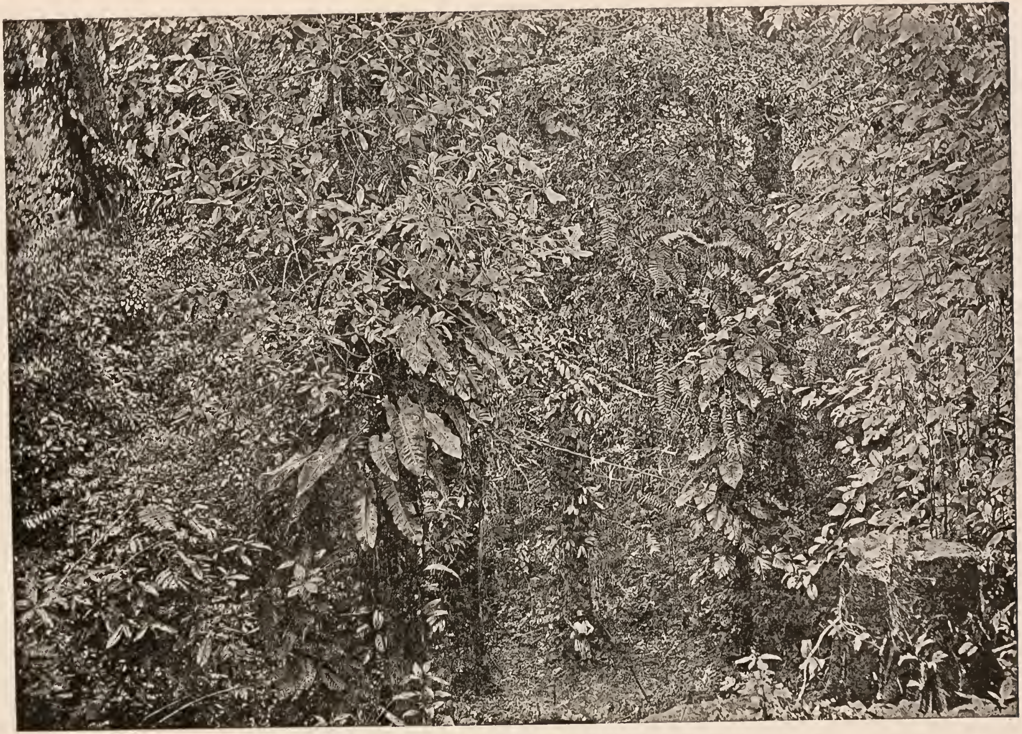


Fig. 199. A rainy tropical forest. Note the density of the vegetation, the abundance of lianas (climbers), and the general branching (compound) character of the leaves.—After Schimper.

CHAPTER XV

THE PLANT GROUPS

147. **Differences in structure.**—It is evident, even to the casual observer, that plants differ very much in structure. They differ not merely in form and size, but also in complexity. Some plants are simple, others are complex, and the former are regarded as of lower rank. For example, a lichen, a moss, and an oak differ very much in form and size, and also in complexity, and because of this last fact an oak would be regarded as a plant of higher rank than either a lichen or a moss. It must not be supposed that rank is measured by size, for in the highest group there are many small plants.

Beginning with the simplest plants—that is, those of lowest rank—one can pass by almost insensible gradations to those of highest rank. At certain points in this advance notable intèrruptions of the continuity are discovered, structures, and hence certain habits of work, changing decidedly, and these breaks enable one to organize the vast array of plants into groups. Some of the breaks appear to be more important than others, and opinions may differ as to those of chief importance, but it is customary to select three of them as indicating the division of the plant kingdom into four great groups.

148. **The great groups.**—The four great groups may be indicated here, but it must be remembered that their names mean nothing until plants representing them have been studied. It will be noticed that all the names have the

constant termination *phytes*, which is a Greek word meaning "plants." The prefix in each case is also a Greek word intended to indicate the kind of plants.

(1) *Thallophytes.*—The name means "thallus plants," but just what a "thallus" is can not well be explained until some of the plants have been examined. In this great group are included some of the simplest forms, known as *Algæ* and *Fungi*, the former represented by green thready growths in fresh water and the great host of seaweeds, the latter by moulds, mushrooms, etc.

(2) *Bryophytes.*—The name means "moss plants," and suggests very definitely the forms which are included. Every one knows mosses in a general way, but associated with them in this great group are the allied liverworts, which are very common but not so generally known.

(3) *Pteridophytes.*—The name means "fern plants," and ferns are well known. Not all Pteridophytes, however, are ferns, for associated with them are the horsetails (scouring rushes) and the club mosses.

(4) *Spermatophytes.*—The name means "seed plants"—that is, those plants which produce seeds. In a general way these are the most familiar plants, and are commonly spoken of as "flowering plants." They are the highest in rank and the most conspicuous, and hence have received much attention. In former times the study of botany in the schools was restricted to the examination of this one group, to the entire neglect of the other three great groups.

149. **Increasing complexity.**—At the very outset it is well to remember that the Thallophytes contain the simplest plants—those whose bodies have developed no organs for special work, and that as one advances through higher Thallophytes, Bryophytes, and Pteridophytes, there is a constant increase in the complexity of the plant body, until in the Spermatophytes it becomes most highly organized, with numerous structures set apart for special work, just as in the highest animals limbs, eyes, ears, bones, muscles, nerves, etc.,

are set apart for special work. The increasing complexity is usually spoken of as *differentiation*—that is, the setting apart of structures for different kinds of work. Hence the Bryophytes are said to be more highly differentiated than the Thallophytes, and the Spermatophytes are regarded as the most highly differentiated group of plants.

150. **Nutrition and reproduction.**—However variable plants may be in complexity, they all do the same general kind of work. Increasing complexity simply means an attempt to do this work more effectively. It is plant work that makes plant structures significant, and hence in this book no attempt will be made to separate them. All the work of plants may be put under two heads, *nutrition* and *reproduction*, the former including all those processes by which a plant maintains itself, the latter those processes by which it produces new plants. In the lowest plants, these two great kinds of work, or *functions*, as they are called, are not set apart in different regions of the body, but usually the first step toward differentiation is to set apart the reproductive function from the nutritive, and to develop special reproductive organs which are entirely distinct from the general nutritive body.

151. **The evolution of plants.**—It is generally supposed that the more complex plants have descended from the simpler ones; that the Bryophytes have been derived from the Thallophytes, and so on. All the groups, therefore, are supposed to be related among themselves in some way, and it is one of the great problems of botany to discover these relationships. This theory of the relationship of plant groups is known as the *theory of descent*, or more generally as *evolution*. To understand any higher group one must study the lower ones related to it, and therefore the attempt of this book will be to trace the evolution of the plant kingdom, by beginning with the simplest forms and noting the gradual increase in complexity until the highest forms are reached.

CHAPTER XVI

THALLOPHYTES: ALGÆ

152. **General characters.**—Thallophytes are the simplest of plants, often so small as to escape general observation, but sometimes with large bodies. They occur everywhere in large numbers, and are of special interest as representing the beginnings of the plant kingdom. In this group also there are organized all of the principal activities of plants, so that a study of Thallophytes furnishes a clew to the structures and functions of the higher, more complex groups.

The word "thallus" refers to the nutritive body, or vegetative body, as it is often called. This body does not differentiate special nutritive organs, such as the leaves and roots of higher plants, but all of its regions are alike. Its natural position also is not erect, but prone. While most Thallophytes have thallus bodies, in some of them, as in certain marine forms, the nutritive body differentiates into regions which resemble leaves, stems, and roots ; also certain Bryophytes have thallus bodies. The thallus body, therefore, is not always a distinctive mark of Thallophytes, but must be supplemented by other characters to determine the group.

153. **Algæ and Fungi.**—It is convenient to separate Thallophytes into two great divisions, known as *Algæ* and *Fungi*. It should be known that this is a very general division and not a technical one, for there are groups of Thallophytes which can not be regarded as strictly either Algæ or Fungi, but for the present these groups may be included.

The great distinction between these two divisions of Thallophytes is that the Algæ contain *chlorophyll* and the Fungi do not. Chlorophyll is the characteristic green coloring matter found in plants, the word meaning "leaf green." It may be thought that to use this coloring material as the basis of such an important division is somewhat superficial, but it should be known that the presence of chlorophyll gives a peculiar power—one which affects the whole structure of the nutritive body and the habit of life. The presence of chlorophyll means that the plant can make its own food, can live independent of other plants and animals. Algæ, therefore, are the independent Thallophytes, so far as their food is concerned, for they can manufacture it out of the inorganic materials about them.

The Fungi, on the other hand, contain no chlorophyll, can not manufacture food from inorganic material, and hence must obtain it already manufactured by plants or animals. In this sense they are dependent upon other organisms, and this dependence has led to great changes in structure and habit of life.

It is supposed that Fungi have descended from Algæ—that is, that they were once Algæ, which gradually acquired the habit of obtaining food already manufactured, lost their chlorophyll, and became absolutely dependent and more or less modified in structure. Fungi may be regarded, therefore, as reduced relatives of the Algæ, of equal rank so far as birth and structure go, but of very different habits.

ALGÆ

154. **General characters.**—As already defined, Algæ are Thallophytes which contain chlorophyll, and are therefore able to manufacture food from inorganic material. They are known in general as "seaweeds," although there are fresh-water forms as well as marine. They are exceedingly variable in size, ranging from forms visible only by means

of the compound microscope to marine forms with enormously bulky bodies. In general they are *hydrophytes*—that is, plants adapted to life in water or in very moist places. The special interest connected with the group is that it is supposed to be the ancestral group of the plant kingdom—the one from which the higher groups have been more or less directly derived. In this regard they differ from the Fungi, which are not supposed to be responsible for any higher groups.

155. **The subdivisions.**—Although all the Algæ contain chlorophyll, some of them do not appear green. In some of them another coloring matter is associated with the chlorophyll and may mask it entirely. Advantage is taken of these color associations to separate Algæ into subdivisions. As these colors are accompanied by constant differences in structure and work, the distinction on the basis of colors is more real than it might appear. Upon this basis four subdivisions may be made. The constant termination *phyceæ*, which appears in the names, is a Greek word meaning "seaweed," which is the common name for Algæ; while the prefix in each case is the Greek name for the color which characterizes the group.

The four subdivisions are as follows: (1) *Cyanophyceæ*, or "Blue Algæ," but usually called "Blue-green Algæ," as the characteristic blue does not entirely mask the green, and the general tint is bluish-green; (2) *Chlorophyceæ*, or "Green Algæ," in which there is no special coloring matter associated with the chlorophyll; (3) *Phæophyceæ*, or "Brown Algæ"; and (4) *Rhodophyceæ*, or "Red Algæ."

It should be remarked that probably the Cyanophyceæ do not belong with the other groups, but it is convenient to present them in this connection.

156. **The plant body.**—By this phrase is meant the nutritive or vegetative body. There is in plants a unit of structure known as the *cell*. The bodies of the simplest plants consist of but one cell, while the bodies of the most com-

plex plants consist of very many cells. It is necessary to know something of the ordinary living plant cell before the bodies of Algæ or any other plant bodies can be understood.

Such a cell if free is approximately spherical in outline (Fig. 204), but if pressed upon by contiguous cells may become variously modified in form (Fig. 200). Bounding it there is a thin, elastic wall, composed of a substance called *cellulose.* The cell wall, therefore, forms a delicate sac, which contains the living substance known as *protoplasm.* This is the substance which manifests life, and is the only substance in the plant which is alive. It is the protoplasm which has organized the cellulose wall about itself, and which does all the plant work. It is a fluid substance which varies much in its consistence, sometimes being a thin viscous fluid, like the white of an egg, sometimes much more dense and compactly organized.

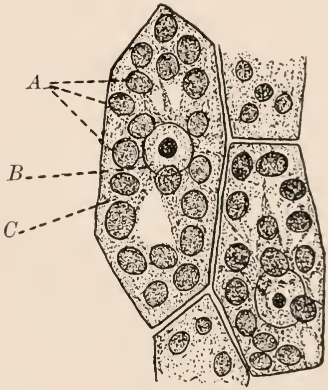


FIG. 200. Cells from a moss leaf, showing nucleus (*B*) in which there is a nucleolus, cytoplasm (*C*), and chloroplasts (*A*).—CALDWELL.

The protoplasm of the cell is organized into various structures which are called *organs of the cell*, each organ having one or more special functions. One of the most conspicuous organs of the living cell is the single *nucleus*, a comparatively compact and usually spherical protoplasmic body, and generally centrally placed within the cell (Fig. 200). All about the nucleus, and filling up the general cavity within the cell wall, is an organized mass of much thinner protoplasm, known as *cytoplasm.* The cytoplasm seems to form the general background or matrix of the cell, and the nucleus lies imbedded within it (Fig. 200). Every working cell consists of at least cytoplasm and nucleus. Sometimes the cellulose wall is absent, and the cell then consists simply of a nucleus with more or less cytoplasm organized about it, and is said to be *naked.*

Another protoplasmic organ of the cell, very conspicuous among the Algæ and other groups, is the *plastid.* Plastids are relatively compact bodies, commonly spherical, variable in number, and lie imbedded in the cytoplasm. There are various kinds of plastids, the most common being the one which contains the chlorophyll and hence is stained green. The chlorophyll-containing plastid is known as the *chloroplastid*, or *chloroplast* (Fig. 200). An ordinary alga-cell, therefore, consists of a cell wall, within which the protoplasm is organized into cytoplasm, nucleus, and chloroplasts.

The bodies of the simplest Algæ consist of one such cell, and it may be regarded as the simplest form of plant body. Starting with such forms, one direction of advance in complexity is to organize several such cells into a loose row, which resembles a chain (Fig. 202); in other forms the cells in a row become more compacted and flattened, forming a simple *filament* (Fig. 203); in still other forms the original filament puts out branches like itself, producing a branching filament (Fig. 207). These *filamentous* bodies are very characteristic of the Algæ.

Starting again with the one-celled body, another line of advance is for several cells to organize in two directions, forming a *plate* of cells. Still another line of advance is for the cells to organize in three directions, forming a *mass* of cells.

The bodies of Algæ, therefore, may be said to be one-celled in the simplest forms, and in the most complex forms they become filaments, plates, or masses of cells.

157. **Reproduction.**—In addition to the work of nutrition, the plant body must organize for reproduction. Just as the nutritive body begins in the lowest forms with a single cell

and becomes more complex in the higher forms, so reproduction begins in very simple fashion and gradually becomes more complex. Two general types of reproduction are employed by the Algæ, and all other plants. They are as follows:

(1) *Vegetative multiplication.*—This is the only type of reproduction employed by the lowest Algæ, but it persists in all higher groups even when the other method has been introduced. In this type no special reproductive bodies are formed, but the ordinary vegetative body is used for the purpose. For example, if the body consists of one cell, that cell cuts itself into two, each half grows and rounds off as a distinct cell, and two new bodies appear where there was one before (Fig. 204). This process of cell division is very complicated and important, involving a division of nucleus and cytoplasm so that the new cells may be organized just as was the old one. Wherever ordinary nutritive cells are used directly to produce new plant bodies the process is *vegetative multiplication.* This method of reproduction may be indicated by a formula as follows: P — P — P — P — P, in which P stands for the plant, the formula indicating that a succession of plants may arise directly from one another without the interposition of any special structure.

(2) *Spores.*—Spores are cells which are specially organized to reproduce, and are not at all concerned in the nutritive work of the plant. Spores are all alike in their power of reproduction, but they are formed in two very distinct ways. It must be remembered that these two types of spores are alike in power but different in origin.

Asexual spores.—These cells are formed by cell division. A cell of the plant body is selected for the purpose, and usually its contents divide and form a variable number of new cells within the old one (Fig. 205, *B*). These new cells are *asexual spores*, and the cell which has formed them within itself is known as the *mother cell.* This peculiar kind of cell division, which does not involve the wall of the old cell, is often called *internal division*, to distinguish it from *fission*, which involves the wall of the old cell, and is the ordinary method of cell division in nutritive cells.

If the mother cell which produces the spores is different from the other cells of the plant body it is called the *sporangium*, which means "spore vessel." Often a cell is nutritive for a time and afterward becomes a mother cell, in which case it is said to function as a sporangium. The wall of a sporangium usually opens, and the spores are discharged, thus being free to produce new plants. Various names have been given to asexual spores to indicate certain peculiarities. As Algæ are mostly surrounded by water, the characteristic asexual spore in the group is one that can swim by means of minute hair-like processes or *cilia*, which have the power of lashing the water (Fig. 206, *C*). These ciliated spores are known as *zoospores*, or "animal-like spores," referring to their power of locomotion; sometimes they are called *swimming spores*, or *swarm spores*. It must be remembered that all of these terms refer to the same thing, a swimming asexual spore.

This method of reproduction may be indicated by a formula as follows: P — o — P — o — P — o — P, which indicates that new plants are not produced directly from the old ones, as in vegetative multiplication, but that between the successive generations there is the asexual spore.

Sexual spores.—These cells are formed by cell union, two cells fusing together to form the spore. This process of forming a spore by the fusion of two cells is called the *sexual process*, and the two special cells (sexual cells) thus used are known as *gametes* (Fig. 205, *C*, *d*, *e*). It must be noticed that gametes are not spores, for they are not able alone to produce a new plant; it is only after two of them have fused and formed a new cell, the spore, that a plant can be produced. The spore thus formed does not differ in its power from the asexual spore, but it differs very much in its method of origin.

The gametes are organized within a mother cell, and if this cell is distinct from the other cells of the plant it is called a *gametangium*, which means "gamete vessel."

This method of reproduction may be indicated by a formula as follows: $P = {}^{\circ}_{\circ} > o - P = {}^{\circ}_{\circ} > o - P = {}^{\circ}_{\circ} > o - P$, which indicates that two special cells (gametes) are produced by the plant, that these two fuse to form one (sexual spore), which then produces a new plant.

At first the two gametes are alike in size and activity, and such plants are said to be *isogamous*—that is, "with similar gametes." In other plants the gametes become very dissimilar, one being large and passive, and called the *egg;* the other being small and active, and called the *sperm;* and such plants are said to be *heterogamous*—that is, "with dissimilar gametes." The gametangium which produces the egg is called an *oogonium;* that which produces sperms is the *antheridium.*

It must not be supposed that if a plant uses one of these three methods of reproduction (vegetative multiplication, asexual spores, sexual spores) it does not employ the other two. All three methods may be employed by the same plant, so that new plants may arise from it in three different ways.

CHAPTER XVII

THE GREAT GROUPS OF ALGÆ

158. **General characters.**—The Algæ are distinguished among Thallophytes by the presence of chlorophyll. It was stated in a previous chapter that in three of the four great groups another coloring matter is associated with the chlorophyll, and that this fact is made the basis of a division into Blue-green Algæ (Cyanophyceæ), Green Algæ (Chlorophyceæ), Brown Algæ (Phæophyceæ), and Red Algæ (Rhodophyceæ). In our limited space it will be impossible to do more than mention a few representatives of each group, but they will serve to illustrate the prominent facts.

1. Cyanophyceæ (*Blue-green Algæ*)

159. **Glœocapsa.**—These forms may be found forming blue-green or olive-green patches on damp tree-trunks, rock, walls, etc. By means of the microscope these patches are seen to be composed of multitudes of spherical cells, each representing a complete *Glœocapsa* body. One of the peculiarities of the body is that the cell wall becomes mucilaginous, swells, and forms a jelly-like matrix about the working cell. Each cell divides in the ordinary way, two new *Glœocapsa* individuals being formed, this method of vegetative multiplication being the only form of reproduction (Fig. 201).

When new cells are formed in this way the swollen mucilaginous walls are apt to hold them together, so that presently a number of cells or individuals are found lying together imbedded in the jelly-like matrix formed by the wall material (Fig. 201). These imbedded groups of individuals are spoken of as *colonies*, and as colonies become large they break up into new colonies, the individual cells composing them continuing to divide and form new individuals. This represents a very simple life history, in fact a simpler one could hardly be imagined.

Fig. 201. *Glœocapsa*, a blue-green alga, showing single cells, and small groups which have been formed by division and are held together by the enveloping mucilage.—Caldwell.

160. **Nostoc.**—These forms occur in jelly-like masses in damp places. If the jelly be examined it will be found to contain imbedded in it numerous cells like those of *Glœocapsa*, but they are strung together to form chains of varying lengths (Fig. 202). The jelly in which these chains are imbedded is the same as that found in *Glœocapsa*, being formed by the cell walls becoming mucilaginous and swollen.

One notable fact is that all the cells in the chain are not alike, for at irregular intervals there occur larger colorless cells, an illustration of the differentiation of cells. These larger cells are known as *heterocysts* (Fig. 202, *A*), which simply means "other cells." It is observed that when the chain breaks up into fragments each fragment is composed of the cells between

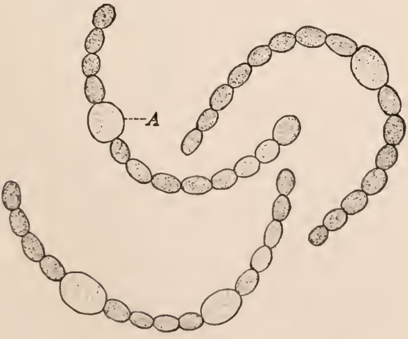


Fig. 202. *Nostoc*, a blue-green alga, showing the chain-like filaments, and the heterocysts (*A*) which determine the breaking up of the chain.—Caldwell.

two heterocysts. The fragments wriggle out of the jelly matrix and start new colonies of chains, each cell dividing to increase the length of the chain. This cell division, to form new cells, is the characteristic method of reproduction.

At the approach of unfavorable conditions certain cells of the chain become thick-walled and well-protected. These cells which endure the cold or other hardships, and upon the return of favorable conditions produce new chains of cells, are often called spores, but they are better called "resting cells."

161. **Oscillatoria.**—These forms are found as bluish-green slippery masses on wet rocks, or on damp soil, or freely floating. They are simple filaments, composed of very short flattened cells (Fig. 203), and the name *Oscillatoria* refers to the fact that they exhibit a peculiar oscillating movement. These motile filaments are isolated, not being held together in a jelly-like matrix as are the chains of *Nostoc*, but the wall develops a certain amount of mucilage, which gives the slippery feeling and sometimes forms a thin mucilaginous sheath about the row of cells.

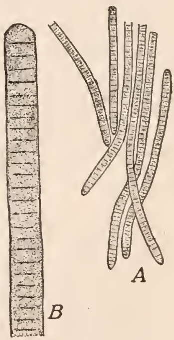


Fig. 203. *Oscillatoria*, a blue-green alga, showing a group of filaments (*A*), and a single filament more enlarged (*B*).—Caldwell.

The cells of a filament are all alike, except that the terminal cell has its free surface rounded. If a filament breaks, and a new cell surface exposed, it at once becomes rounded. If a single cell of the filament is freed from all the rest, both flattened ends become rounded, and the cell becomes spherical or nearly so. These facts indicate at least two important things: (1) that the cell wall is elastic, so that it can be made to change its form, and (2) that it is pressed upon from within, so that if free it will bulge outward. In all active living cells there is this pressure upon the wall from within.

Each cell of the *Oscillatoria* filament has the power of dividing, thus forming new cells and elongating the filament. A filament may break up into fragments of varying lengths, and each fragment by cell division organizes a new filament. Here again reproduction is by means of vegetative multiplication.

162. **Conclusions.**—Taking *Glœocapsa*, *Nostoc*, and *Oscillatoria* as representatives of the group Cyanophyceæ, or "green slimes," we may come to some conclusions concerning the group in general. The plant body is very simple, consisting of single cells, or chains and filaments of cells. Although in *Nostoc* and *Oscillatoria* the cells are organized into chains and filaments, each cell seems to be able to live and act independently, and the chain and filament seem to be little more than colonies of individual cells. In this sense, all of these plants may be regarded as one-celled.

Differentiation is exhibited in the appearance of heterocysts in *Nostoc*, peculiar cells which seem to be connected in some way with the breaking up of filamentous colonies, although the *Oscillatoria* filament breaks up without them.

The power of motion is also well exhibited by the group, the free filaments of *Oscillatoria* moving almost continually, and the imbedded chains of *Nostoc* at times moving to escape from the restraining mucilage.

The whole group also shows a strong tendency in the cell-wall material to become converted into mucilage and much swollen, a tendency which reaches an extreme expression in such forms as *Nostoc* and *Glœocapsa.*

Another distinguishing mark is that reproduction is exclusively by means of vegetative multiplication, through ordinary cell division or fission, which takes place very freely. Individual cells are organized with heavy resistant walls to enable them to endure the winter or other unfavorable conditions, and to start a new series of individuals upon the return of favorable conditions. These may be regarded as resting cells. So notable is the fact of reproduction by fission that Cyanophyceæ are often separated from the other groups of Algæ and spoken of as "Fission Algæ," which put in technical form becomes Schizophyceæ. In this particular, and in several others mentioned above, they resemble the "Fission Fungi" (Schizomycetes), commonly called "bacteria," so closely that they are often associated with them in a common group called "Fission plants" (Schizophytes), distinct from the ordinary Algæ and Fungi.

2. Chlorophyceæ (*Green Algæ*).

163. **Pleurococcus.**—This may be taken as a type of one-celled Green Algæ. It is most commonly found in masses covering damp tree-trunks, etc., and looking like a green stain. These finely granular green masses are found to be made up of multitudes of spherical cells resembling those of *Glœocapsa*, except that there is no blue with the chlorophyll, and the cells are not imbedded in such jelly-like masses. The cells may be solitary, or may cling together in colonies of various sizes (Fig. 204). Like *Glœocapsa*, a cell divides and forms two new cells, the only reproduction

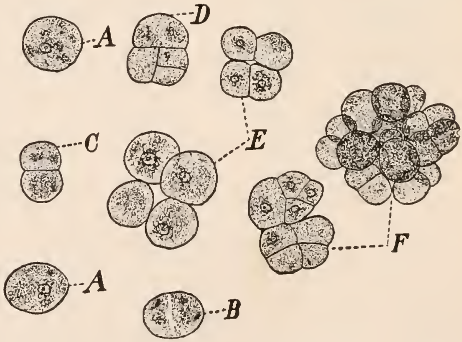


Fig. 204. *Pleurococcus*, a one-celled green alga: *A*, showing the adult form with its nucleus; *B*, *C*, *D*, *E*, various stages of division (fission) in producing new cells; *F*, colonies of cells which have remained in contact.—Caldwell.

being of this simple kind. It is evident, therefore, that the group Chlorophyceæ begins with forms just as simple as are to be found among the Cyanophyceæ.

Pleurococcus is used to represent the group of Protococcus forms, one-celled forms which constitute one of the subdivisions of the Green Algæ. It should be said that *Pleurococcus* is possibly not a Protococcus form, but may be a reduced member of some higher group; but it is so common, and represents so well a typical one-celled green alga, that it is used in this connection. It should be known, also, that while the simplest Protococcus forms reproduce only by fission, others add to this the other methods of reproduction.

164. **Ulothrix.**—This form is very common in fresh waters, being recognized easily by its simple filaments composed of short squarish cells, each cell containing a single conspicuous cylindrical chloroplast (Fig. 205).

The cells are all alike, excepting that the lowest one of the filament is mostly colorless, and is elongated and more or less modified to act as a holdfast, anchoring the filament to some firm support. With this exception the cells are all nutritive; but any one of them has the power of organizing for reproduction. This indicates that at first nutritive and reproductive cells are not distinctly differentiated, but that the same cell may be nutritive at one time and reproductive at another. This plant uses cell division to multiply the cells of a filament, and to develop new filaments from fragments of old ones; but it also produces asexual spores in the form of zoospores, and gametes which conjugate and form zygotes. Both zoospores and zygotes have the power of germination—that is, the power to begin the development of a new plant. In the germination of the zygote a new filament is not produced directly, but there are formed within it zoospores, each of which produces a new filament (Fig. 205, *F*, *G*). All three kinds of reproduction are represented, therefore, but the sexual method is the low type called isogamy, the pairing gametes being alike.

Ulothrix is taken as a representative of the Conferva forms, the most characteristic group of Chlorophyceæ. All

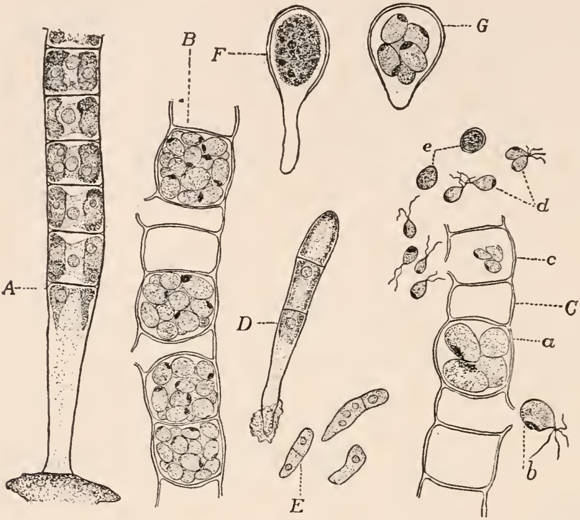


FIG. 205. *Ulothrix*, a Conferva form. *A*, base of filament, showing lowest holdfast cell and five vegetative cells, each with its single conspicuous cylindrical chloroplast (seen in section) inclosing a nucleus; *B*, four cells containing numerous small zoospores, the others emptied; *C*, fragment of a filament showing one cell (*a*) containing four zoospores, another zoospore (*b*) displaying four cilia at its pointed end and just having escaped from its cell, another cell (*c*) from which most of the small biciliate gametes have escaped, gametes pairing (*d*), and the resulting zygotes (*e*); *D*, beginning of new filament from zoospore; *E*, feeble filaments formed by the small zoospores; *F*, zygote growing after rest; *G*, zoospores produced by zygote.—CALDWELL, except *F* and *G*, which are after DODEL-PORT.

the Conferva forms, however, are not isogamous, as will be illustrated by the next example.

165. **Œdogonium.**—This is a very common green alga, found in fresh waters (Fig. 206). The filaments are long and simple, the lowest cell acting as a holdfast, as in *Ulothrix*

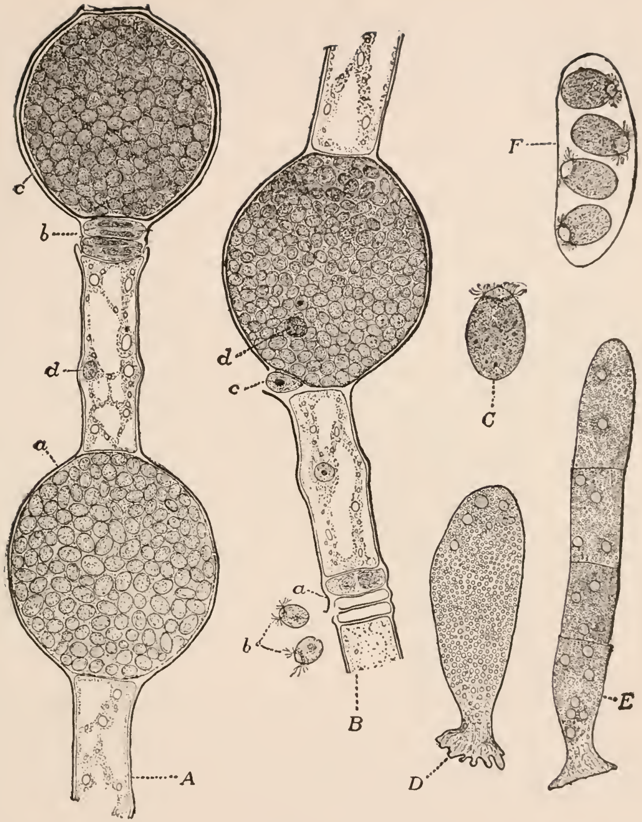


FIG. 206. *Œdogonium nodosum*, a Conferva form : *A*, portion of a filament showing a vegetative cell with its nucleus (*d*), an oogonium (*a*) filled by an egg packed with food material, a second oogonium (*c*) containing a fertilized egg or oospore as shown by the heavy wall, and two antheridia (*b*), each containing two sperms; *B*, another filament showing antheridia (*a*) from which two sperms (*b*) have escaped, a vegetative cell with its nucleus, and an oogonium which a sperm (*c*) has entered and is coming in contact with the egg whose nucleus (*d*) may be seen; *C*, a zoospore which has been formed in a vegetative cell, showing the crown of cilia and the clear apex, as in the sperms; *D*, a zoospore producing a new filament, putting out a holdfast at base and elongating; *E*, a further stage of development; *F*, the four zoospores formed by the oospore when it germinates.—CALDWELL, except *C* and *F*, which are after PRINGSHEIM.

(§ 164). The other cells are longer than in *Ulothrix*, each cell containing a single nucleus and apparently several chloroplasts, but really there is but one large complex chloroplast.

The cells of the filament have the power of division, thus increasing the length of the filament. Any cell also may act as a sporangium, the contents of a mother cell organizing a single large asexual spore, which is a zoospore. The zoospore escapes from the mother cell into the water, and at its more pointed clear end there is a little crown of cilia, by means of which it swims about rapidly (Fig. 206, *C*). After moving about for a time the zoospore comes to rest, attaches itself by its clear end to some support, elongates, begins to divide, and develops a new filament (Fig. 206, *D*, *E*).

Other cells of the filament become very different from the ordinary cells, swelling out into globular form (Fig. 206, *A*, *B*), and each such cell organizes within itself a single large egg (oosphere). As the egg is a female gamete, the large globular cell which produces it, and which is differentiated from the other cells of the body, is the oogonium. A perforation in the oogonium wall is formed for the entrance of sperms.

Other cells in the same filament, or in some other filament, are observed to differ from the ordinary cells in being much shorter, as though an ordinary cell had been divided several times without subsequent elongation (Fig. 206, *A*, *f*, *B*, *a*). In each of these short cells one or two sperms are organized, and therefore each short cell is an antheridium. When the sperms are set free they are seen to resemble very small zoospores, having the same little crown of cilia at one end.

The sperms swim actively about in the vicinity of the oogonia, and sooner or later one enters the oogonium through the perforation provided in the wall, and fuses with the egg (Fig. 206, *B*, *c*). As a result of this act of fertilization an oospore is formed, which organizes a firm wall about itself. This firm wall indicates that the oospore is not to germinate immediately, but is to pass into a resting condition. Spores which form heavy walls and pass into the resting condition are often spoken of as "resting spores," and it is very common for the zygotes and oospores to be resting spores. These resting spores enable the plant to endure through unfavorable conditions, such as failure of food supply, cold, drought, etc. When favorable conditions return, the protected resting spore is ready for germination.

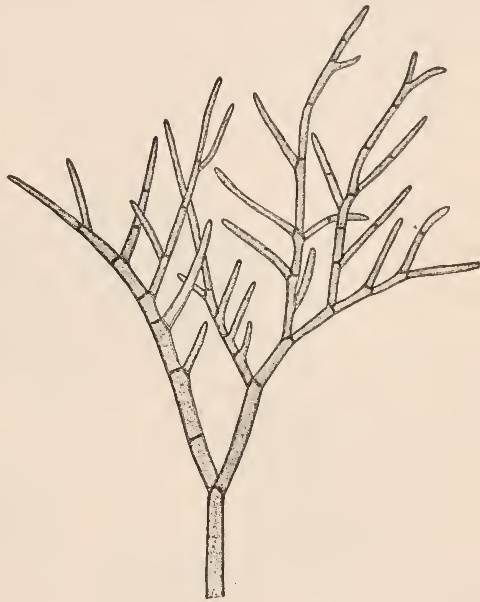


FIG. 207. *Cladophora*, a branching green alga, a very small part of the plant being shown. The branches arise at the upper ends of cells, and the cells are cœnocytic.—CALDWELL.

When the oospore of *Œdogonium* germinates it does not develop directly into a new filament, but the contents become organized into four zoospores (Fig. 206, *F*), which escape, and each zoospore develops a filament. In this way each oospore may give rise to four filaments.

It is evident that *Œdogonium* is a heterogamous plant, and is another one of the Conferva forms. Conferva bodies are not always simple filaments, as are those of *Ulothrix* and *Œdogonium*, but they are sometimes extensively branching filaments, as in *Cladophora*, a green alga very common in rivers and lakes (Fig. 207). The cells are long and densely crowded with chloroplasts; and in certain cells at the tips of branches large numbers of zoospores are formed, which have two cilia at the pointed end, and hence are said to be *biciliate.*

166. **Vaucheria.**—This is one of the most common of the Green Algæ, found in felt-like masses of coarse filaments in shallow water and on muddy banks, and often called "green

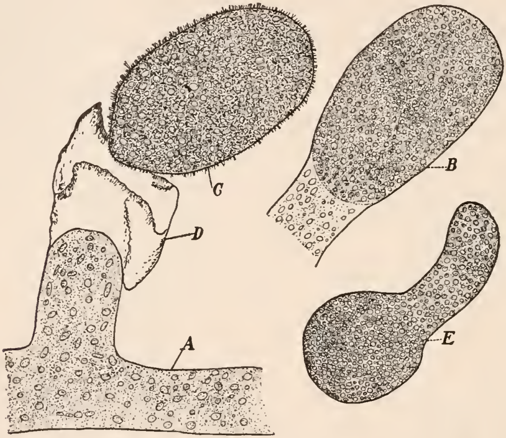


Fig. 208. *Vaucheria geminata*, a Siphon form, showing a portion of the cœnocytic body (A) which has sent out a branch at the tip of which a sporangium (B) formed, within which a large zoospore was organized, and from which (D) it is discharged later as a large multiciliate body (C), which then begins the development of a new cœnocytic body (E).—Caldwell.

felt." The filament is very long, and usually branches extensively, but its great peculiarity is that there is no partition wall in the whole body, which forms one long continuous cavity (Fig. 208). This is sometimes spoken of as a one-celled body, but it is a mistake. Imbedded in the extensive cytoplasm mass, which fills the whole cavity, there are not only very numerous chloroplasts, but also numerous nuclei. As has been said, a single nucleus with some cytoplasm organized about it is a cell, whether it has a wall or not. Therefore the body of *Vaucheria* is made up of as many cells as there are nuclei, cells whose protoplasmic structures have not been kept separate by cell walls. Such a body, made up of numerous cells, but with no partitions, is called a *cœnocyte*, or it is said to be *cœnocytic*. *Vaucheria* represents a great group of Chlorophyceæ whose members have cœnocytic bodies, and on this account they are called the Siphon forms.

Vaucheria produces very large zoospores. The tip of a branch becomes separated from the rest of the body by a partition and thus acts as a sporangium (Fig. 208, *B*). In this improvised sporangium the whole of the contents organize a single large zoospore, which is ciliated all over, escapes by squeezing through a perforation in the wall (Fig. 208, *C*), swims about for a time, and finally develops another *Vaucheria* body (Figs. 208, *E*, 209). It should be said that this large body, called a zoospore and acting like one, is really a mass of small biciliate zoospores, just as the apparently one-celled vegetative body is really composed of many cells. In this large compound zoospore there are many nuclei, and in connection with each nucleus two cilia are developed. Each nucleus with its cytoplasm and two cilia represents a small biciliate zoospore, such as those of *Cladophora*, §165.

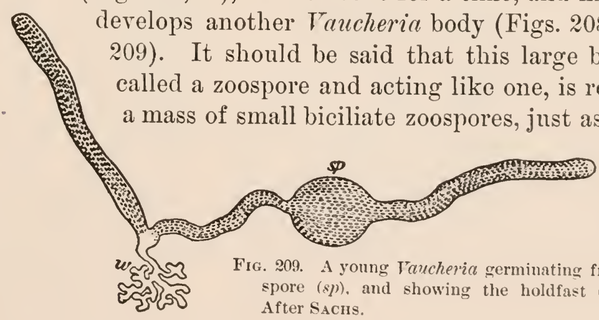


FIG. 209. A young *Vaucheria* germinating from a spore (*sp*), and showing the holdfast (*w*).—After SACHS.

Antheridia and oogonia are also developed. In a common form these two sex organs appear as short special branches developed on the side of the large cœnocytic body, and cut off from the general cavity by partition walls (Fig. 210). The oogonium becomes a globular cell, which usually

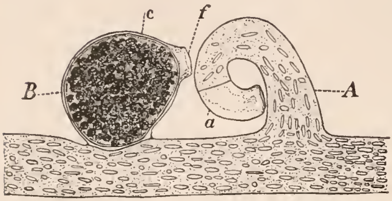


FIG. 210. *Vaucheria sessilis*, a Siphon form, showing a portion of the cœnocytic body, an antheridial branch (A) with an empty antheridium (a) at its tip; and an oogonium (B) containing an oospore (c) and showing the opening (f) through which the sperms passed to reach the egg.—CALDWELL.

develops a perforated beak for the entrance of the sperms, and organizes within itself a single large egg (Fig. 210, B). The antheridium is a much smaller cell, within which numerous very small sperms are formed (Fig. 210, A, a). The sperms are discharged, swarm about the oogonium, and finally one passes through the beak and fuses with the egg, the result being an oospore. The oospore organizes a thick wall and becomes a resting spore.

FIG. 211. *Botrydium*, one of the Siphon forms of green algæ, the whole body containing one continuous cavity, with a bulbous, chlorophyll-containing portion, and root-like branches which penetrate the mud in which the plant grows. —CALDWELL.

It is evident that *Vaucheria* is heterogamous, but all the other Siphon forms are isogamous, of which *Botrydium* may be taken as an illustration (Fig. 211).

167. **Spirogyra.**—This is one of the commonest of the "pond scums," occurring in slippery and often frothy masses of delicate filaments floating in still water or about

springs. The filaments are simple, and are not anchored by a special basal cell, as in *Ulothrix* and *Œdogonium*. The

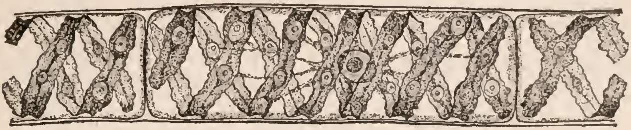


FIG. 212. *Spirogyra*, a Conjugate form, showing one complete cell and portions of two others. The band-like chloroplasts extend in a spiral from one end of the cell to the other, in them are imbedded nodule-like bodies (*pyrenoids*), and near the center of the cell the nucleus is swung by radiating strands of cytoplasm.—CALDWELL.

cells contain remarkable chloroplasts, which are bands passing spirally about within the cell wall. These bands may

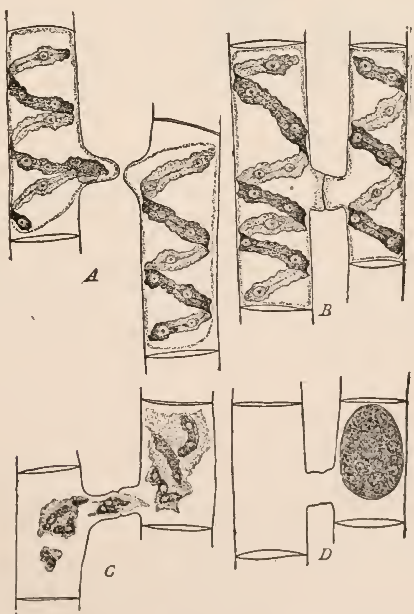


FIG. 213. *Spirogyra*, showing conjugation: *A*, conjugating tubes approaching each other; *B*, tubes in contact but end walls not absorbed; *C*, tube complete and contents of one cell passing through; *D*, a completed zygospore.—CALDWELL.

be solitary or several in a cell, and form very striking and conspicuous objects (Figs. 212, 213).

Spirogyra and its associates are further peculiar in producing no asexual spores, and also in the method of sexual reproduction. Two adjacent filaments put out tubular processes toward one another. A cell of one filament sends out a process which seeks to meet a corresponding process from a cell of the other filament. When the tips of two such processes come together, the end walls disappear,

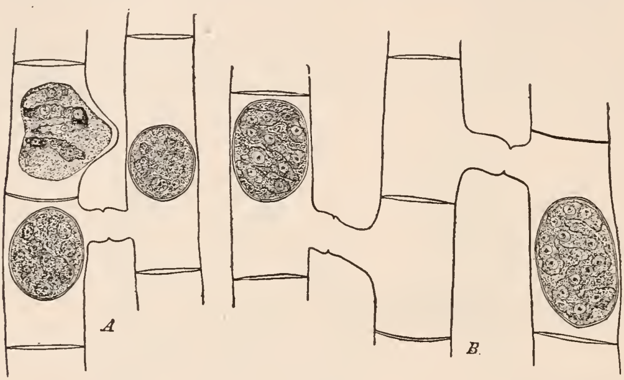


FIG. 214. *Spirogyra*, showing some common exceptions. At *A* two cells have been connected by a tube, but without fusion a zygote has been organized in each cell; also, the upper cell to the left has attempted to conjugate with the cell to the right. At *B* there are cells from three filaments, the cells of the central one having conjugated with both of the others.—CALDWELL.

and a continuous tube extending between the two cells is organized (Figs. 213, 214). When many of the cells of two parallel filaments become thus united, the appearance is that of a ladder, with the filaments as the side pieces, and the connecting tubes as the rounds.

While the connecting tube is being developed the contents of the two cells are organizing, and after the completion of the tube the contents of one cell pass through and enter the other cell, fuse with its contents, and a sexual spore is organized. As the gametes look alike, the process is conjugation, and the sex spore is a zygote, which, with its heavy wall, is recognized to be a resting spore. At the beginning of each growing season, the well-protected zygotes which have endured the winter germinate directly into new *Spirogyra* filaments.

On account of this peculiar style of sexual reproduction, in which gametes are not discharged, but reach each other through special tubes, *Spirogyra* and its allies are called Conjugate forms—that is, forms whose bodies are "yoked together" during the fusion of the gametes.

In some of the Conjugate forms the zygote is formed in the connecting tube (Fig. 215, *A*), and sometimes zygotes are formed without conjugation (Fig. 215, *B*). Among the Conjugate forms the Desmids are of great interest and beauty, being one-celled, the cells being organized into two distinct halves (Fig. 216).

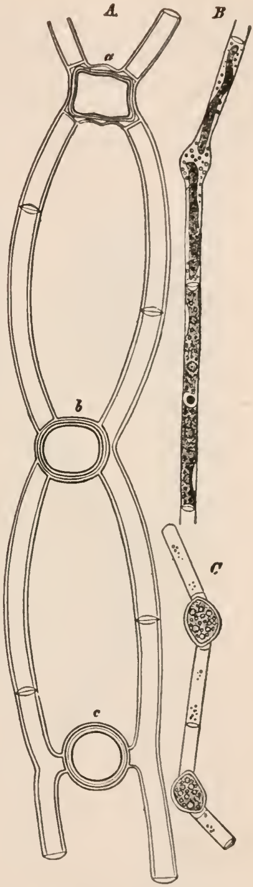


FIG. 215. Two Conjugate forms: *A* (*Mougeotia*), showing formation of zygote in conjugating tube; *B*, *C* (*Gonatonema*), showing formation of zygote without conjugation. —After WITTROCK.

168. **Conclusions.** — The Green Algæ, as indicated by the illustrations given above, include simple one-celled forms which reproduce by fission, but they are chiefly filamentous forms, simple or branching. These filamentous bodies either have the cells separated from one another

by walls, or they are cœnocytic, as in the Siphon forms. The characteristic asexual spores are zoospores, but these may be wanting, as in the Conjugate forms. In addition to asexual reproduction, both isogamy and heterogamy are developed, and both zygotes and oospores are resting spores.

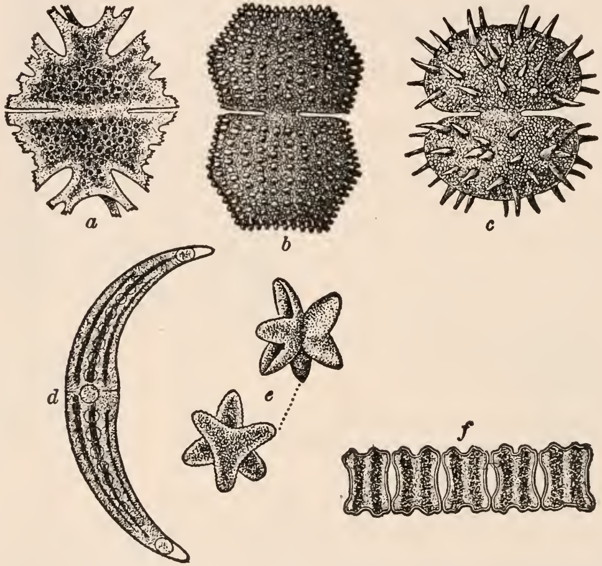


FIG. 216. A group of Desmids, one-celled Conjugate forms, showing various patterns, and the cells organized into distinct halves.—After KERNER.

The Green Algæ are of special interest in connection with the evolution of higher plants, which are supposed by some to have been derived from them.

3. PHÆOPHYCEÆ (*Brown Algæ*)

169. **General characters.**—The Blue-green Algæ and the Green Algæ are characteristic of fresh water, but the Brown Algæ, or "kelps," are almost all marine, being very charac-

teristic coast forms. All of them are anchored by holdfasts, which are sometimes highly developed root-like structures; and the yellow, brown, or olive-green floating bodies are buoyed in the water usually by the aid of floats or air-bladders, which are often very conspicuous. The kelps are most highly developed in the colder waters, and form much of the "wrack," "tangle," etc., of the coasts. The group is well adapted to live exposed to waves and currents with its strong holdfasts, air-bladders, and tough leathery bodies. Certain Brown Algæ, as *Ectocarpus* (Fig. 18), are of great interest on account of their possible relation to the evolution of higher plants. It is in this group that we have found our only suggestions as to the origin of the complex sex-organs occurring in Bryophytes and Pteridophytes.

170. **The plant body.**—There is very great diversity in the structure of the plant body. Some of them, as *Ectocarpus* (Fig. 217), are filamentous forms, like the Confervas among the Green Algæ, but others are very much more complex. The thallus of *Laminaria* is like a huge floating leaf, frequently nine to ten

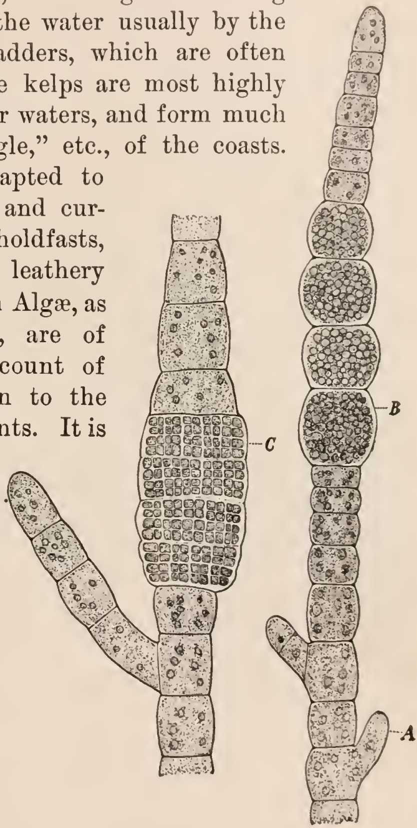


FIG. 217. A brown alga (*Ectocarpus*), showing a body consisting of a simple filament which puts out branches (A), some sporangia (B) containing zoospores, and gametangia (C) containing gametes.—CALDWELL.

Fig. 218. A group of brown seaweeds (*Laminarias*). Note the various habits of the plant body with its leaf-like thallus and root-like holdfasts.—After Kerner.

feet long, whose stalk develops root-like holdfasts (Fig. 218). The largest body is developed by an Antarctic *Laminaria* form, which rises to the surface from a sloping bottom with a floating thallus six hundred to nine hundred feet long. Other forms rise from the sea bottom like trees, with thick trunks, numerous branches, and leaf-like appendages.

The common *Fucus*, or "rock weed," is ribbon-form and constantly branches by forking at the tip (Fig. 219). This method of branching is called *dichotomous*, as distinct from that in which branches are put out from the sides of the axis (*monopodial*). The swollen air-bladders distributed throughout the body are very conspicuous.

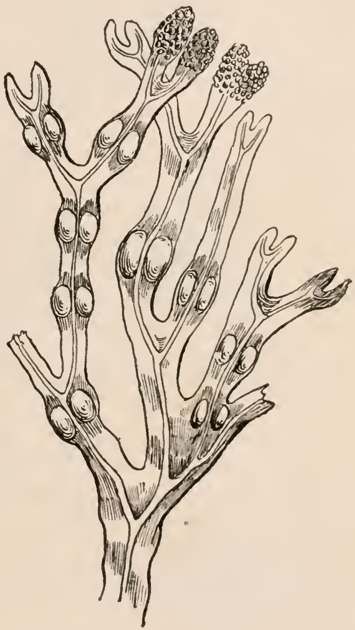


Fig. 219. Fragment of a common brown alga (*Fucus*), showing the body with dichotomous branching and bladder-like air-bladders.—After Luerssen.

The most differentiated thallus is that of *Sargassum* (Fig. 220), or "gulf weed," in which there are slender branching stem-like axes bearing lateral members of various kinds, some of them like ordinary foliage leaves; others are floats or air-bladders, which sometimes resemble clusters of berries; and other branches bear the sex organs. All of these structures are but different regions of a branching thallus. *Sargassum* forms are often torn from their anchorage by the waves and carried away from the coast by currents, collecting in the great sea eddies produced by oceanic currents and forming the so-called "Sargasso seas," as that of the North Atlantic.

FIG. 220. A portion of a brown alga (*Sargassum*), showing the thallus differentiated into stem-like and leaf-like portions, and also the bladder-like floats.—After BENNETT and MURRAY.

171. **Reproduction.**—The two main groups of Brown Algæ differ from each other in their reproduction. One, represented by the Laminarias and a majority of the forms, produces zoospores and is isogamous (Fig. 217). The zoospores and gametes are peculiar in having the two cilia attached at one side rather than at an end; and they resemble each other very closely, except that the gametes fuse in pairs and form zygotes.

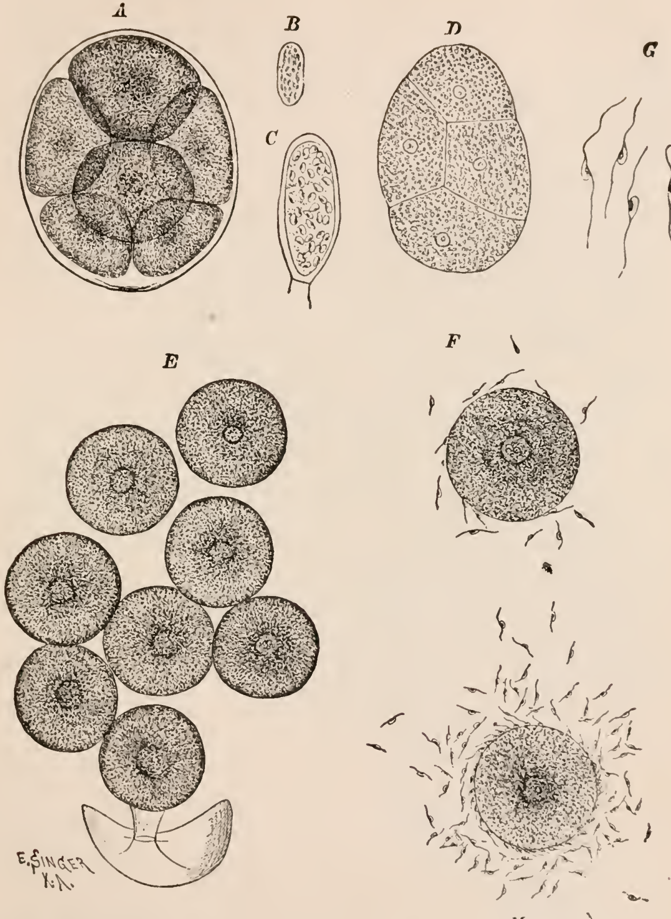


FIG. 221. Sexual reproduction of *Fucus*, showing the eight eggs (six in sight) discharged from the oogonium and surrounded by a membrane (A), eggs liberated from the membrane (E), antheridium containing sperms (C), the discharged laterally biciliate sperms (G), and eggs surrounded by swarming sperms (F, H).—After SINGER.

The other group, represented by *Fucus* (Fig. 221), produces no asexual spores, but is heterogamous. A single oogonium usually forms eight eggs (Fig. 221, *A*), which are discharged and float freely in the water (Fig. 221, *E*). The antheridia (Fig. 221, *C*) produce numerous minute laterally biciliate sperms, which are discharged (Fig. 221, *G*), swim in great numbers about the large eggs (Fig. 221, *F*, *H*), and finally one fuses with an egg, and an oospore is formed. As the sperms swarm very actively about the egg and impinge against it they often set it rotating. Both antheridia and oogonia are formed in cavities of the thallus.

4. Rhodophyceæ (*Red Algæ*)

172. **General characters.**—On account of their red coloration these forms are often called *Florideæ*. They are mostly marine forms, and are anchored by holdfasts of various kinds. They belong to the deepest waters in which Algæ grow, and it is probable that the red coloring matter which characterizes them is associated with the depth at which they live. The Red Algæ are also a highly specialized line, and will be mentioned very briefly.

Fig. 222. A red alga (*Gigartina*), showing branching habit, and "fruit bodies."—After Schenck.

173. **The plant body.**—The Red Algæ, in general, are more delicate than the Brown Algæ, or kelps, their graceful forms, delicate texture, and brightly tinted bodies (shades of red, violet, dark purple,

Fig. 223. A red alga (*Callophyllis*), with a greatly branched body composed of thin plates of cells.—Caldwell.

FIG. 224. A red alga (*Dasya*), showing a finely divided thallus body.—CALDWELL.

FIG 225. A red alga (*Rabdonia*), showing holdfasts and branching thallus body.—CALDWELL.

FIG. 226. A red alga (*Ptilota*), whose branching body resembles moss.—CALDWELL.

and reddish-brown) making them very attractive. They show the greatest variety of forms, branching filaments, ribbons, and filmy plates prevailing, sometimes branching very profusely and delicately, and resembling mosses of fine texture (Figs. 222, 223, 224, 225, 226). The differentiation of the thallus into root and stem and leaf-like structures is also common, as in the Brown Algæ.

174. **Reproduction.**—Red Algæ are very peculiar in both their asexual and sexual reproduction. A sporangium produces just four asexual spores, but they have no cilia and no power of motion. They can not be called zoospores, therefore, and as each sporangium always produces just four, they have been called *tetraspores* (Fig. 227).

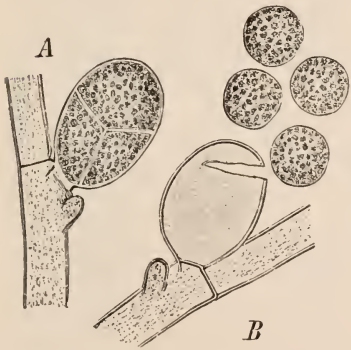


Fig. 227. A red alga (*Callithamnion*), showing sporangium (*A*), and the tetraspores discharged (*B*).—After Thuret.

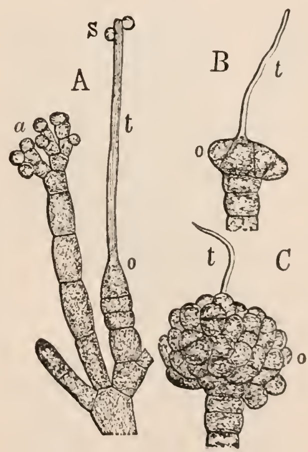


Fig. 228. A red alga (*Nemalion*): *A*, sexual branches, showing antheridia (*a*), oogonium (*o*) with its trichogyne (*t*), to which are attached two spermatia (*s*); *B*, beginning of a cystocarp (*o*), the trichogyne (*t*) still showing; *C*, an almost mature cystocarp (*o*), with the disorganizing trichogyne (*t*).—After Kny.

Red Algæ are also heterogamous, but the sexual process has been so much and so variously modified that it is very poorly understood. The antheridia (Fig. 228, *A*, *a*) develop sperms which, like the tetraspores, have no cilia and no power of motion. To distinguish them from the ciliated sperms, or spermatozoids, which have the power of locomotion, these motionless male gametes of the Red Algæ are usually called *spermatia* (singular, *spermatium*) (Fig. 228, *A*, *s*).

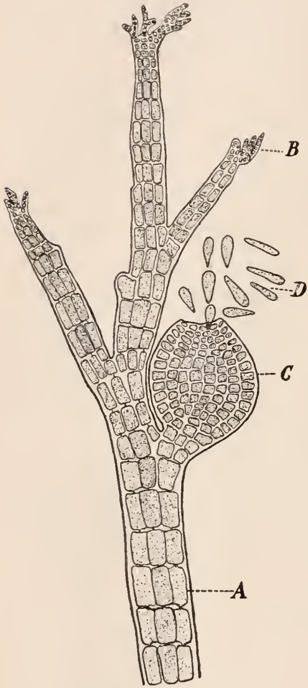


Fig. 229. A branch of *Polysiphonia*, one of the red algæ, showing the rows of cells composing the body (*A*), small branches or hairs (*B*), and a cystocarp (*C*) with escaping spores (*D*) which have no cilia (carpospores).—Caldwell.

The oogonium is very peculiar, being differentiated into two regions, a bulbous base and a hair-like process (*trichogyne*), the whole structure resembling a flask with a long, narrow neck, excepting that it is closed (Fig. 228, *A*, *o*, *t*). Within the bulbous part fertilization usually takes place; a spermatium attaches itself to the trichogyne (Fig. 228, *A*, *s*); at the point of contact the two walls become perforated, and the contents of the spermatium thus enter the trichogyne, and so reach the bulbous base of the oogonium. The above account represents the very simplest conditions of the process of fertilization in this group, and gives no idea of the great and puzzling complexity exhibited by the majority of forms.

After fertilization the trichogyne wilts, and the bulbous base in one way or another develops a conspicuous structure called the *cystocarp* (Figs. 228, 229), which is a case containing asexual spores; in other words, a spore case, or kind of sporangium. In the life history of a red alga, therefore, two sorts of asexual spores are produced: (1) the *tetraspores*, developed in ordinary sporangia; and (2) the *carpospores*, developed in the cystocarp, which has been produced as the result of fertilization.

OTHER CHLOROPHYLL-CONTAINING THALLOPHYTES

175. **Diatoms.**—These are peculiar one-celled forms, which occur in very great abundance in fresh and salt waters.

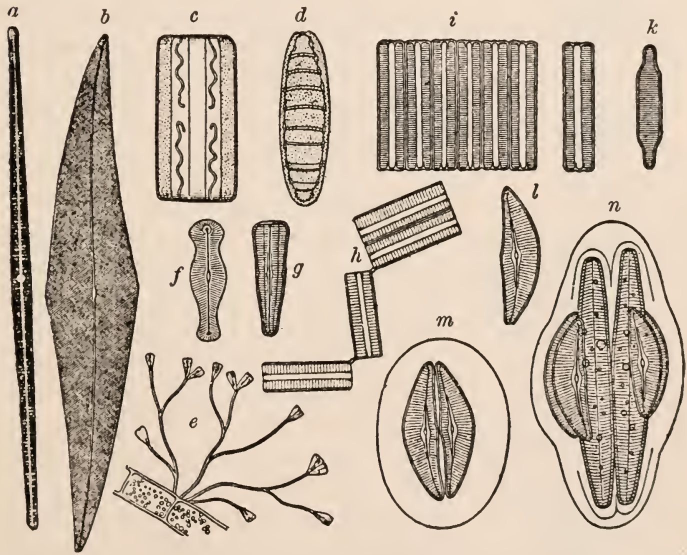


FIG. 230. A group of Diatoms: *c* and *d*, top and side views of the same form; *e*, colony of stalked forms attached to an alga; *f* and *g*, top and side views of the form shown at *e*; *h*, a colony; *i*, a colony, the top and side view shown at *k*.—After KERNER.

They are either free-swimming or attached by gelatinous stalks; solitary, or connected in bands or chains, or imbedded in gelatinous tubes or masses. In form they are rod-shaped, boat-shaped, elliptical, wedge-shaped, straight or curved (Fig. 230).

The chief peculiarity is that the wall is composed of two valves, one of which fits into the other like the two parts of a pill box. This wall is so impregnated with silica that it is practically indestructible, and siliceous skeletons of diatoms are preserved abundantly in certain rock deposits. They multiply by cell division in a peculiar way, and some of them have been observed to conjugate.


FIG. 231. A common *Chara*, showing tip of main axis. —After STRASBURGER.

They occur in such numbers in the ocean that they form a large part of the free-swimming forms on the surface of the sea, and doubtless showers of the siliceous skeletons are constantly falling on the sea bottom. There are certain deposits known as "siliceous earths," which are simply masses of fossil diatoms.

Diatoms have been variously placed in schemes of classification. Some have put them among the Brown Algæ because they contain a brown coloring matter; others have placed them in the Conjugate forms among the Green Algæ on account of the occasional conjugation that has been observed. They are so different from other forms, however, that it seems best to keep them separate from all other Algæ.

176. **Characeæ.**—These are commonly called "stoneworts," and are often included as a group of Green Algæ, as they seem to be Thallophytes, and have no other coloring matter than chlorophyll. However, they are so peculiar that they are better kept by themselves among the Algæ. They are such

specialized forms, and are so much more highly organized than all other Algæ, that they will be passed over here with a bare mention. They grow in fresh or brackish waters, fixed to the bottom, and forming great masses. The cylindrical stems are jointed, the joints sending out circles of branches, which repeat the jointed and branching habit (Fig. 231).

The walls become incrusted with a deposit of lime, which makes the plants harsh and brittle, and has suggested the name "stoneworts." In addition to the highly organized nutritive body, the antheridia and oogonia are peculiarly complex, being entirely unlike the simple sex organs of the other Algæ.

CHAPTER XVIII

THALLOPHYTES: FUNGI

177. **General characters.**—In general, Fungi include Thallophytes which do not contain chlorophyll. From this fact it follows that they can not manufacture food entirely out of inorganic material, but are dependent for it upon other plants or animals. This food is obtained in two general ways, either (1) directly from the living bodies of plants or animals, or (2) from dead bodies or the products of living bodies. In the first case, in which living bodies are attacked, the attacking fungus is called a *parasite*, and the plant or animal attacked is called the *host*. In the second case, in which living bodies are not attacked, the fungus is called a *saprophyte*. Some Fungi can live only as parasites, or as saprophytes, but some can live in either way.

Fungi form a very large assemblage of plants, much more numerous than the Algæ. As many of the parasites attack and injure useful plants and animals, producing many of the so-called "diseases," they are forms of great interest. Governments and Experiment Stations have expended a great deal of money in studying the injurious parasitic Fungi, and in trying to discover some method of destroying them or of preventing their attacks. Many of the parasitic forms, however, are harmless; while many of the saprophytic forms are decidedly beneficial.

It is generally supposed that the Fungi are derived from the Algæ, having lost their chlorophyll and power of independent living. Some of them resemble certain Algæ so closely that the connection seems very plain; but others have been so modified by their parasitic and saprophytic habits that they have lost all likeness to the Algæ, and their connection with them is very obscure.

178. **The plant body.**—Discarding certain problematical forms, to be mentioned later, the bodies of all true Fungi are organized upon a uniform general plan, to which they can all be referred (Fig. 232). A set of colorless branching

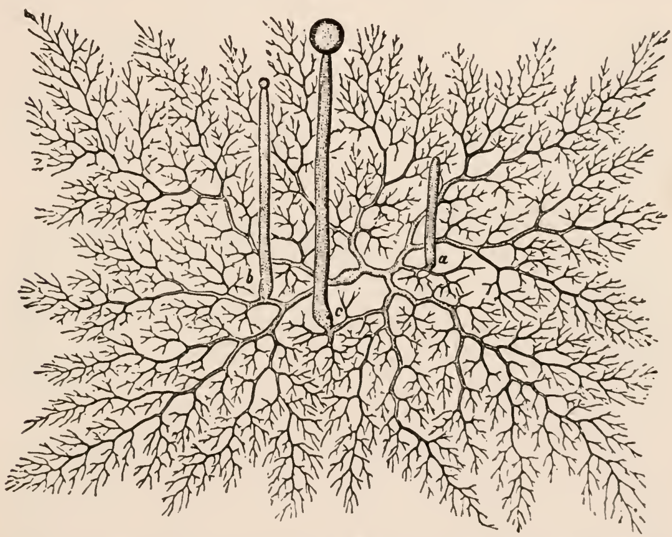


FIG. 232. A diagrammatic representation of *Mucor*, showing the profusely branching mycelium, and three vertical hyphæ (sporophores), sporangia forming on *b* and *c*. —After ZOPF.

filaments, either isolated or interwoven, forms the main working body, and is called the *mycelium*. The interweaving may be very loose, the mycelium looking like a delicate cobweb; or it may be close and compact, forming a felt-like mass, as may often be seen in connection with preserved fruits. The individual threads are called *hyphæ* (singular, *hypha*) or *hyphal threads*. The mycelium is in contact with its source of food supply, which is called the *substratum*.

From the hyphal threads composing the mycelium vertical ascending branches arise, which are set apart to produce the asexual spores, which are scattered and produce new mycelia. These branches are called *ascending hyphæ* or *sporophores*, meaning "spore bearers."

Sometimes, especially in the case of parasites, special descending branches are formed, which penetrate the substratum or host and absorb the food material. These special absorbing branches are called *haustoria*, meaning "absorbers."

Such a mycelial body, with its sporophores, and perhaps haustoria, lies either upon or within a dead substratum in the case of saprophytes, or upon or within a living plant or animal in the case of parasites.

179. **The subdivisions.**—The classification of Fungi is in confusion on account of lack of knowledge. They are so much modified by their peculiar life habits that they have lost or disguised the structures which prove most helpful in classification among the Algæ. Four groups will be presented, often made to include all the Fungi, but doubtless they are insufficient and more or less unnatural.

The constant termination of the group names is *mycetes*, a Greek word meaning "fungi." The prefix in each case is intended to indicate some important character of the group. The names of the four groups to be presented are as follows: (1) *Phycomycetes* ("Alga-Fungi"), referring to the fact that the forms plainly resemble the Algæ; (2) *Ascomycetes* ("Ascus-Fungi"); (3) *Æcidiomycetes* ("Æcidium-Fungi"); (4) *Basidiomycetes* ("Basidium-Fungi"). Just what the prefixes *ascus*, *æcidium*, and *basidium* mean will be explained in connection with the groups. The last three groups are often associated together under the name *Mycomycetes*, meaning "Fungus-Fungi," to distinguish them from the Phycomycetes, or "Alga-Fungi," referring to the fact that they do not resemble the Algæ, and are only like themselves.

One of the ordinary life processes which seems to be seriously interfered with by the saprophytic and parasitic habit is the sexual process. At least, while sex organs and sexual spores are about as evident in Phycomycetes as in Algæ, they are either obscure or wanting in the Mycomycete groups.

1. Phycomycetes (*Alga-Fungi*)

180. **Saprolegnia.**—This is a group of "water-moulds," with aquatic habit like the Algæ. They live upon the dead bodies of water plants and animals (Fig. 233), and sometimes attack living fish, one kind being very destructive to young fish in hatcheries. The hyphæ composing the mycelium are cœnocytes, as in the Siphon forms.

Sporangia are organized at the ends of branches by forming a partition wall separating the cavity of the tip from the general cavity (Fig. 233, *B*). The tip becomes more or less swollen, and within it are formed numerous biciliate zoospores, which are discharged into the water (Fig. 233, *C*), swim about for a short time, and rapidly form new mycelia. The process is very suggestive of *Cladophora* and *Vaucheria*. Oogonia and antheridia are also formed at the ends of the branches (Fig. 233, *F*), much as in *Vaucheria*. The oogonia are spherical, and form one and sometimes many eggs (Fig. 233, *D*, *E*). The antheridia are formed on branches near the oogonia. An antheridium comes in contact with an oogonium, and sends out a delicate tube which pierces the oogonium wall (Fig. 233, *F*). Through this tube the contents of the antheridium pass, fuse with the egg, and a heavy-walled oospore or resting spore is the result.

It is an interesting fact that sometimes the contents of an antheridium do not enter an oogonium, or antheridia may not even be formed, and still the egg, without fertilization, forms an oospore which can germinate. This peculiar habit is called *parthenogenesis*, which means reproduction by an egg without fertilization.

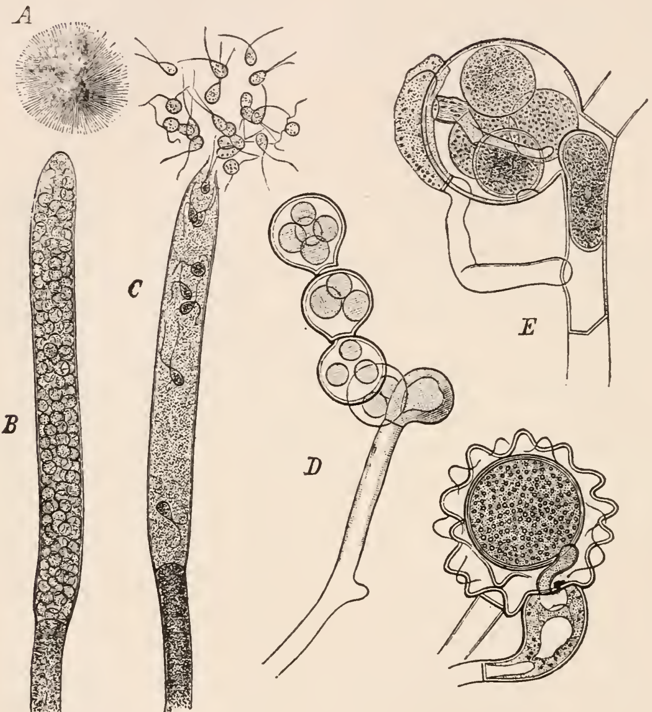


FIG. 233. A common water mould (*Saprolegnia*): *A*, a fly from which mycelial filaments of the parasite are growing; *B*, tip of a branch organized as a sporangium; *C*, sporangium discharging biciliate zoospores; *F*, oogonium with antheridium in contact, the tube having penetrated to the egg; *D* and *E*, oogonia with several eggs.—*A-C* after THURET, *D-F* after DEBARY.

181. **Mucor.**—One of the most common of the Mucors, or "black moulds," forms white furry growths on damp bread, preserved fruits, manure heaps, etc. It is therefore a saprophyte, the cœnocytic mycelium branching extensively through the substratum (Fig. 234).

Erect sporophores arise from it in abundance, and at the top of each sporophore a globular sporangium is formed, within which are numerous small asexual spores (Figs. 235,

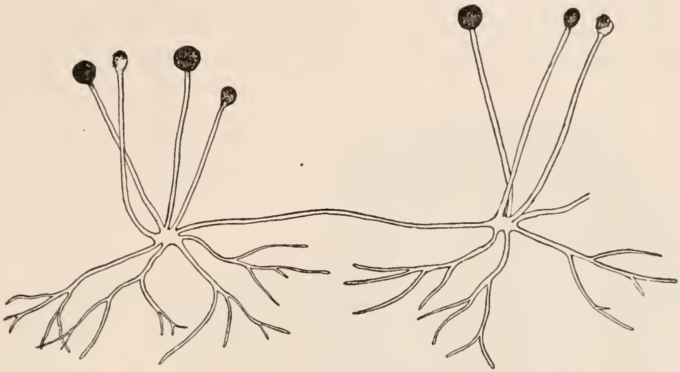


FIG. 234. Diagram showing mycelium and sporophores of a common *Mucor*.—MOORE.

236). The sporangium wall bursts (Fig. 237), the light spores are scattered by the wind, and, falling upon a suitable substratum, germinate and form new mycelia. It is evident that these asexual spores are not zoospores, for there is no water medium and swimming is impossible. This method of transfer being impossible, the spores are scattered by currents of air, and must be correspondingly light and powdery. They are usually spoken of simply as "spores," without any prefix.

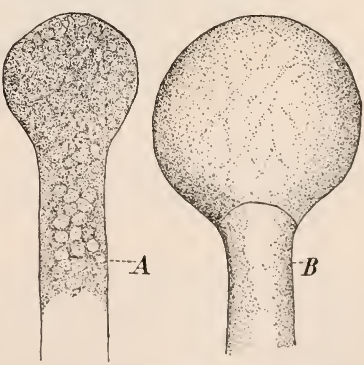


FIG. 235. Forming sporangia of *Mucor*, showing the swollen tip of the sporophore (*A*), and a later stage (*B*), in which a wall is formed separating the sporangium from the rest of the body.—MOORE.

While the ordinary method of reproduction through the growing season is by means of these rapidly germinating spores, in certain conditions a sexual process is observed, by which a heavy-walled sexual spore is formed as a resting spore, able to outlive unfavorable conditions. Branches arise from the hyphæ of the mycelium just as in the forma-

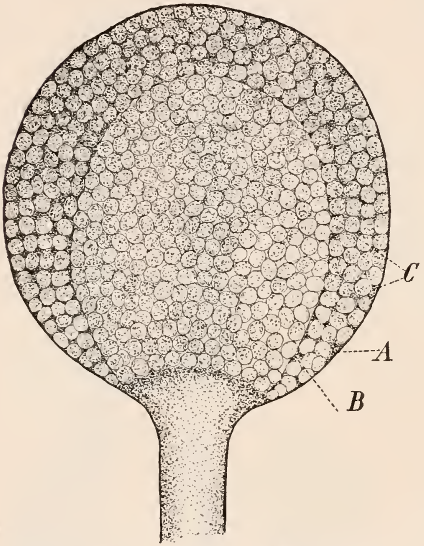


FIG. 236. Mature sporangium of *Mucor*, showing the wall (*A*), the numerous spores (*C*), and the columella (*B*)—that is, the partition wall pushed up into the cavity of the sporangium. —MOORE.

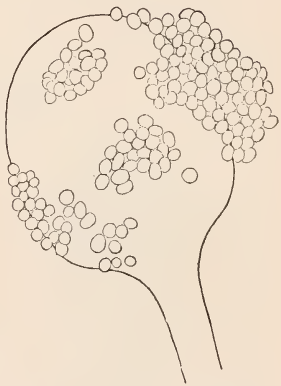


FIG. 237. Bursted sporangium of *Mucor*, the ruptured wall not being shown, and the loose spores adhering to the columella.—MOORE.

tion of sporophores (Fig. 238). Two contiguous branches come in contact by their tips (Fig. 238, *A*), the tips are cut off from the main cœnocytic body by partition walls (Fig. 238, *B*), the walls in contact disorganize, the contents of the two tip cells fuse, and a heavy-walled sexual spore is the result (Fig. 238, *C*). It is evident that the process is conjugation, suggesting the Conjugate forms among the

Algæ; that the sexual spore is a zygote; and that the two pairing tip cells cut off from the main body by partition walls are gametangia. *Mucor*, therefore, is isogamous.

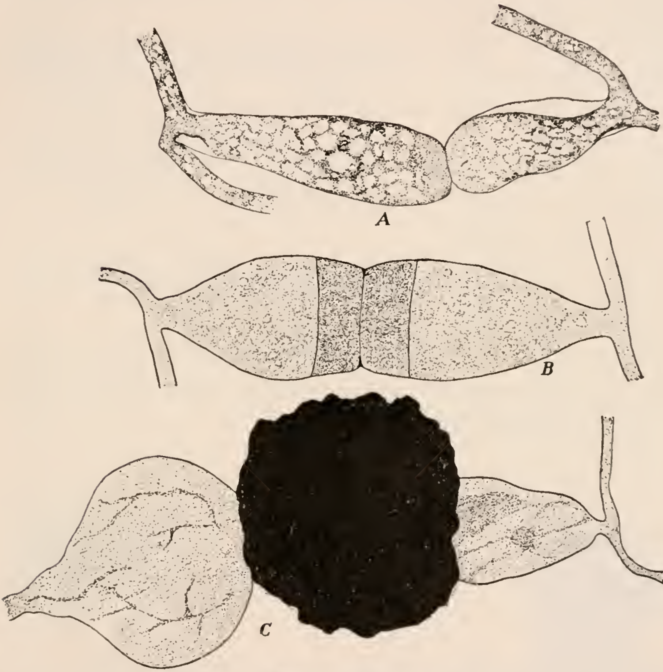


Fig. 238. Sexual reproduction of *Mucor*, showing tips of sex branches meeting (*A*), the two gametangia cut off by partition walls (*B*), and the heavy-walled zygote (*C*).—Caldwell.

182. **Peronospora.**—These are the "downy mildews," very common parasites on seed plants as hosts, one of the most common kind attacking grape leaves. The mycelium is cœnocytic and entirely internal, ramifying among the tissues within the leaf, and piercing the living cells with haustoria which rapidly absorb their contents (Fig. 239). The presence of the parasite is made known by discolored and

finally deadened spots on the leaves, where the tissues have been killed.

From this internal mycelium numerous sporophores arise, coming to the surface of the host and securing the scattering of their spores, which fall upon other leaves and germinate, the new mycelia penetrating among the tissues and beginning their ravages. The sporophores, after rising above the surface of the leaf, branch freely; and many of them rising near together, they form little velvety patches on the surface, suggesting the name "downy mildew."

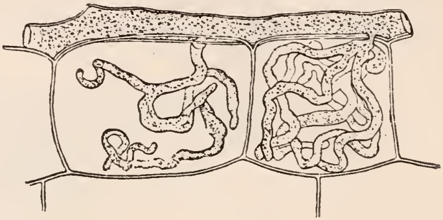


Fig. 239. A branch of *Peronospora* in contact with two cells of a host plant, and sending into them its large haustoria.—After DeBary.

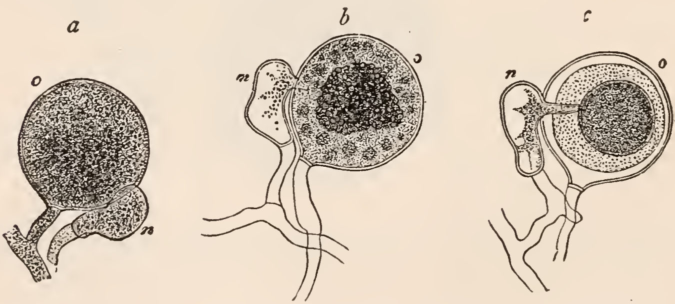


Fig. 240. *Peronospora*, one of the Phycomycetes, showing at *a* an oogonium (*o*) containing an egg, and an antheridium (*n*) in contact; at *b* the antheridial tube penetrating the oogonium and discharging the contents of the antheridium into the egg; at *c* the oogonium containing the oospore or resting spore.—After DeBary.

In certain conditions special branches arise from the mycelium, which organize antheridia and oogonia, and remain within the host (Fig. 240). The oogonium is of the usual spherical form, organizing a single egg. The antheridium comes in contact with the oogonium, puts out a tube which pierces the oogonium wall and enters the egg, into which the contents of the antheridium are discharged, and fertilization is effected. The result is a heavy-walled oospore. As the oospores are not for immediate germination, they are not brought to the surface of the host and scattered, as are the asexual spores. When they are ready to germinate, the leaves bearing them have perished and the oospores are liberated.

183. **Conclusions.**—The cœnocytic bodies of the whole group are very suggestive of the Siphon forms among Green Algæ, as is also the method of forming oogonia and antheridia.

The water-moulds, *Saprolegnia* and its allies, have retained the aquatic habit of the Algæ, and their asexual spores are zoospores. Such forms as *Mucor* and *Peronospora*, however, have adapted themselves to terrestrial conditions, zoospores are abandoned, and light spores are developed which can be carried about by currents of air.

In most of them motile gametes are abandoned. Even in the heterogamous forms sperms are not organized within the antheridium, but the contents of the antheridium are discharged through a tube developed by the wall and penetrating the oogonium. It should be said, however, that a few forms in this group develop sperms, which make them all the more alga-like.

They are both isogamous and heterogamous, both zygotes and oospores being resting spores. Taking the characters all together, it seems reasonably clear that the Phycomycetes are an assemblage of forms derived from Green Algæ (Chlorophyceæ) of various kinds.

2. Ascomycetes (*Ascus- or Sac-Fungi*)

184. **Mildews.**—These are very common parasites, growing especially upon leaves of seed plants, the mycelium spreading over the surface like a cobweb. A very common mil-

dew, *Microsphæra*, grows on lilac leaves, which nearly always show the whitish covering after maturity (Fig. 241). The branching hyphæ show numerous partition walls, and are not cœnocytic as in the Phycomycetes. Small disk-like haustoria penetrate into the superficial cells of the host, anchoring the mycelium and absorbing the cell contents.

Sporophores arise, which form asexual spores in a peculiar way. The end of the sporophore rounds off, almost separating itself from the part below, and becomes a spore or spore-like body. Below this another organizes in the same way, then another, until a chain of spores is developed, easily broken apart and scattered by the wind. Falling upon other suitable leaves, they germinate and form new mycelia, enabling the fungus to spread rapidly. This method of cutting a branch into sections to form spores is called *abstriction*, and the spores formed in this way are called *conidia*, or *conidiospores* (Fig. 243, *B*).

Fig. 241. Lilac leaf covered with mildew (*Microsphæra*), the shaded regions representing the mycelium, and the black dots the ascocarps.—S. M. Coulter.

At certain times the mycelium develops special branches which develop sex organs, but they are seldom seen and may not always occur. An oogonium and an antheridium, of the usual forms, but probably without organizing gametes, come into contact, and as a result an elaborate structure is developed—the *ascocarp*, sometimes called the "spore fruit." These ascocarps appear on the lilac leaves as minute dark dots, each one being a little sphere, which suggested the name *Microsphæra* (Fig. 241). The heavy wall of the ascocarp bears beautiful branching hair-like appendages (Fig. 242).

Bursting the wall of this spore fruit several very delicate, bladder-like sacs are extruded, and through the transparent wall of each sac there may be seen several spores (Fig. 242). The ascocarp, therefore, is a spore case, just as is the cystocarp of the Red Algæ (§ 174). The delicate sacs within are the *asci*, a word meaning "sacs," and each ascus is evidently a mother cell within which asexual spores are formed. These spores are distinguished from other asexual spores by the name *ascospore*.

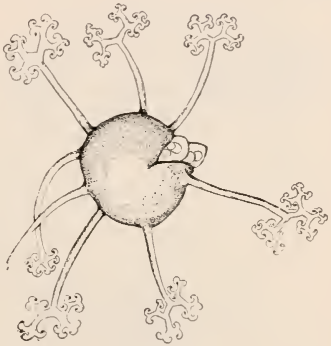


Fig. 242. Ascocarp of the lilac mildew, showing branching appendages and two asci protruding from the ruptured wall and containing ascospores.—S. M. Coulter.

It is these peculiar mother cells, or asci, which give name to the group, and an Ascomycete, Ascus-fungus, or Sac-fungus, is one which produces spores in asci; and an ascocarp is a spore case which contains asci.

In the mildews, therefore, there are two kinds of asexual spores: (1) *conidia*, formed from a hyphal branch by abstriction, by which the mycelium may spread rapidly; and (2) *ascospores*, formed in a mother cell and protected by a heavy case, so that they may bridge over unfavorable conditions, and may germinate when liberated and form new mycelia. The resting stage is not a zygote or an oospore, as in the Algæ and Phycomycetes, no sexual spore probably being formed, but a heavy-walled ascocarp.

185. **Other forms.**—The mildews have been selected as a simple illustration of Ascomycetes, but the group is a very

large one, and contains a great variety of forms. All of them, however, produce spores in asci, but the asci are not always inclosed by an ascocarp. Here belong the common blue mould (*Penicillium*) found on bread, fruit, etc., in which stage the branching chains of conidia are very conspicuous (Fig. 243); the truffle-fungi, upon whose subter-

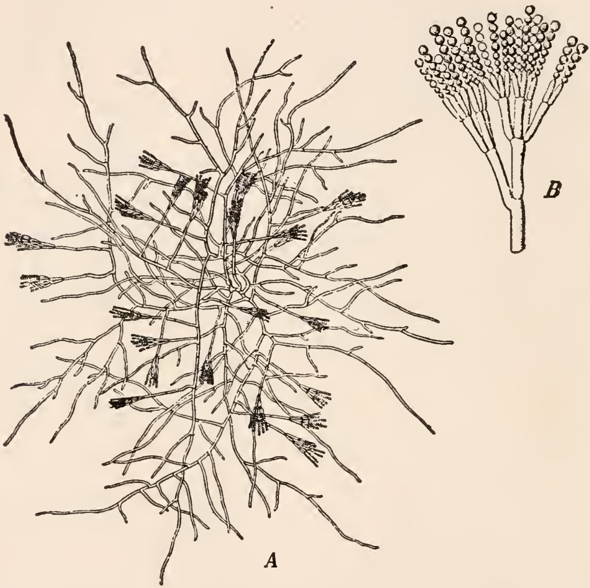


Fig. 243. *Penicillium*, a common mould: *A*, mycelium with numerous branching sporophores bearing conidia; *B*, apex of a sporophore enlarged, showing branching and chains of conidia.—After Brefeld.

ranean mycelia ascocarps develop which are known as "truffles"; the black fungi, which form the diseases known as "black knot" of the plum and cherry, the "ergot" of rye (Fig. 244), and many black wart-like growths upon the bark of trees; other forms causing "witches'-brooms" (abnormal growths on various trees), "peach curl," etc., the cup-fungi (Figs. 245, 246), and the edible morels (Fig. 247).

Fig. 244. Head of rye attacked by "ergot" (*a*), peculiar grain-like masses replacing the grains of rye; also a mass of "ergot" germinating to form spores (*b*).—After Tulasne.

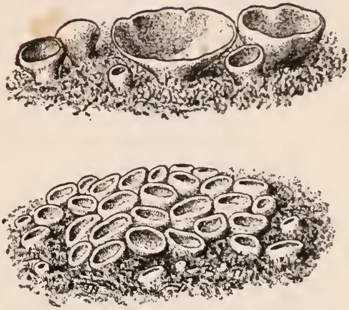


Fig. 245. Two species of cup-fungus (*Peziza*).—After Lindau.

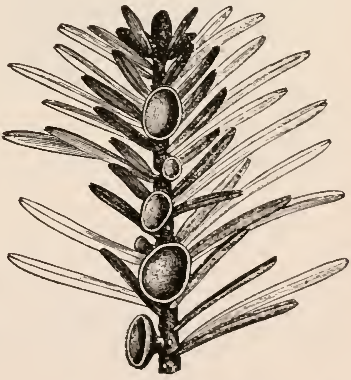


Fig. 246. A cup-fungus (*Pitya*) growing on a spruce (*Picea*).—After Rehm.

In some of these forms the ascocarp is completely closed, as in the lilac mildew; in others it is flask-shaped; in others, as in the cup-fungi, it is like a cup or disk; but in all the spores are inclosed by a delicate sac, the ascus.

Here must probably be included the yeast-fungi (Fig. 248), so commonly used to excite alcoholic fermentation.

FIG. 247. The common edible morel (*Morchella esculenta*). The structure shown and used represents the ascocarp, the depressions of whose surface are lined with asci containing ascospores.—After GIBSON.

FIG. 248. Yeast cells, reproducing by budding, and forming chains.—LAND.

The "yeast cells" seem to be conidia having a peculiar budding method of multiplication, and the remarkable power of exciting alcoholic fermentation in sugary solutions.

3. ÆCIDIOMYCETES (*Æcidium-Fungi*)

186. **General characters.**—This is a large group of very destructive parasites known as "rusts" and "smuts." The rusts attack particularly the leaves of higher plants, producing rusty spots, the wheat rust probably being the best known. The smuts especially attack the grasses, and are very injurious to cereals, producing in the heads of oats, barley, wheat, corn, etc., the disease called smut.

In some forms an obscure sexual process has been described, but it is beyond the reach of ordinary observation. The Æcidiomycetes do not form an independent and natural group, but are now generally placed under the Basidiomycetes, but they are so unlike the ordinary forms of that group that they are here kept distinct for convenience.

Most of the forms are very *polymorphic*—that is, a plant assumes several dissimilar appearances in the course of its life history. These phases are often so dissimilar that they have been described as different plants. This polymorphism is often further complicated by the appearance of different phases upon entirely different hosts. For example, the wheat-rust fungus in one stage lives on wheat, and in another on barberry.

187. **Wheat rust.**—This is one of the few rusts whose life histories have been traced, and it may be taken as an illustration of the group.

The mycelium of the fungus is found ramifying among the leaf and stem tissues of the wheat. While the wheat is growing this mycelium sends to the surface numerous spo-

Fig. 249. Wheat rust, showing sporophores breaking through the tissues of the host and bearing summer spores (uredospores).—After H. Marshall Ward.

rophores, each bearing at its apex a reddish spore (Fig. 249). As the spores occur in great numbers they form the rusty-looking lines and spots which give name to the disease. The spores are scattered by currents of air, and falling upon other plants, germinate very promptly, thus spreading the disease with great rapidity (Fig. 250). Once it was thought that this completed the life cycle, and the fungus received the name *Uredo.* When it was known that this is but one

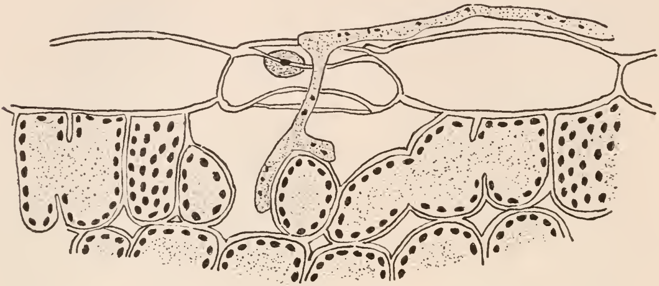


Fig. 250. Wheat rust, showing a young hypha forcing its way from the surface of a leaf down among the nutritive cells.—After H. Marshall Ward.

stage in a polymorphic life history it was called the Uredo-stage, and the spores *uredospores*, sometimes "summer spores."

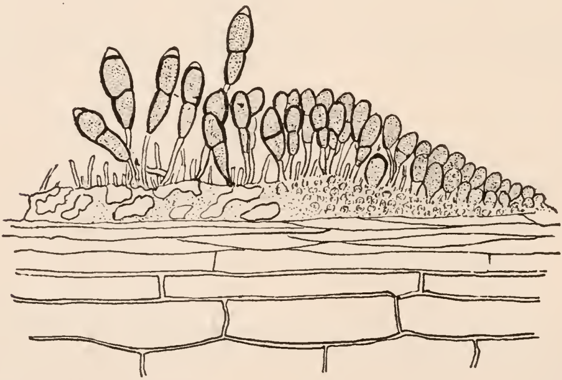


Fig. 251. Wheat rust, showing the winter spores (teleutospores).—After H. Marshall Ward.

Toward the end of the summer the same mycelium develops sporophores which bear an entirely different kind of spore (Fig. 251). It is two-celled, with a very heavy black wall, and forms what is called the "black rust," which appears late in the summer on wheat stubble. These spores are the resting spores, which last through the winter and germinate in the following spring. They are called *teleutospores*, meaning the "last spores" of the growing season. They are also called "winter spores," to distinguish them from the uredospores or "summer spores." At first this teleutospore-bearing mycelium was not recognized to be identical with the uredospore-bearing mycelium, and it was called *Puccinia*. This name is now retained for the whole polymorphous plant, and wheat rust is *Puccinia graminis*. This mycelium on the wheat, with its summer spores and winter spores, is but one stage in the life history of wheat rust.

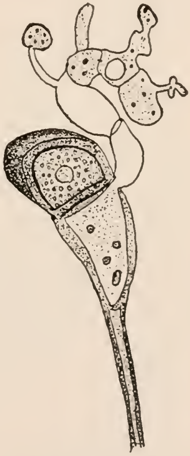


FIG. 252. Wheat rust, showing a teleutospore germinating and forming a short filament, from four of whose cells a spore branch arises, the lowest one bearing at its tip a sporidium.—After H. MARSHALL WARD.

In the spring the teleutospore germinates, each cell developing a small few-celled filament (Fig. 252). From each cell of the filament a little branch arises which develops at its tip a small spore, called a *sporidium*, which means "spore-like." This little filament, which is not a parasite, and which bears sporidia, is a second phase of the wheat rust, really the first phase of the growing season.

The sporidia are scattered, fall upon barberry leaves, germinate, and develop a mycelium which spreads through the leaf. This mycelium produces sporophores which emerge on the under surface of the leaf in the form of chains of reddish-yellow conidia (Fig. 253). These chains of conidia are closely packed in cup-like receptacles, and these reddish-yellow cup-like masses are often called "cluster-cups." This mycelium on the barberry, bearing cluster-cups, was thought to be a distinct plant, and was called *Æcidium.* The name now is applied to the cluster-cups, which are called *æcidia*, and the conidia-like spores which they produce are known as *æcidiospores.*

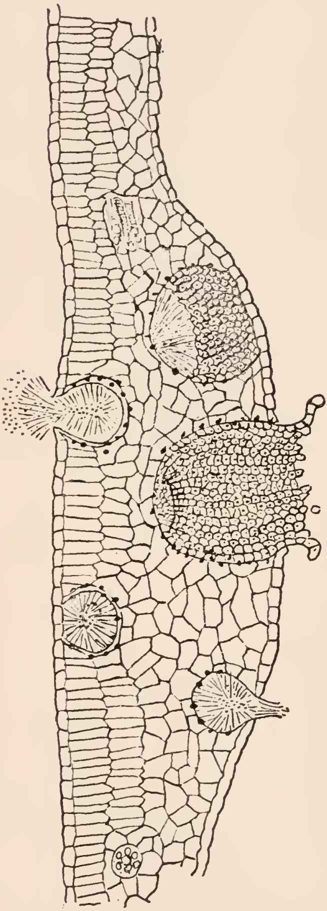


Fig. 253. Wheat rust, showing section of barberry leaf, with two æcidia below, one of them having broken through the epidermis and exposed its chains of conidia (æcidiospores). Above is a flask-shaped mass discharging very minute bodies, which are probably still other spores of the parasite.—After H. Marshall Ward.

It is the æcidia which give name to the group, and Æcidiomycetes are those Fungi in whose life history æcidia or cluster-cups appear.

The æcidiospores are scattered by the wind, fall upon the spring wheat, germinate, and develop again the mycelium which produces the rust on the wheat, and so the life cycle is completed. There are thus at least three distinct stages in the life history of wheat rust. Beginning with the growing season they are as follows: (1) The phase bearing the sporidia, which is not parasitic; (2) the æcidium phase, parasitic on the barberry; (3) the uredo-teleutospore phase, parasitic on the wheat.

In this life cycle at least four kinds of asexual spores appear: (1) *sporidia*, which develop the stage on the barberry; (2) *æcidiospores*, which develop the stage on the wheat; (3) *uredospores*, which repeat the mycelium on the wheat; (4) *teleutospores*, which last through the winter, and in the spring produce the stage bearing sporidia. It should be said that there are other structures of this plant produced on the barberry (Fig. 53), but they are too uncertain to be included here.

The barberry is not absolutely necessary to this life cycle. In many cases there is no available barberry to act as host, and the sporidia germinate directly upon the young wheat, forming the rust-producing mycelium, and the cluster-cup stage is omitted.

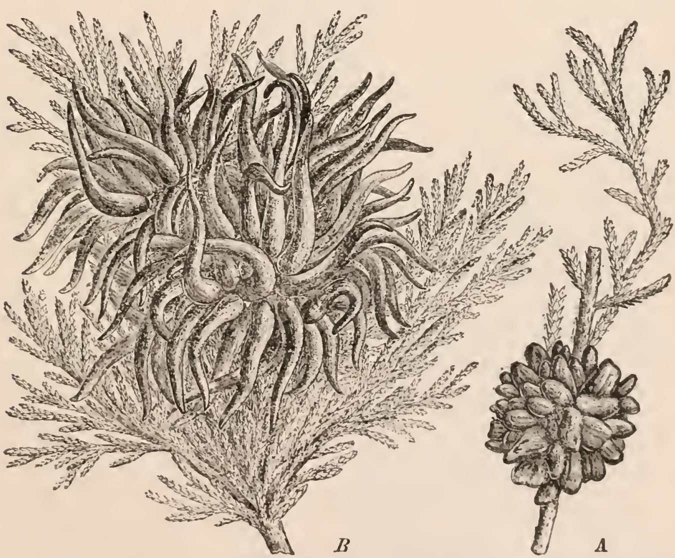


FIG. 254. Two species of "cedar apple" (*Gymnosporangium*), both on the common juniper (*Juniperus Virginiana*).—*A* after FARLOW, *B* after ENGLER and PRANTL.

188. **Other rusts.**—Many rusts have life histories similar to that of the wheat rust, in others one or more of the stages are omitted. In very few have the stages been con-

nected together, so that a mycelium bearing uredospores is called a *Uredo*, one bearing teleutospores a *Puccinia*, and one bearing æcidia an *Æcidium;* but what forms of *Uredo, Puccinia*, and *Æcidium* belong together in the same life cycle is very difficult to discover.

Another life cycle which has been discovered is in connection with the "cedar apples" which appear on red cedar (Fig. 254). In the spring these diseased growths become conspicuous, especially after a rain, when the jelly-like masses containing the orange-colored spores swell. This corresponds to the phase which produces rust in wheat. On the leaves of apple trees, wild crab, hawthorn, etc., the æcidium stage of the same parasite develops.

4. Basidiomycetes (*Basidium-Fungi*).

189. **General characters.**—This group includes the mushrooms, toadstools, and puffballs. They are not destructive parasites, as are many forms in the preceding groups, but mostly harmless and often useful saprophytes. They must also be regarded as the most highly organized of the Fungi. The popular distinction between toadstools and mushrooms is not borne out by botanical characters, toadstool and mushroom being the same thing botanically, and forming one group, puffballs forming another.

Fig. 255. The common edible mushroom, *Agaricus campestris.*—After Gibson.

As in Æcidiomycetes, an obscure sexual process is reported. The life history seems simple, but this apparent simplicity may represent a very complicated history. The structure of the common mushroom (*Agaricus*) will serve as an illustration of the group (Fig. 255).

190. **A common mushroom.** — The mycelium, of white branching threads, spreads extensively through the decaying substratum, and in cultivated forms is spoken of as the "spawn." Upon this mycelium little knob-like protuberances begin to arise, growing larger and larger, until they are organized into the so-called "mushrooms." The real body of the plant is the white thread-like mycelium, while the "mushroom" part seems to represent a great number of sporophores organized together to form a single complex spore-bearing structure.

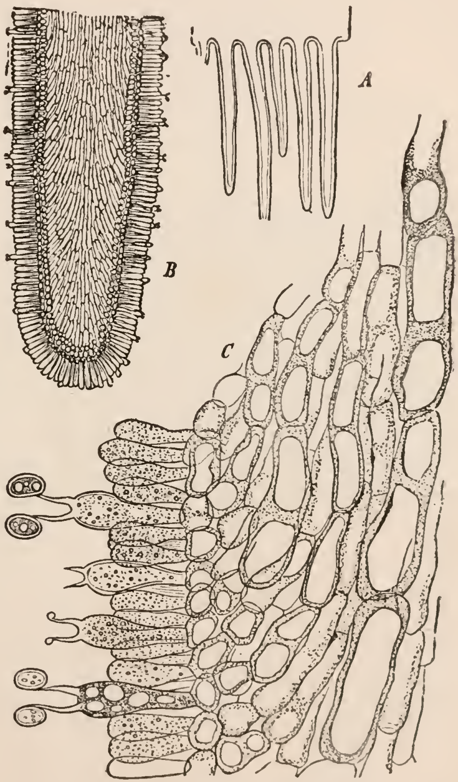


FIG. 256. A common *Agaricus*: *A*, section through one side of pileus, showing sections of the pendent gills; *B*, section of a gill more enlarged, showing the central tissue, and the broad border formed by the basidia; *C*, still more enlarged section of one side of a gill, showing the club-shaped basidia standing at right angles to the surface, and sending out a pair of small branches, each of which bears a single basidiospore.—After SACHS.

The mushroom

Fig. 257. A "fairy ring" fungus (*Marasmius oreades*); edible.—After Gibson.

Fig. 258. A common edible mushroom (*Lepiota*), showing stipe, pileus, and gills.—Caldwell.

Fig. 259. The "shaggy mane" fungus (*Coprinus comatus*); edible.—After Gibson.

has a stalk-like portion, the *stipe*, at the base of which the slender mycelial threads look like white rootlets; and an expanded, umbrella-like top called the *pileus*. From the under surface of the pileus there hang thin radiating plates, or *gills* (Fig. 255). Each gill is a mass of interwoven filaments (hyphæ), whose tips turn toward the surface and form a compact layer of end cells (Fig. 256). These end

FIG. 260. A bracket fungus (*Polyporus*) growing on the trunk of a red oak.—CALDWELL.

cells, forming the surface of the gill, are club-shaped, and are called *basidia*. From the broad end of each basidium two or four delicate branches arise, each bearing a minute spore, very much as the sporidia appear in the wheat rust.

These spores, called *basidiospores*, shower down from the gills when ripe, germinate, and produce new mycelia. The peculiar cell called the basidium gives name to the group Basidiomycetes.

191. **Other forms.**—Mushrooms display a great variety of form and coloration, many of them being very attractive

FIG. 261. A toadstool of the bracket form which has grown about blades of grass without interfering with their activity.—CALDWELL.

(Figs. 257, 258, 259). The " pore-fungi " have pore-like depressions for their spores, instead of gills, as in the very common " bracket-fungus " (*Polyporus*), which forms hard shell-like outgrowths on tree-trunks and stumps (Figs. 260,

FIG. 262. The common edible *Boletus* (*B. edulis*), in which the gills are replaced by pores.—After GIBSON.

FIG. 263. Another edible *Boletus* (*B. strobilaceus*).—After GIBSON.

FIG. 264. The common edible "coral fungus" (*Clavaria*).—After GIBSON.

FIG. 265. *Hydnum repandum*, in which gills are replaced by spinous processes ; edible.—After GIBSON.

261), and the mushroom-like *Boleti* (Figs. 262, 263). The "ear-fungi" form gelatinous, dark-brown, shell-shaped masses, and the "coral fungi" resemble branching corals (Fig. 264). The Hydnum forms have spinous processes instead of gills (Fig. 265). The puffballs organize globular bodies (Fig. 266), within which the spores develop, and are not liberated until ripe; and with them belong also the "bird's nest fungus," the "earth star," the ill-smelling "stink-horn," etc.

FIG. 266. Puffballs, in which the basidia and spores are inclosed ; edible.—After GIBSON.

OTHER THALLOPHYTES WITHOUT CHLOROPHYLL

192. **Slime-moulds.**—These perplexing forms, named *Myxomycetes*, do not seem to be related to any group of plants, and it is a question whether they are to be regarded as plants or animals. The working body is a mass of naked protoplasm called a *plasmodium*, suggesting the term "slime," and slips along like a gigantic amœba. They are common in forests, upon black soil, fallen leaves, and decaying logs, the slimy yellow or orange masses ranging from the size of a pinhead to as large as a man's hand. They are saprophytic, and are said to engulf food as do the amœbas. So suggestive of certain low animals is this body and food habit that slime-moulds have also been called *Mycetozoa* or "fungus-animals."

In certain conditions, however, these slimy bodies come to rest and organize most elaborate and often very beautiful sporangia, full of spores (Fig. 267). These varied and easily preserved sporangia are used to classify the

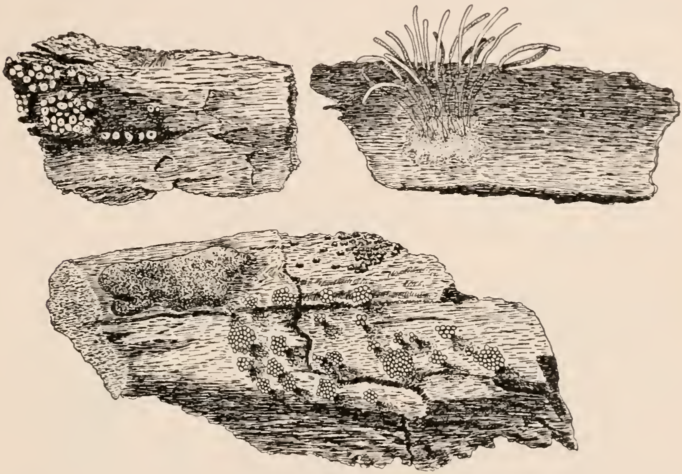


FIG. 267. Three common slime moulds (Myxomycetes) on decaying wood: to the left above, groups of the sessile sporangia of *Trichia*; to the right above, a group of the stalked sporangia of *Stemonitis*, with remnant of old plasmodium at base; below, groups of sporangia of *Hemiarcyria*, with a plasmodium mass at upper left hand.—GOLDBERGER.

forms. Slime-moulds, or "slime-fungi," therefore, seem to have animal-like bodies which produce plant-like sporangia.

193. **Bacteria.**—These are the "Fission-Fungi," or Schizomycetes, and are popularly known as "bacteria," "bacilli," "microbes," "germs," etc. They are so important and peculiar in their life habits that their study has developed a special branch of botany, known as "Bacteriology." In many ways they resemble the Cyanophyceæ, or "Fission-Algæ," so closely that they are often associated with them in classification (see § 162).

Fig. 268. A group of Bacteria, the bodies being black, and bearing motile cilia in various ways. *A*, the two to the left the common hay *Bacillus* (*B. subtilis*), the one to the right a *Spirillum*; *B*, a Coccus form (*Planococcus*); *C*, *D*, *E*, species of *Pseudomonas*: *F*, *G*, species of Bacillus, *F* being that of typhoid fever; *H*, *Microspira*; *J*, *K*, *L*, *M*, species of *Spirillum*.—After Engler and Prantl.

They are the smallest known living organisms, the one-celled form which develops on cooked potatoes, bread, milk, meat, etc., forming a blood-red stain, having a diameter of but 0.0005 mm. ($\frac{1}{50000}$ in.). They are of various forms (Fig. 268), as Coccus forms, single spherical cells; Bacterium forms, short rod-shaped cells; Bacillus forms, longer rod-shaped cells; Leptothrix forms, simple filaments; Spirillum forms, spiral filaments, etc.

They multiply by cell division with wonderful rapidity, and also form resting spores for preservation and distribution. They occur everywhere—in the air, in the water, in the soil, in the bodies of plants and animals; many of them harmless, many of them useful, many of them dangerous.

They are intimately concerned with fermentation and decay, inducing such changes as the souring of fruit juices, milk, etc., and the development of pus in wounds. What is called antiseptic surgery is the use of various means to exclude bacteria and so prevent inflammation and decay.

The pathogenic forms—that is, those which induce diseases of plants and animals—are of great importance, and means of making them harmless or destroying them are being searched for constantly. They are the causes of such diseases as pear-blight and peach-yellows among plants, and such human diseases as tuberculosis, cholera, diphtheria, typhoid fever, etc.

LICHENS

194. **General character.**—Lichens are abundant everywhere, forming various colored splotches on tree-trunks, rocks, old boards, etc., and growing also upon the ground (Figs. 269, 270, 271). They have a general greenish-gray color, but brighter colors may also be observed.

The great interest connected with Lichens is that they are not single plants, but each Lichen is formed of a fungus and an alga, living together so intimately as to appear like a single

FIG. 269. A ledge of rock, showing the face to the right covered by a dense growth of lichens, and on top a growth of ferns (*Cystopteris bulbifera*). Near Deer Park, Ill.—CALDWELL.

plant. In other words, a Lichen is not an individual, but a firm of two individuals very unlike each other. This habit

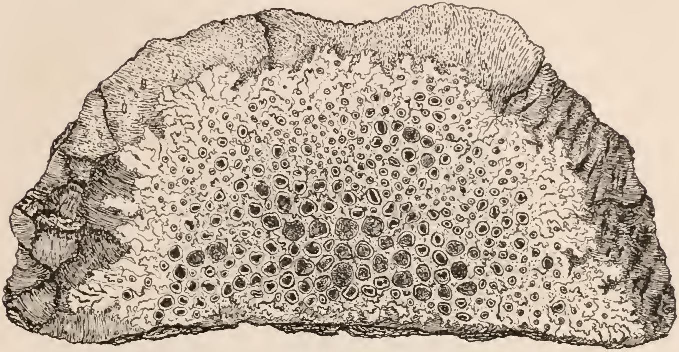


FIG. 270. A common lichen (*Physcia*) growing on bark, showing the spreading thallus and the numerous dark disks (apothecia) bearing the asci.—GOLDBERGER.

of living together has been called *symbiosis*, and the individuals entering into this relation are called *symbionts*.

FIG. 271. A common foliose lichen (*Parmelia*) growing upon a board, and showing apothecia.—GOLDBERGER.

If a Lichen be sectioned, the relation between the symbionts will be seen (Fig. 272). The fungus makes the bulk of the body with its interwoven mycelial threads, in the meshes of which lie the Algæ, sometimes scattered, some-

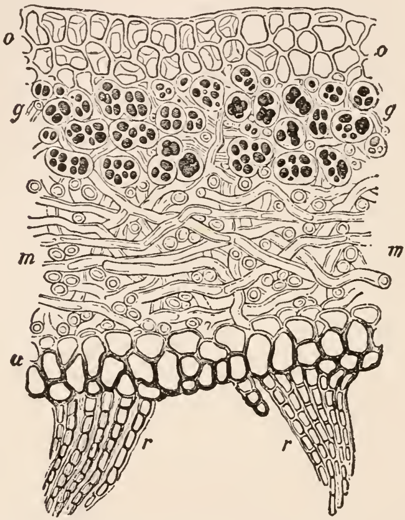


FIG. 272. Section through thallus of a lichen (*Sticta*), showing holdfasts (*r*), lower (*u*) and upper (*o*) surfaces, fungus hyphæ (*m*), and enmeshed algæ (*g*).—After SACHS.

times massed. It is these enmeshed Algæ, showing through the transparent mycelium, that give the greenish tint to the Lichen.

In the case of Lichens the symbionts are thought by some to be mutually helpful, the alga manufacturing food for the fungus, and the fungus providing protection and water containing food materials for the alga. Others do not recognize any special benefit to the alga, and see in a Lichen simply a parasitic fungus living on the products of an alga. In any event the Algæ are not destroyed but seem to thrive. It is discovered that the alga symbiont can live quite independently of the fungus. In fact, the enmeshed Algæ are often recognized as identical with forms living independently, those thus used being various Blue-green, Protococcus, and Conferva forms (see p. 159).

On the other hand, the fungus symbiont has become quite dependent upon the alga, and its germinating spores do not develop far unless the young mycelium can lay hold of suitable Algæ. At certain times cup-like or disk-like bodies appear on the surface of the lichen thallus, with brown, or black, or more brightly-colored lining (Figs. 270, 271). These bodies are the *apothecia*, and a section through them shows that the colored lining is largely made up of delicate sacs containing spores (Figs. 273, 274). These sacs are evidently asci, the apothecia correspond to ascocarps, and the Lichen fungus proves to be an Ascomycete.

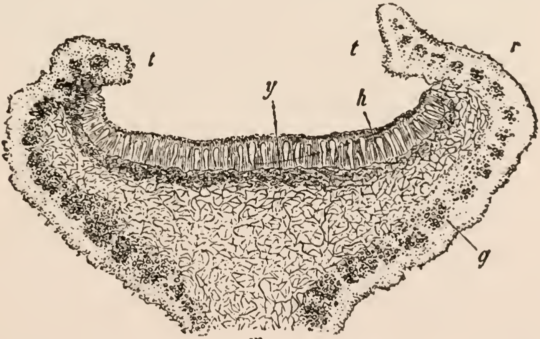


FIG. 273. Section through an apothecium of *Anaptychia*, showing stalk of the cup (m), masses of algal cells (g), outer margin of cup (r), overlapping edge (t, t), layer of asci (h), and massing of hyphæ beneath asci (y).—After SACHS.

Certain Ascomycetes, therefore, have learned to use certain Algæ in this peculiar way, and a Lichen is the result. Some Basidiomycetes have also learned the same habit, and form Lichens.

Various forms of Lichen bodies can be distinguished as follows: (1) *Crustaceous Lichens*, in which the thallus resembles an incrustation upon its substratum of rock, soil, etc.; (2) *Foliose Lichens*, with flattened, leaf-like, lobed bodies, at-

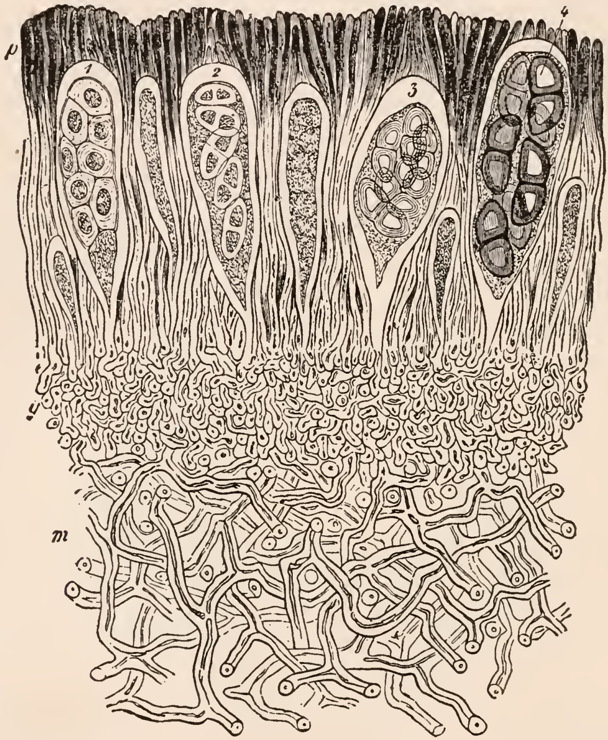


FIG. 274. Much enlarged section of a portion of the apothecium of *Anaptychia*, showing the fungus mycelium (*m*), which is massed above (*y*), just beneath the layer of asci (*1*, *2*, *3*, *4*), in which spores in various stages of development are shown.—After SACHS.

tached only at the middle or irregularly to the substratum; (3) *Fruticose Lichens*, with filamentous bodies branching like shrubs, either erect, pendulous, or prostrate.

CHAPTER XIX

BRYOPHYTES (MOSS PLANTS)

195. **Summary from Thallophytes.**—Before considering the second great division of plants it is well to recall the most important facts connected with the Thallophytes, those things which may be regarded as the contribution of the Thallophytes to the evolution of the plant kingdom, and which are in the background when one enters the region of the Bryophytes.

(1) *Increasing complexity of the body.*—Beginning with single isolated cells, the plant body attains considerable complexity, in the form of simple or branching filaments, cell-plates, and cell-masses.

(2) *Appearance of spores.*—The setting apart of reproductive cells, known as spores, as distinct from nutritive cells, and of reproductive organs to organize these spores, represents the first important differentiation of the plant body into nutritive and reproductive regions.

(3) *Differentiation of spores.*—After the introduction of spores they become different in their mode of origin, but not in their power. The asexual spore, ordinarily formed by cell division, is followed by the appearance of the sexual spore, formed by cell union, the act of cell union being known as the sexual process.

(4) *Differentiation of gametes.*—At the first appearance of sex the sexual cells or gametes are alike, but afterward they become different in size and activity, the large passive one being called the egg, the small active one the

sperm, the organs producing the two being known as oogonium and antheridium respectively.

(5) *Algæ the main line.*—The Algæ, aquatic in habit, appear to be the Thallophytes which lead to the Bryophytes and higher groups, the Fungi being regarded as their degenerate descendants; and among the Algæ the Chlorophyceæ seem to be most probable ancestors of higher forms. It should be remembered that among these Green Algæ the ciliated swimming spore (zoospore) is the characteristic asexual spore, and the sexual spore (zygote or oospore) is the resting stage of the plant, to carry it over from one growing season to the next.

196. **General characters of Bryophytes.**—The name given to the group means "moss plants," and the Mosses may be regarded as the most representative forms. Associated with them in the group, however, are the Liverworts, and these two groups are plainly distinguished from the Thallophytes below, and from the Pteridophytes above. Starting with the structures that the Algæ have worked out, the Bryophytes modify them still further, and make their own contributions to the evolution of the plant kingdom, so that Bryophytes become much more complex than Thallophytes.

197. **Alternation of generations.**—Probably the most important fact connected with the Bryophytes is the distinct alternation of generations which they exhibit. So important is this fact in connection with the development of the plant kingdom that its general nature must be clearly understood. Probably the clearest definition may be obtained by tracing in bare outline the life history of an ordinary moss.

Beginning with the asexual spore, which is not ciliated, as there is no water in which it can swim, we may imagine that it has been carried by the wind to some spot suitable for its germination. It develops a branching filamentous growth which resembles some of the Conferva forms among the Green Algæ (Fig. 275). It is prostrate, and is a regular thallus body, not at all resembling the "moss plant" of ordinary observation, and is not noticed by those unaware of its existence.

Presently one or more buds appear on the sides of this alga-like body (Fig. 275, *b*). A bud develops into an erect

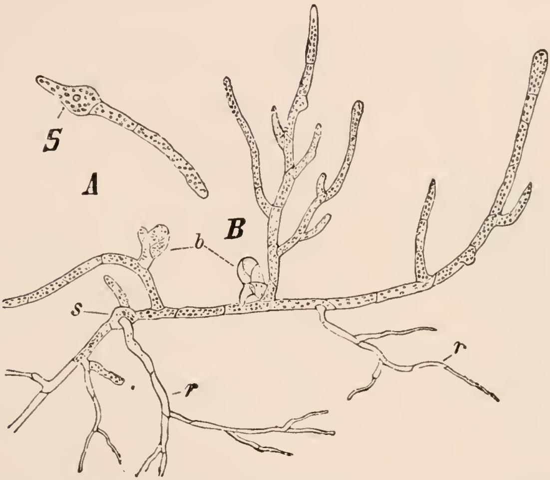


FIG. 275. Protonema of moss: *A*, very young protonema, showing spore (*S*) which has germinated it; *B*, older protonema, showing branching habit, remains of spore (*s*), rhizoids (*r*), and buds (*b*) of leafy branches (gametophores).—After MÜLLER and THURGAU.

stalk upon which are numerous small leaves (Figs. 276, 290). This leafy stalk is the "moss plant" of ordinary observation, and it will be noticed that it is simply an erect leafy branch from the prostrate alga-like body.

At the top of this leafy branch sex-organs appear, corresponding to the antheridia and oogonia of the Algæ, and within them there are sperms and eggs. A sperm and egg fuse and an oospore is formed at the summit of the leafy branch.

The oospore is not a resting spore, but germinates immediately, forming a structure entirely unlike the moss

FIG. 276. A common moss (*Polytrichum commune*), showing the leafy gametophore with rhizoids (*rh*), and two sporophytes (sporogonia), with seta (*s*), calyptra (*c*), and operculum (*d*), the calyptra having been removed.—After SCHENCK.

plant from which it came. This new leafless body consists of a slender stalk bearing at its summit an urnlike case in which are developed numerous asexual spores (Figs. 276, 292). This whole structure is often called the "spore fruit," and its stalk is imbedded at base in the summit of the leafy branch, thus obtaining firm anchorage and absorbing what nourishment it needs, but no more a part of the leafy branch than is a parasite a part of the host.

When the asexual spores, produced by the "spore fruit," germinate, they reproduce the alga-like body with which we began, and the life cycle is completed.

In examining this life history, it is apparent that each spore produces a different structure. The asexual spore produces the alga-like body with its erect leafy branch, while the oospore produces the "spore fruit" with its leafless stalk and spore case. These two structures, one produced by the asexual spore, the other by the oospore, appear in alternating succession, and this is what is meant by *alternation of generations*.

These two "generations" differ strikingly from one another in the spores which they produce. The generation composed of alga-like body and erect leafy branch produces only sexual spores (oospores), and therefore produces sex organs and gametes. It is known, therefore, as the *gametophyte*—that is, "the gamete plant."

The generation which consists of the "spore fruit"—that is, leafless stalk and spore case—produces only asexual spores, and is called the *sporophyte*—that is, "the spore plant."

The relation between the two alternating generations may be indicated clearly by the following formula, in which G and S are used for gametophyte and sporophyte respectively:

$$G \equiv {}^{o}_{o} > o—S—o—G \equiv {}^{o}_{o} > o—S—o—G, \text{ etc.}$$

The formula indicates that the gametophyte produces two gametes (sperm and egg), which fuse to form an oospore, which produces the sporophyte, which produces an asexual spore, which produces a gametophyte, etc.

In reference to the sporophytes and gametophytes of Bryophytes two peculiarities may be mentioned at this point: (1) the sporophyte is dependent upon the gametophyte for its nourishment, and remains attached to it; (2) the gametophyte is the special chlorophyll-generation, and hence is the more conspicuous.

If the ordinary terms in reference to Mosses be fitted to the facts given above, it is evident that the "moss plant" is the leafy branch of the gametophyte; that the "moss fruit" is the sporophyte; and that the alga-like part of the gametophyte has escaped attention and a common name.

The names now given to the different structures which appear in this life history are as follows: The alga-like part of the gametophyte is the *protonema*, the leafy branch is the *gametophore* ("gamete-bearer"); the whole sporophyte is the *sporogonium* (a name given to this peculiar leafless sporophyte of Bryophytes), the stalk-like portion is the *seta*, the part imbedded in the gametophore is the *foot*, and the urn-like spore-case is the *capsule*.

198. **The antheridium.**—The male organ of the Bryophytes is called an antheridium, just as among Thallophytes, but it has a very different structure. In general among the

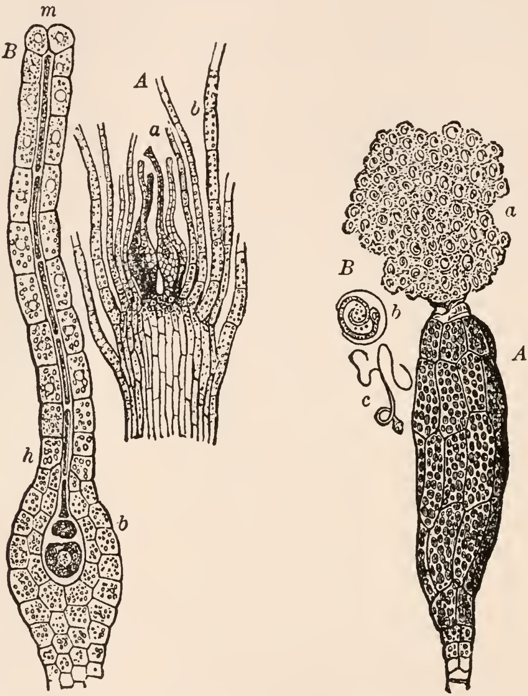


FIG. 277. Sex organs of a common moss (*Funaria*): the group to the right represents an antheridium (*A*) discharging from its apex a mass of sperm mother cells (*a*), a single mother cell with its sperm (*b*), and a single sperm (*c*), showing body and two cilia; the group to the left represents an archegonial cluster at summit of stem (*A*), showing archegonia (*a*), and paraphyses and leaf sections (*b*), and also a single archegonium (*B*), with venter (*b*) containing egg and ventral canal cell, and neck (*h*) containing the disorganizing axial row (neck canal cells).—After SACHS.

Thallophytes it is a single cell (mother cell), and may be called a simple antheridium, but in the Bryophytes it is a many-celled organ, and may be regarded as a compound antheridium. It is usually a stalked, club-shaped, or oval to globular body (Figs. 277, 278). A section through this body shows it to consist of a single layer of cells, which forms the wall of the antheridium, and within this a compact mass of small cubical (square in section) cells, within each one of which there is formed a single sperm (Fig. 278). The sperm is a very small cell with two long cilia (Fig. 277). These small biciliate sperms are one of the distinguishing marks of the Bryophytes. When the mature antheridia are wet they are opened at the apex and discharge their contents (Fig. 277), and the sperms escaping swim actively about.

FIG. 278. Antheridium of a liverwort in section, showing single layer of wall cells surrounding the mass of mother cells.—After STRASBURGER.

199. **The archegonium.**—This name is given to the female sex organ, which is a many-celled structure, shaped like a flask (Figs. 277, 287). The neck of the flask is more or less elongated, and within the bulbous base (*venter*) the single egg is organized. To this neck the swimming sperms are attracted, enter and pass down it, one of them fuses with the egg, and this act of fertilization results in an oospore.

200. **Germination of the oospore.**—The oospore in Bryophytes is not a resting spore, but germinates immediately by cell division, forming the sporophyte embryo, which presently develops into the mature sporophyte (Fig. 279, *A*). The lower part of the embryo develops the foot, which obtains a firm anchorage in the gametophore by the latter growing up around it (Fig. 279, *B*, *C*). The upper part of the embryo develops upward, organizing the seta and capsule. As the embryo increases in size, the venter of the archegonium grows also, forming what is called the *calyptra*; and in true mosses the embryo presently breaks loose the calyptra at its base and carries it upward perched on the top

of the capsule like a loose cap or hood (Fig. 276, *c*), which sooner or later falls off. As stated before, the mature structure developed from the oospore or egg is called a sporogonium, a form of sporophyte peculiar to the Bryophytes.

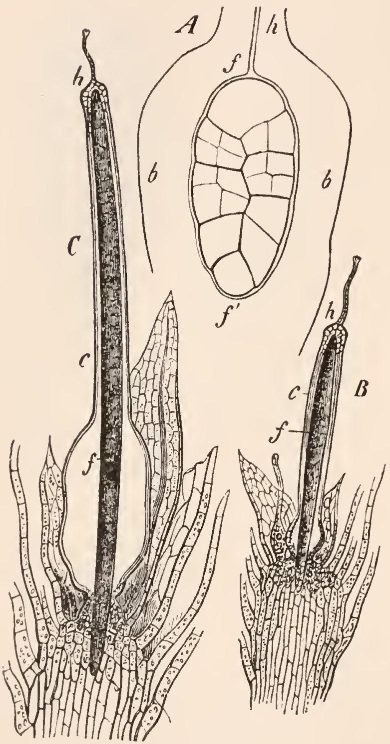


Fig. 279. Sporogonium of *Funaria*: *A*, an embryo sporogonium (f, f'), developing within the venter (b, b) of an archegonium; *B*, *C*, tips of leafy shoots bearing young sporogonia, pushing up calyptra (c) and archegonium neck (h), and the foot becoming imbedded in the apex of the gametophore.—After Goebel.

201. **The sporogonium.**—In its fullest development the sporogonium is differentiated into the three regions, foot, seta, and capsule (Fig. 276); but in some forms the seta may be lacking, and in others the foot also, the sporogonium in this last case being only the capsule or spore case, which, after all, is the essential part of any sporogonium.

At first the capsule is solid, and its cells are all alike. Later a group of cells within begins to differ in appearance from those about them, being set apart for the production of spores. This initial group of spore-producing cells is called the *archesporium*, a word meaning "the beginning of spores."

The archesporium forms new cells, and the last ones formed are mother cells, in each one of which four spores are organized, the group of four being called a *tetrad.* Among Bryophytes and the higher groups asexual spores are always produced in tetrads.

After the spores are formed the walls of the mother cells disorganize, and the spores are left lying loose in a cavity which was formerly occupied by the sporogenous tissue. All mother cells do not always organize spores. In some cases some of them are used up in supplying nourishment to those which form spores. In other cases, certain mother cells become much modified in form, being organized into elongated, spirally-banded cells called *elaters* (Fig. 286), meaning "drivers" or "hurlers." These elaters lie among the loose ripe spores, are discharged with them, and by their jerking movements assist in scattering them.

The sporogonium is a very important structure from the standpoint of evolution, for it represents the conspicuous part of the higher plants. The "fern plant," and the herbs, shrubs, and trees among "flowering plants," correspond to the sporogonium of Bryophytes, and not to the leafy branch (gametophore) or "moss plant."

CHAPTER XX

THE GREAT GROUPS OF BRYOPHYTES

Hepaticæ (*Liverworts*)

202. **General character.**—Liverworts live in a variety of conditions, some floating on the water, many in damp places, and many on the bark of trees. In general they are moisture-loving plants (hydrophytes), though some can endure great dryness. The gametophyte body is prostrate, though there may be erect and leafless gametophores.

This prostrate habit develops a *dorsiventral* body—that is, one whose two surfaces (*dorsal* and *ventral*) are exposed to different conditions and become unlike in structure. In Liverworts the ventral surface is against the substratum, and puts out hair-like processes (*rhizoids*) for anchorage and possibly absorption. The dorsal region is exposed to the light and its cells develop chlorophyll. If the thallus is thin, chlorophyll is developed in all the cells; if it be so thick that the light is cut off from the ventral cells, the thallus is differentiated into a green dorsal region doing the chlorophyll work, and a colorless ventral region producing anchoring rhizoids. This latter represents a simple differentiation of the nutritive body into working regions, the ventral region absorbing material and conducting it to the green dorsal cells which use it in making food.

There seem to have been at least three main lines of development among Liverworts, each beginning in forms with a very simple thallus, and developing in different directions. They are briefly indicated as follows:

203. **Marchantia forms.**—In this line the simple thallus gradually becomes changed into a very complex one. The thallus retains its simple outlines, but becomes thick and differentiated in *tissues* (groups of similar cells). The line may be distinguished, therefore, as one in which the differentiation of the tissues of the gametophyte is emphasized (Figs. 280–282). In *Marchantia* proper the thallus becomes very complex, and it may be taken as an illustration.

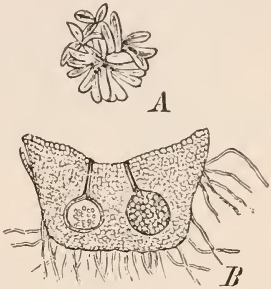


FIG. 280. A very small species of *Riccia*, one of the Marchantia forms: *A*, a group of thallus bodies slightly enlarged; *B*, section of a thallus, showing rhizoids and two sporogonia imbedded and communicating with the outside by tubular passages in the thallus.—After STRASBURGER.

The thallus is so thick that there are very distinct green dorsal and colorless ventral regions (Fig. 283). The latter puts out numerous rhizoids and scales from the single layer of epidermal cells. Above the ventral epidermis are several layers of colorless

FIG. 281. *Ricciocarpus*, a Marchantia form, showing numerous rhizoids from ventral surface, the dichotomous branching, and the position of the sporogonia on the dorsal surface along the "midribs."—GOLDBERGER.

FIG. 282. Two common liverworts: to the left is *Conocephalus*, a Marchantia form, showing rhizoids, dichotomous branching, and the conspicuous rhombic areas (areolæ) on the dorsal surface; to the right is *Anthoceros*, with its simple thallus and pod-like sporogonia.—GOLDBERGER.

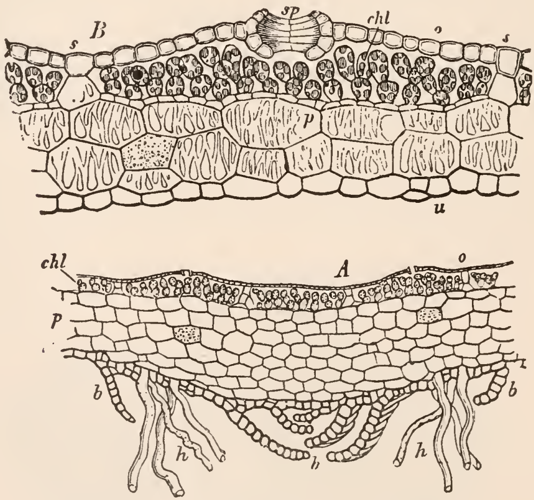


FIG. 283. Cross-sections of thallus of *Marchantia*: *A*, section from thicker part of thallus, where supporting tissue (*p*) is abundant, and showing lower epidermis giving rise to rhizoids (*h*) and plates (*b*), also chlorophyll tissue (*chl*) organized into chambers by partitions (*o*); *B*, section near margin of thallus more magnified, showing lower epidermis, two layers of supporting tissue (*p*) with reticulate walls, a single chlorophyll chamber with its bounding walls (*s*) and containing short, often branching filaments whose cells contain chloroplasts (*chl*), overarching upper epidermis (*o*) pierced by a large chimney-like air-pore (*sp*).—After GOEBEL.

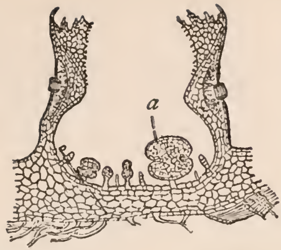


Fig. 284. Section through cupule of *Marchantia*, showing wall in which are chlorophyll-bearing air-chambers with air-pores, and gemmæ (*a*) in various stages of development.—After Dodel-Port.

Fig. 285. *Marchantia polymorpha*: the lower figure represents a gametophyte bearing a mature antheridial branch (*d*), some young antheridial branches, and also some cupules with toothed margins, in which the gemmæ may be seen; the upper figure represents a partial section through the antheridial disk, and shows antheridia within the antheridial cavities (*a, b, c, d, e, f*).—After Kny.

cells more or less modified for conduction. Above these the dorsal region is organized into a series of large air chambers, into which project chlorophyll-containing cells in the

Fig. 286. *Marchantia polymorpha*, a common liverwort: *1*, thallus, with rhizoids, bearing a mature archegonial branch (*f*) and several younger ones (*a*, *b*, *c*, *d*, *e*); *2* and *3*, dorsal and ventral views of archegonial disk; *4* and *5*, young sporophyte (sporogonium) embryos; *6*, more mature sporogonium still within enlarged venter of archegonium; *7*, mature sporogonium discharging spores; *8*, three spores and an elater.—After Kny.

form of short branching filaments. Overarching the air chambers is the dorsal epidermis, and piercing through it into each air chamber is a conspicuous air pore (Fig. 283, *B*).

The air chambers are outlined on the surface as small rhombic areas (*areolæ*), each containing a single air pore.

Peculiar reproductive bodies are also developed upon the dorsal surface of *Marchantia* for vegetative multiplica-

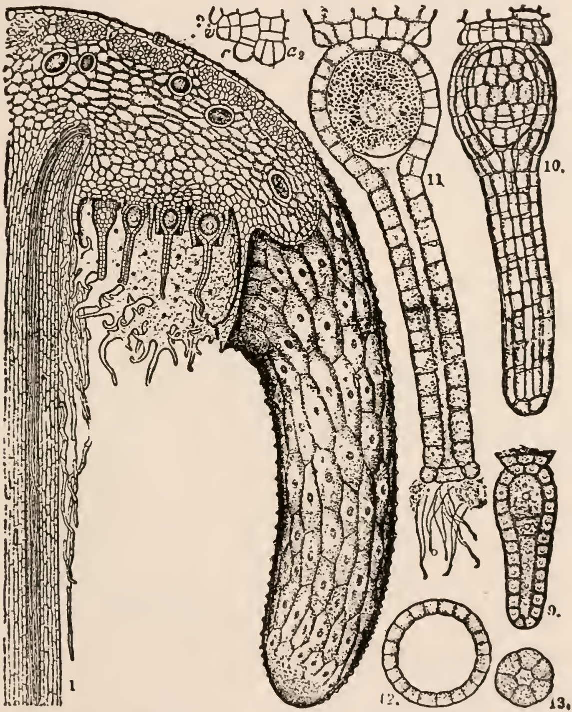


FIG. 287. *Marchantia polymorpha*: *1*, partial section through archegonial disk, showing archegonia with long necks, and venters containing eggs; *9*, young archegonium showing axial row; *10*, superficial view at later stage; *11*, mature archegonium, with axial row disorganized and leaving an open passage to the large egg; *12*, cross-section of venter; *13*, cross-section of neck.—After KNY.

tion. Little cups (*cupules*) appear, and in them are numerous short-stalked bodies (*gemmæ*), which are round and flat (biscuit-shaped) and many-celled (Figs. 284, 285). The gemmæ fall off and develop new thallus bodies, making rapid multiplication possible. *Marchantia* also possess remarkably prominent gametophores, or "sexual branches" as they are often called. In this case the gametophores are differentiated, one bearing only antheridia (Fig. 285), and known as the "antheridial branch," the other bearing only archegonia (Figs. 286, 287), and known as the "archegonial branch." The scalloped antheridial disk and the star-shaped archegonial disk, each borne up by the stalk-like gametophore, are seen in the illustrations.

204. **Jungermannia forms.**—This is the greatest line of the Liverworts, the forms being much more numerous than in the other lines. They grow in damp places; or in drier

FIG. 288. Two liverworts, both Jungermannia forms: to the left is *Blasia*, which retains the thallus forms but has lobed margins; to the right is *Scapania*, with distinct leaves and sporogonia (*A*).—GOLDBERGER.

situations on rocks, ground, or tree-trunks; or in the tropics also on the leaves of forest plants. They are generally delicate plants, and resemble small Mosses, many of them doubtless being commonly mistaken for Mosses (Fig. 288).

In this line the thallus gradually passes into bodies organized into a central stem-like axis bearing two rows of small, often crowded leaves. In consequence of this such *Jungermannia* forms are usually called "leafy liverworts," to distinguish them from the other Liverworts, which are "thallose." They are also often called "scale mosses," on account of their moss-like appearance and their small scale-like leaves.

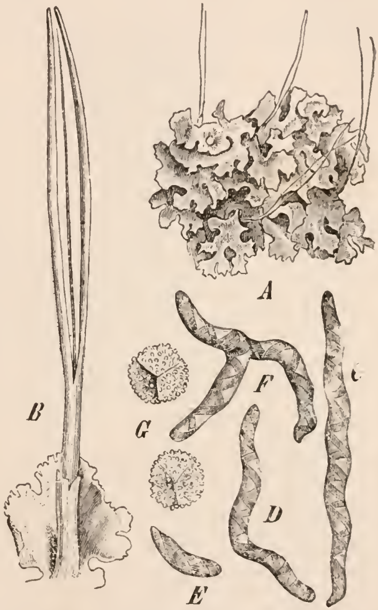


FIG. 289. *Anthoceros gracilis*: *A*, several gametophytes, on which sporogonia have developed; *B*, an enlarged sporogonium, showing its elongated character and dehiscence by two valves leaving exposed the slender columella on the surface of which are the spores; *C*, *D*, *E*, *F*, elaters of various forms; *G*, spores.—After SCHIFFNER.

205. **Anthoceros forms.**—This line contains comparatively few forms, but they are of great interest, as they are supposed to represent forms which have given rise to the Mosses, and possibly to the Pteridophytes also. The thallus is very simple, being differentiated neither in structure nor form, as in the two other lines; but the special development has been in connection with the sporogonium (Figs. 282, 289). This complex sporogonium (sporophyte) has a large bulbous foot imbedded in the simple thallus, while above there arises a long pod-like capsule.

The chief direction of the development of the three liverwort lines may be summed up briefly as follows: The *Marchantia* line has differentiated the structure of the gametophyte; the *Jungermannia* line has differentiated the form of the gametophyte; the *Anthoceros* line has differentiated the structure of the sporophyte. It should be remembered that other characters also serve to distinguish the lines from one another.

MUSCI (*Mosses*)

206. **General character.**—Mosses are highly specialized plants, probably derived from Liverworts, the numerous forms being adapted to all conditions, from submerged to very dry, being most abundantly displayed in temperate and arctic regions. Many of them may be dried out completely and then revived in the presence of moisture, as is true of many Lichens and Liverworts, with which forms Mosses are very commonly associated.

They also have great power of vegetative multiplication, new leafy shoots putting out from old ones and from the protonema indefinitely, thus forming thick carpets and masses. Bog mosses often completely fill up bogs or small ponds and lakes with a dense growth, which dies below and continues to grow above as long as the conditions are favorable. These quaking bogs or "mosses," as they are sometimes called, furnish very treacherous footing unless rendered firmer by other plants. In these moss-filled bogs the water shuts off the lower strata of moss from complete disorganization, and they become modified into a coaly substance called *peat*, which may accumulate to considerable thickness by the continued upward growth of the mass of moss.

The gametophyte body is differentiated into two very distinct regions: (1) the prostrate dorsiventral thallus, which is called protonema in this group, and which may be either a broad flat thallus or a set of branching filaments (Figs. 275, 290); (2) the erect leafy branch or gametophore (Fig. 276). This erect branch is said to be *radial*, in contrast with the dorsiventral thallus, referring to the fact that it is exposed to similar conditions all around, and its organs are arranged about a central axis like the parts of a radiate animal. This position is much more favorable for the chlorophyll work than the dorsiventral position, as the special chlorophyll organs (leaves) can be spread out to the light freely in all directions.

The leafy branch of the Mosses usually becomes independent of the thallus by putting out rhizoids at its base (Fig. 290), the thallus part dying. Sometimes, however, the filamentous protonema is very persistent, and gives rise to a perennial succession of leafy branches.

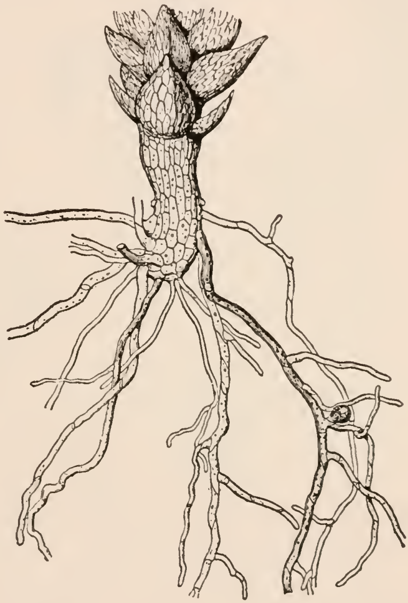


FIG. 290. A moss (*Bryum*), showing base of a leafy branch (gametophore) attached to the protonema, and having sent out rhizoids. On the protonemal filament to the right and below is the young bud of another leafy branch. —MÜLLER.

At the summit of the leafy gametophore, either upon the main axis or upon a lateral branch, the antheridia and archegonia are borne (Fig. 277). Often the leaves at the summit become modified in form and arranged to form a rosette, in the center of which are the sex organs. This rosette is often called the "moss flower," but it holds no relation to the flower of Seed-plants, and the phrase should not be used. A rosette may contain but one kind of sex organ (Fig. 277), or it may contain both kinds, for Mosses are both diœcious and monœcious. The two principal groups are as follows:

207. **Sphagnum forms.**—These are large and pallid bog mosses, found abundantly in marshy ground, especially of temperate and arctic regions, and are conspicuous peat-

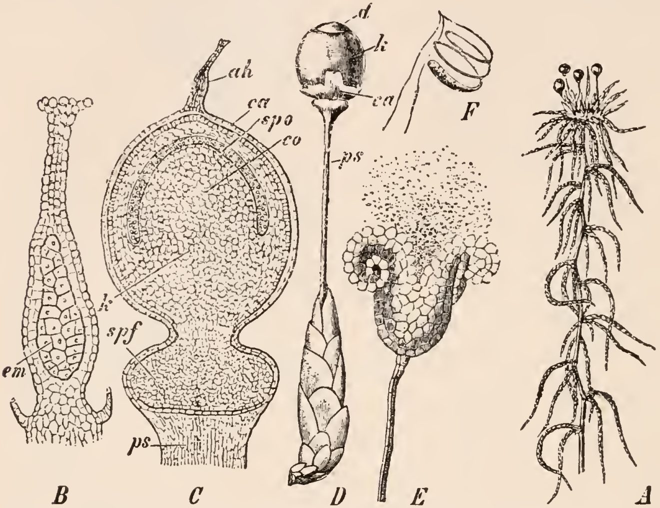


FIG. 291. *Sphagnum:* *A*, a leafy branch (gametophore) bearing four mature sporogonia; *B*, archegonium in whose venter a young embryo sporophyte (*em*) is developing; *C*, section of a young sporogonium (sporophyte), showing the bulbous foot (*spf*) imbedded in the apex of the pseudopodium (*ps*), the capsule (*k*), the columella (*co*) capped by the dome-shaped archesporium (*spo*), a portion of the calyptra (*ca*), and the old archegonium neck (*ah*); *D*, branch bearing mature sporogonium and showing pseudopodium (*ps*), capsule (*k*), and operculum (*d*); *E*, antheridium discharging sperms; *F*, a single sperm, showing coiled body and two cilia.—After SCHIMPER.

formers (Fig. 291). The leaves and gametophore axis are of peculiar structure to enable them to suck up and hold a large amount of water. This abundant water-storage tissue and the comparatively poor display of chlorophyll-containing cells gives the peculiar pallid appearance.

208. **True Mosses.**—This immense and most highly organized Bryophyte group contains the great majority of the

Mosses, which are sometimes called the *Bryum* forms, to distinguish them from the *Sphagnum* forms. They are the representative Bryophytes, the only group vying with them being the leafy Liverworts, or *Jungermannia* forms. They grow in all conditions of moisture, from actual submergence in water to dry rocks, and they also form extensive peat deposits in bogs.

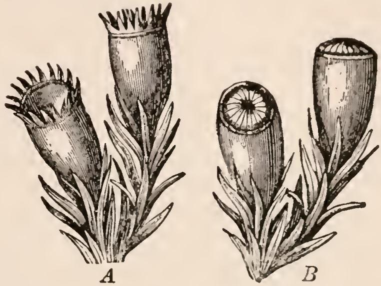


Fig. 292. Sporogonia of *Grimmia*, from all of which the operculum has fallen, displaying the peristome teeth: *A*, position of the teeth when dry; *B*, position when moist.—After Kerner.

The sporogonium has a foot and usually a long slender seta, but the capsule is especially complex. When the lid-like operculum falls off, the capsule is left like an urn full of spores, and at the mouth of the urn there is usually displayed a set of slender, often very beautiful teeth (Fig. 292), converging from the circumference toward the center, and called the *peristome*, meaning "about the mouth." These teeth by bending inward and outward help to discharge the spores.

CHAPTER XXI

PTERIDOPHYTES (FERN PLANTS)

209. **Summary from Bryophytes.**—In introducing the Bryophytes a summary from the Thallophytes was given (see § 60), indicating certain important things which that group has contributed to the evolution of the plant kingdom. In introducing the Pteridophytes it is well to notice certain important additions made by the Bryophytes.

(1) *Alternation of generations.*—The great fact of alternating sexual (gametophyte) and sexless (sporophyte) generations is first clearly expressed by the Bryophytes, although its beginnings are to be found among the Thallophytes. Each generation produces one kind of spore, from which is developed the other generation.

(2) *Gametophyte the chlorophyll generation.*—On account of this fact the food is chiefly manufactured by the gametophyte, which is therefore the more conspicuous generation. When a moss or a liverwort is spoken of, therefore, the gametophyte is usually referred to.

(3) *Gametophyte and sporophyte not independent.*—The sporophyte is mainly dependent upon the gametophyte for its nutrition, and remains attached to it, being commonly called the sporogonium, and its only function is to produce spores.

(4) *Differentiation of thallus into stem and leaves.*—This appears incompletely in the leafy Liverworts (*Jungermannia* forms) and much more clearly in the erect and radial leafy branch (gametophore) of the Mosses.

(5) *Many-celled sex organs.*—The antheridia and the flask-shaped archegonia are very characteristic of Bryophytes as contrasted with Thallophytes.

210. **General characters of Pteridophytes.**—The name means "fern plants," and the Ferns are the most numerous and the most representative forms of the group. Associated with them, however, are the Horsetails (Scouring rushes) and the Club-mosses. By many the Pteridophytes are thought to have been derived from such Liverworts as the *Anthoceros* forms, while some think that they may possibly have been derived directly from the Green Algæ. Whatever their origin, they are very distinct from Bryophytes.

One of the very important facts is the appearance of the vascular system, which means a "system of vessels," organized for conducting material through the plant body. The appearance of this system marks some such epoch in the evolution of plants as is marked in animals by the appearance of the "backbone." As animals are often grouped as "vertebrates" and "invertebrates," plants are often grouped as "vascular plants" and "non-vascular plants," the former being the Pteridophytes and Spermatophytes, the latter being the Thallophytes and Bryophytes. Pteridophytes are of great interest, therefore, as being the first vascular plants.

211. **Alternation of generations.**—This alternation continues in the Pteridophytes, but is even more distinct than in the Bryophytes, the gametophyte and sporophyte becoming independent of one another. An outline of the life history of an ordinary fern will illustrate this fact, and will serve also to point out the prominent structures. Upon the lower surface of the leaves of an ordinary fern dark spots or lines are often seen. These are found to yield spores, with which the life history may be begun.

When such a spore germinates it gives rise to a small, green, heart-shaped thallus, resembling a delicate and simple liverwort (Fig. 293, *A*). Upon this thallus antheridia and archegonia appear, so that it is evidently a gametophyte. This gametophyte escapes ordinary attention, as it is usually very small, and lies prostrate upon the substratum. It has received the name *prothallium* or *prothallus,* so that when the term prothallium is used the gametophyte of Pteridophytes is generally referred to; just as when the term sporogonium is used the sporophyte of the Bryophytes is referred to. Within an archegonium borne upon this little prothallium an oospore is formed. When the oospore ger-

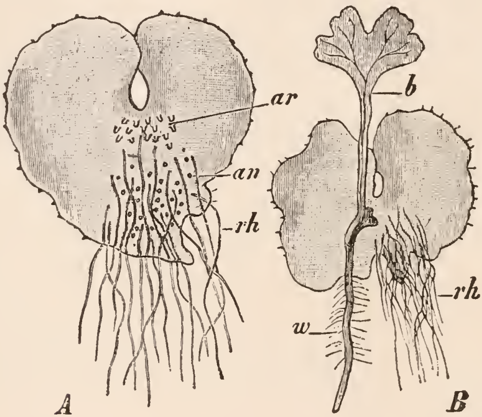


FIG. 293. Prothallium of a common fern (*Aspidium*): *A*, ventral surface, showing rhizoids (*rh*), antheridia (*an*), and archegonia (*ar*); *B*, ventral surface of an older gametophyte, showing rhizoids (*rh*) and young sporophyte with root (*w*) and leaf (*b*).—After SCHENCK.

minates it develops the large leafy plant ordinarily spoken of as "the fern," with its subterranean stem, from which roots descend, and from which large branching leaves rise above the surface of the ground (Fig. 293, *B*). It is in this complex body that the vascular system appears. No sex organs are developed upon it, but the leaves bear numerous sporangia full of asexual spores. This complex vascular plant, therefore, is a sporophyte, and corresponds in this life history to the sporogonium of the Bryophytes. This completes the life cycle, as the asexual spores develop the prothallium again.

In contrasting this life history with that of Bryophytes several important differences are discovered. The most striking one is that the sporophyte has become a large, leafy, vascular, and independent structure, not at all resembling its representative (the sporogonium) among the Bryophytes.

Also the gametophyte has become much reduced, as compared with the gametophytes of the larger Liverworts and Mosses. It seems to have resumed the simplest liverwort form.

212. **The gametophyte.**—The prothallium, like a simple liverwort, is a dorsiventral body, and puts out numerous

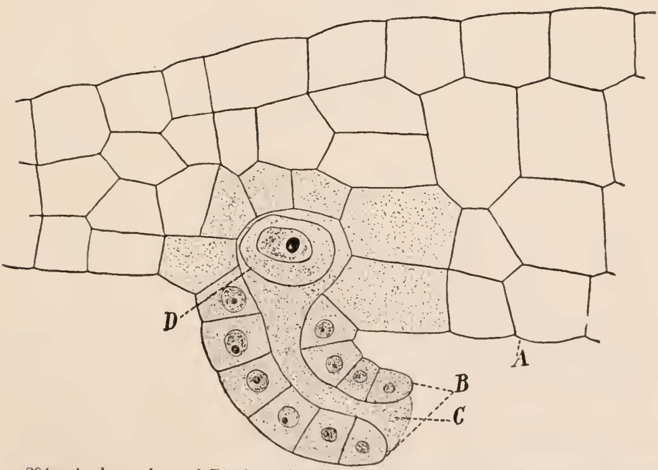


FIG. 294. Archegonium of *Pteris* at the time of fertilization, showing tissue of gametophyte (*A*), the cells forming the neck (*B*), the passageway formed by the disorganization of the canal cells (*C*), and the egg (*D*) lying exposed in the venter. —CALDWELL.

rhizoids from its ventral surface (Fig. 293). It is so thin that all the cells contain chlorophyll, and it is usually short-lived.

At the bottom of the conspicuous notch in the prothallium is the growing point, representing the apex of the plant. This notch is always a conspicuous feature.

The antheridia and archegonia are usually developed on the under surface of the prothallium (Fig. 293, *A*), and differ from those of all Bryophytes, except the *Anthoceros* forms, in being sunk in the tissue of the prothallium and opening on the surface, more or less of the neck of the archegonium projecting (Fig. 294). The eggs are not different from those formed within the archegonia of Bryo-

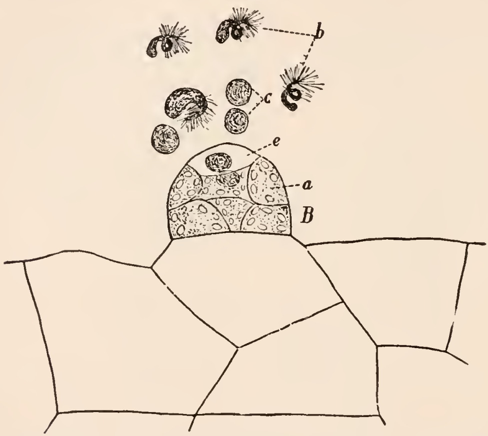


FIG. 295. Antheridium of *Pteris* (*B*), showing wall cells (*a*), opening for escape of sperm mother cells (*e*), escaped mother cells (*c*), sperms free from mother cells (*b*), showing spiral and multiciliate character.—CALDWELL.

phytes, but the sperms are very different. The Bryophyte sperm has a small body and two long cilia, while the Pteridophyte sperm has a long spirally coiled body, blunt behind and tapering to a point in front, where numerous cilia are developed (Fig. 295). It is, therefore, a large, spirally coiled, multiciliate sperm, and is quite characteristic of all Pteridophytes excepting the Club-mosses.

When the prothallia are developing the antheridia begin to appear very early, and later the archegonia. If the prothallium is poorly nourished, only antheridia appear; it needs to be well developed and nourished to develop archegonia. There seems to be a very definite relation, therefore, between nutrition and the development of the two sex organs, a fact which must be remembered in connection with certain later developments.

213. **The sporophyte.**—This complex body is differentiated into root, stem, and leaf, and is more highly organized than any plant body heretofore mentioned (Fig. 296).

In most of the Ferns the stem is subterranean and dorsiventral (Fig. 296), but in the "tree ferns" of the tropics it forms an erect, aërial shaft bearing a crown of leaves (Fig. 297). In the other groups of Pteridophytes there are also aërial stems, both erect and prostrate. The stem is complex in structure, the cells being organized into different "tissue systems," prominent among which is the vascular system.

One of the peculiarities of ordinary fern leaves is that the vein system of the leaves branches dichotomously, the forking veins being very conspicuous (Fig. 298). Another fern habit is that the leaves in expanding seem to unroll from the base, as though they had been rolled from the apex downward, the apex being in the centre of the roll (Fig. 296). This habit is spoken of as *circinate*, from a word meaning "circle" or "coil," and circinate leaves when unrolling have a crozier-like tip. The arrangement of leaves in bud is called *vernation* ("spring condition"), and therefore the Ferns are said to have circinate vernation. The combination of dichotomous venation and circinate vernation is very characteristic of Ferns.

214. **Sporangia.**—The sporangia are borne by the leaves, generally upon the under surface, and are usually closely associated with the veins, and organized into groups of definite form known as *sori*. A sorus may be round or elon-

Fig. 296. A fern (*Aspidium*), showing three large branching leaves coming from a horizontal subterranean stem (rootstock); young leaves are also shown, which show circinate vernation. The stem, young leaves, and petioles of the large leaves are thickly covered with protecting hairs. The stem gives rise to numerous small roots from its lower surface. The figure marked *3* represents the under surface of a portion of the leaf, showing seven sori with shield-like indusia; at *5* is represented a section through a sorus, showing the sporangia attached and protected by the indusium; while at *6* is represented a single sporangium opening and discharging its spores, the heavy annulus extending along the back and over the top.—After Wossidlo.

FIG. 297. A group of tropical plants. To the left of the center is a tree fern, with its slender columnar stem and crown of large leaves. The large-leaved plants to the right are bananas (monocotyledons).

gated, and is usually covered by a delicate flap (*indusium*) which arises from the epidermis (Fig. 296). Occasionally the sori are extended along the under surface of the margin of the leaf, as in maidenhair fern (*Adiantum*), and the common brake (*Pteris*), in which case they are protected by the inrolled margin (Fig. 298), which may be called a "false indusium."

It is evident that such leaves are doing two distinct kinds of work—chlorophyll work and spore formation. This is true of most of the ordinary Ferns, but some of them show a tendency to divide the work. Certain leaves, or certain leaf-branches, produce spores and do no chlorophyll work, while others do chlorophyll work and produce no spores. This differentiation in the leaves or leaf-regions is indicated by appropriate names. Those leaves which produce only spores are called *sporophylls*, meaning "spore leaves," while the leaf branches thus set apart are called sporophyll branches. Those leaves which only do chlorophyll work are called *foliage leaves;* and such branches are foliage branches. As sporophylls are not called upon for chlorophyll work they often become much modified, being much more compact, and not at all resembling the foliage leaves. Such a differentiation may be seen in the ostrich fern and sensitive fern (*Onoclea*) (Fig. 299), the climbing fern (*Lygodium*), the royal fern (*Osmunda*), the moonwort (*Botrychium*) (Fig. 300), and the adder's tongue (*Ophioglossum*).

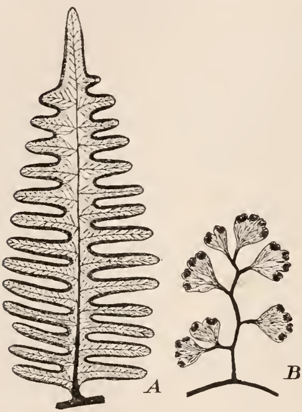


FIG. 298. Leaflets of two common ferns: *A*, the common brake (*Pteris*); *B*, maidenhair (*Adiantum*); both showing sori borne at the margin and protected by the infolded margin, which thus forms a false indusium.—CALDWELL.

FIG. 299. The sensitive fern (*Onoclea sensibilis*), showing differentiation of foliage leaves and sporophylls.—From "Field, Forest, and Wayside Flowers."

An ordinary fern sporangium consists of a slender stalk and a bulbous top which is the spore case (Fig. 296, *6*). This case has a delicate wall formed of a single layer of cells, and extending around it from the stalk and nearly to the stalk again, like a meridian line about a globe, is a row of peculiar cells with thick walls, forming a heavy ring, called the *annulus*. The annulus is like a bent spring, and when the delicate wall becomes yielding the spring straightens violently, the wall is torn, and in the recoil the spores are discharged with considerable force (Fig. 301). This discharge of fern spores may be seen by placing some sporangia upon a moist slide, and under a low power watching them as they dry and burst.

FIG. 300. A moonwort (*Botrychium*), showing the leaf differentiated into foliage and sporophyll branches. —After STRASBURGER.

215. **Heterospory.**—This phenomenon appears first among Pteridophytes, but it is not characteristic of them, being entirely absent from the true Ferns, which far outnumber all other Pteridophytes. Its chief interest lies in the fact that it is universal among the Spermatophytes, and that it represents the change which leads to the appearance of that high group. It is impossible to understand the greatest group of plants, therefore, without knowing something about heterospory. As it begins in simple fashion among Pteridophytes, and is probably the greatest contribution they have made to the evolution of the plant kingdom, unless it be the leafy sporophyte, it is best explained here.

In the ordinary Ferns all the spores in the sporangia are alike, and when they germinate each spore produces a prothallium upon which both antheridia and archegonia appear.

In some Pteridophytes, however, there is a decided difference in the size of the spores, some being quite small and

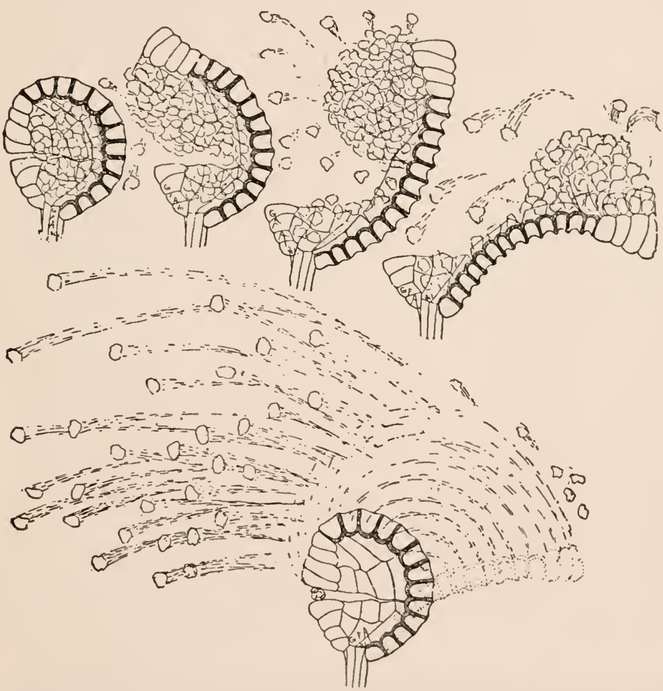


FIG. 301. A series showing the dehiscence of a fern sporangium, the rupture of the wall, the straightening and bending back of the annulus, and the recoil.—After ATKINSON.

others relatively large, the small ones producing male gametophytes (prothallia with antheridia), and the large ones female gametophytes (prothallia with archegonia). When asexual spores differ thus permanently in size, and give rise to gametophytes of different sexes, we have the condition called *heterospory* ("spores different"), and such plants are called *heterosporous* (Fig. 307). In contrast with heterosporous plants, those in which the asexual spores appear alike are called *homosporous*, or sometimes *isosporous*, both terms meaning "spores similar." The corresponding noun form is *homospory* or *isospory*. Bryophytes and most Pteridophytes are homosporous, while some Pteridophytes and all Spermatophytes are heterosporous.

It is convenient to distinguish by suitable names the two kinds of asexual spores produced by the sporangia of heterosporous plants (Fig. 307). The large ones are called *megaspores*, or by some writers *macrospores*, both terms meaning "large spores"; the small ones are called *microspores*, or "small spores." It should be remembered that megaspores always produce female gametophytes, and microspores male gametophytes.

This differentiation does not end with the spores, but soon involves the sporangia (Fig. 307). Some sporangia produce only megaspores, and are called *megasporangia;* others produce only microspores, and are called *microsporangia.* It is important to note that while microsporangia usually produce numerous microspores, the megasporangia produce much fewer megaspores, the tendency being to diminish the number and increase the size, until finally there are megasporangia which produce but a single large megaspore.

A formula may indicate the life history of a heterosporous plant. The formula of homosporous plants with alternation of generations (Bryophytes and most Pteridophytes) was given as follows (§ 197):

$$\mathrm{G}\begin{smallmatrix}-\mathrm{o}\\-\mathrm{o}\end{smallmatrix}>\mathrm{o}-\mathrm{S}-\mathrm{o}-\mathrm{G}\begin{smallmatrix}-\mathrm{o}\\-\mathrm{o}\end{smallmatrix}>\mathrm{o}-\mathrm{S}-\mathrm{o}-\mathrm{G}\begin{smallmatrix}-\mathrm{o}\\-\mathrm{o}\end{smallmatrix}>\mathrm{o}-\mathrm{S},\ \text{etc.}$$

In the case of heterosporous plants (some Pteridophytes and all Spermatophytes) it would be modified as follows:

$$\begin{smallmatrix}\mathrm{G}-\mathrm{o}\\\mathrm{G}-\mathrm{o}\end{smallmatrix}>\mathrm{o}-\mathrm{S}\begin{smallmatrix}-\mathrm{o}-\mathrm{G}-\mathrm{o}\\-\mathrm{o}-\mathrm{G}-\mathrm{o}\end{smallmatrix}>\mathrm{o}-\mathrm{S}\begin{smallmatrix}-\mathrm{o}-\mathrm{G}-\mathrm{o}\\-\mathrm{o}-\mathrm{G}-\mathrm{o}\end{smallmatrix}>\mathrm{o}-\mathrm{S},\ \text{etc.}$$

In this case two gametophytes are involved, one producing a sperm, the other an egg, which fuse and form the oospore, which in germination produces the sporophyte, which produces two kinds of asexual spores (megaspores and microspores), which in germination produce the two gametophytes again.

One additional fact connected with heterospory should be mentioned, and that is the great reduction of the gametophyte. In the homosporous ferns the spore develops a small but free and independent prothallium which produces both sex organs. When in heterosporous plants this work of producing sex organs is divided between two gametophytes they become very much reduced in size and lose their freedom and independence. They are so small that they do not escape entirely, if at all, from the embrace of the spores which produce them, and are mainly dependent for their nourishment upon the food stored up in the spores.

CHAPTER XXII

THE GREAT GROUPS OF PTERIDOPHYTES

216. **The great groups.**—At least three independent lines of Pteridophytes are recognized: (1) *Filicales* (Ferns), (2) *Equisetales* (Scouring rushes, Horsetails), and (3) *Lycopodiales* (Club-mosses). The Ferns are much the most abundant, the Club-mosses are represented by a few hundred forms, while the Horsetails include only about twenty-five species. These three great groups are so unlike that they hardly seem to belong together in the same division of the plant kingdom.

Filicales (*Ferns*)

217. **General characters.**—The Ferns were used in the preceding chapter as types of Pteridophytes, so that little need be added. They well deserve to stand as types, as they contain about four thousand of the four thousand five hundred species belonging to Pteridophytes. Although found in considerable numbers in temperate regions, their chief display is in the tropics, where they form a striking and characteristic feature of the vegetation. In the tropics not only are great masses of the low forms to be seen, from those with delicate and filmy moss like leaves to those with huge leaves, but also tree forms with cylindrical trunks encased by the rough remnants of fallen leaves and sometimes rising to a height of thirty-five to forty-five feet, with a great crown of leaves fifteen to twenty feet long (Fig. 297).

FIG. 302. A bank of ferns (*Osmunda Claytoniana*).—CALDWELL.

There are also *epiphytic* forms (air plants)—that is, those which perch "upon other plants" but derive no nourishment from them (Fig. 95). This habit belongs chiefly to the warm and moist tropics, where the plants can absorb sufficient moisture from the air without sending roots into the soil. In this way many of the tropical ferns are found growing upon living and dead trees and other plants. In the temperate regions the chief epiphytes are Lichens, Liverworts, and Mosses, the Ferns being chiefly found in moist woods and ravines (Fig. 302), although a number grow in comparatively dry and exposed situations, sometimes covering extensive areas, as the common brake (*Pteris*).

The Filicales differ from the other groups of Pteridophytes chiefly in having few large leaves, which do chlorophyll work and bear sporangia. In a few of them there is a differentiation of functions in foliage branches and sporophyll branches (Figs. 299, 300), but even this is exceptional. Another distinction is that the stems are unbranched.

218. **Origin of sporangia.**—An important feature in the Ferns is the origin of the sporangia. In some of them a sporangium is developed from a single epidermal cell of the leaf, and is an entirely superficial and generally stalked affair (Fig. 296, *5*); in others the sporangium in its development involves several epidermal and deeper cells of the leaf, and is more or less of an imbedded affair. In the first case the ferns are said to be *leptosporangiate;* in the second case they are *eusporangiate.*

Another small but interesting group of Ferns includes the "Water-ferns," floating forms or sometimes on muddy flats. The common *Marsilia* may be taken as a type (Fig. 303). The slender creeping stem sends down numerous roots into the mucky soil, and at intervals gives rise to a comparatively large leaf. This leaf has a long erect petiole and a blade of four spreading wedge-shaped leaflets like a "four-leaved clover." The dichotomous venation and circinate vernation at once suggest the fern alliance. From near the base of the petiole another leaf branch arises, in which the blade is modified as a sporophyll. In this case the sporophyll incloses the sporangia and becomes hard and nutlike. Another common form is the

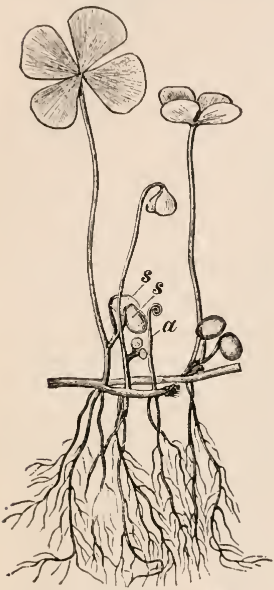


FIG. 303. A water-fern (*Marsilia*), showing horizontal stem, with descending roots, and ascending leaves; *a*, a young leaf showing circinate vernation; *s*, *s*, sporophyll branches ("sporocarps").—After BISCHOFF.

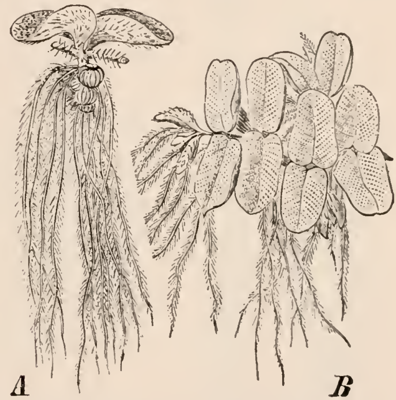


FIG. 304. One of the floating water-ferns (*Salvinia*), showing side view (*A*) and view from above (*B*). The dangling root-like processes are the modified submerged leaves. In *A*, near the top of the cluster of submerged leaves, some sporophyll branches ("sporocarps") may be seen.—After BISCHOFF.

floating *Salvinia* (Fig. 304). The chief interest lies in the fact that the water-ferns are heterosporous. As they are leptosporangiate they are thought to have been derived from the ordinary leptosporangiate Ferns, which are homosporous.

EQUISETALES (*Horsetails or Scouring rushes*)

219. **General characters.**—The twenty-five forms now representing this great group belong to a single genus (*Equise-*

tum, meaning "horsetail"), but they are but the lingering remnants of an abundant flora which lived in the time of the Coal-measures, and helped to form the forest vegetation. The living forms are small and inconspicuous, but very characteristic in appearance. They grow in moist or dry places, sometimes in great abundance (Fig. 305).

The stem is slender and conspicuously jointed, the joints separating easily; it is also green, and fluted with small longitudinal ridges; and there is such an abundant deposit of silica in the epidermis that the plants feel rough. This last property suggested its former use in scouring, and its name "scouring rush." At each joint is a sheath of minute leaves, more or less coalesced, the individual leaves sometimes being indicated only by minute teeth. This arrangement of leaves in a circle about the joint is called the *cyclic* arrangement, or sometimes the *whorled* arrangement, each such set of leaves being called a *cycle* or a *whorl*. These leaves contain no chlorophyll and have evidently abandoned chlorophyll work, which is carried on by the green stem. Such leaves are known as *scales*, to distinguish them from foliage leaves. The aërial stem (really a branch) is either simple or profusely branched (Fig. 305). In the species illustrated the early aërial branches are simple, usually not green, and bear the strobili; while the later branches are sterile, profusely branched, and green.

220. **The strobilus.**—One of the distinguishing characters of the group is that chlorophyll-work and spore-formation are completely differentiated. Although the foliage leaves are reduced to scales, and the chlorophyll-work is done by the stem, there are well-organized sporophylls. The sporophylls are grouped close together at the end of the stem in a compact conical cluster which is called a *strobilus*, the Latin name for "pine cone," which this cluster of sporophylls resembles (Fig. 305).

Each sporophyll consists of a stalk-like portion and a shield-like (*peltate*) top. Beneath the shield hang the

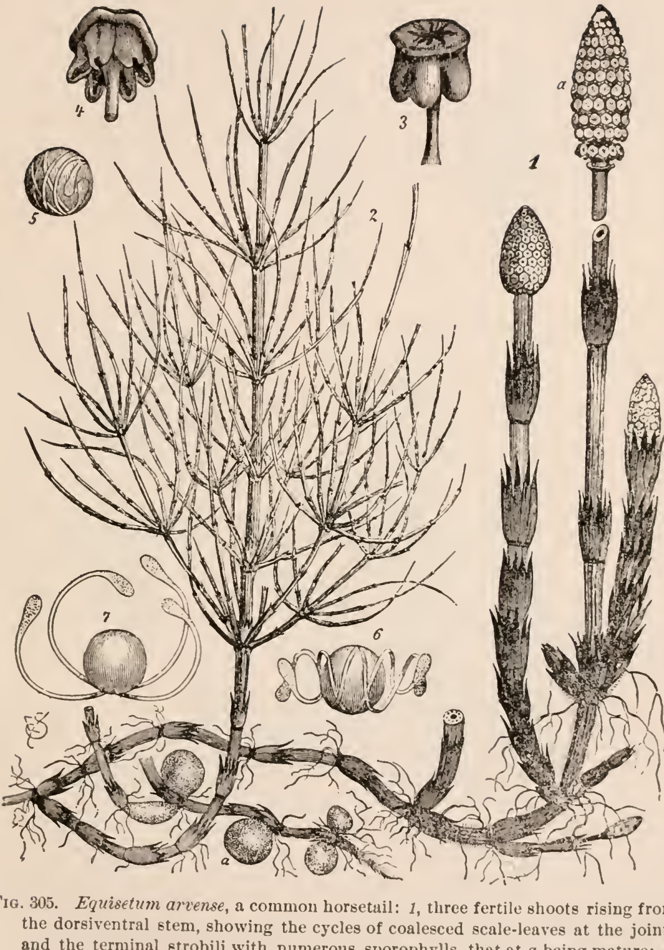


Fig. 305. *Equisetum arvense*, a common horsetail: *1*, three fertile shoots rising from the dorsiventral stem, showing the cycles of coalesced scale-leaves at the joints and the terminal strobili with numerous sporophylls, that at *a* being mature; *2*, a sterile shoot from the same stem, showing branching; *3*, a single peltate sporophyll bearing sporangia; *4*, view of sporophyll from beneath, showing dehiscence of sporangia; *5*, *6*, *7*, spores, showing the unwinding of the outer coat, which aids in dispersal.—After Wossidlo.

sporangia, which produce spores of but one kind, hence these plants are homosporous; and as the sporangia originate in eusporangiate fashion, *Equisetum* has the homosporous-eusporangiate combination shown by one of the Fern groups. It is interesting to know, however, that some of the ancient, more highly organized members of this group were heterosporous, and that the present forms have diœcious gametophytes.

Lycopodiales (*Club-mosses*)

221. **General characters.**—This group is now represented by about five hundred species, most of which belong to the two genera *Lycopodium* and *Selaginella*, the latter being much the larger genus. The plants have slender, branching, prostrate, or erect stems completely clothed with small foliage leaves, having a general moss-like appearance (Figs. 306, 307). Often the erect branches are terminated by conspicuous conical or cylindrical strobili, which are the "clubs" that enter into the name "Club-mosses." There is also a certain kind of resemblance to miniature pines, so that the name "Ground-pines" is sometimes used.

Lycopodiales were once much more abundant than now, and more highly organized, forming a conspicuous part of the forest vegetation of the Coal-measures.

One of the distinguishing marks of the group is that the sperm does not resemble that of the other Pteridophytes, but is of the Bryophyte type (Fig. 277); that is, it consists of a small body with two cilia, instead of a large spirally coiled body with many cilia. Another distinguishing character is that there is but a single sporangium produced by each sporophyll (Fig. 306). This is in marked contrast with the Filicales, whose leaves bear very numerous sporangia, and with the Equisetales, whose sporophylls bear several sporangia.

FIG. 306. A common club-moss (*Lycopodium clavatum*): *1*, the whole plant, showing horizontal stem giving rise to roots and to erect branches bearing strobili; *2*, a single sporophyll with its sporangium; *3*, spores, much magnified.—After WOSSIDLO.

Fig. 307. *Selaginella Martensii: A*, branch bearing strobili; *B*, a microsporophyll with a microsporangium, showing microspores through a rupture in the wall; *C*, a megasporophyll with a megasporangium; *D*, megaspores; *E*, microspores.—Goldberger.

CHAPTER XXIII

SPERMATOPHYTES: GYMNOSPERMS

222. **Summary from Pteridophytes.**—In considering the important contributions of Pteridophytes to the evolution of the plant kingdom the following seem worthy of note:

(1) *Prominence of sporophyte and development of vascular system.*—This prominence is associated with the display of leaves for chlorophyll work, and the leaves necessitate the work of conduction, which is arranged for by the vascular system. This fact is true of the whole group.

(2) *Differentiation of sporophylls.*—The appearance of sporophylls as distinct from foliage leaves, and their organization into the cluster known as the strobilus, are facts of prime importance. This differentiation appears more or less in all the great groups, but the strobilus is distinct only in Horsetails and Club-mosses.

(3) *Introduction of heterospory and reduction of gametophytes.*—Heterospory appears independently in all of the three great groups—in the water-ferns among the Filicales, in the ancient horsetails among the Equisetales, and in *Selaginella* and *Isoetes* among Lycopodiales. All the other Pteridophytes, and therefore the great majority of them, are homosporous. The importance of the appearance of heterospory lies in the fact that it leads to the development of Spermatophytes, and associated with it is a great reduction of the gametophytes, which project little, if at all, from the spores which produce them.

223. **Summary of the four groups.**—It may be well in this connection to give certain prominent characters which will

serve to distinguish the four great groups of plants. It must not be supposed that these are the only characters, or even the most important ones in every case, but they are convenient for our purpose. Two characters are given for each of the first three groups—one a positive character which belongs to it, the other a negative character which distinguishes it from the group above, and becomes the positive character of that group.

(1) *Thallophytes.*—Thallus body, but no archegonia.

(2) *Bryophytes.*—Archegonia, but no vascular system.

(3) *Pteridophytes.*—Vascular system, but no seeds.

(4) *Spermatophytes.*—Seeds.

224. **General characters of Spermatophytes.**—This is the greatest group of plants in rank and in display. So conspicuous are they, and so much do they enter into our experience, that they have often been studied as "botany," to the exclusion of the other groups. The lower groups are not merely necessary to fill out any general view of the plant kingdom, but they are absolutely essential to an understanding of the structures of the highest group.

This great dominant group has received a variety of names. Sometimes they are called *Anthophytes*, meaning "Flowering plants," with the idea that they are distinguished by the production of "flowers." A flower is difficult to define, but in the popular sense all Spermatophytes do not produce flowers, while in another sense the strobilus of Pteridophytes is a flower. Hence the flower does not accurately limit the group, and the name Anthophytes is not in general use. Much more commonly the group is called *Phanerogams* (sometimes corrupted into Phænogams or even Phenogams), meaning "evident sexual reproduction." At the time this name was proposed all the other groups were called *Cryptogams*, meaning "hidden sexual reproduction." It is a curious fact that the names ought to have been reversed, for sexual reproduction is much more evident in Cryptogams than in Phanerogams, the mistake arising from the fact that what were supposed to be sexual organs in Phanerogams have proved not to be such. The name Phanerogam, therefore, is being generally abandoned; but the name Cryptogam is a useful one when the lower groups are to be referred to; and the Pteridophytes are still very frequently called the *Vascular Cryptogams.* The most distinguishing mark of the group seems to be the production of seeds, and hence the name *Spermatophytes,* or "Seed-plants," is coming into general use.

The seed can be better defined after its development has been described, but it results from the fact that in this group the single megaspore is never discharged from its megasporangium, but germinates just where it is developed. The great fact connected with the group, therefore, is the retention of the megaspore, which results in a seed. The full meaning of this will appear later.

There are two very independent lines of Seed-plants, the *Gymnosperms* and the *Angiosperms.* The first name means "naked seeds," referring to the fact that the seeds are always exposed; the second means "inclosed seeds," as the seeds are inclosed in a seed vessel.

Gymnosperms

225. **General characters.**—The most familiar Gymnosperms in temperate regions are the pines, spruces, hemlocks, cedars, etc., the group so commonly called "evergreens." It is an ancient tree group, for its representatives were associated with the giant club-mosses and horsetails in the forest vegetation of the Coal-measures. Only about four hundred species exist to-day as a remnant of its former display, although the pines still form extensive forests. The group is so diversified in its structure that all forms can not be included in a single description. The common pine (*Pinus*), therefore, will be taken as a type, to show the general Gymnosperm character.

226. **The plant body.**—The great body of the plant, often forming a large tree, is the sporophyte; in fact, the gametophytes are not visible to ordinary observation. It should be remembered that the sporophyte is distinctly a sexless generation, and that it develops no sex organs. This great sporophyte body is elaborately organized for nutritive work, with its roots, stems, and leaves. These organs are very complex in structure, being made up of various tissue systems that are organized for special kinds of work. The leaves are the most variable organs, being differentiated into three distinct kinds: (1) foliage leaves, (2) scales, and (3) sporophylls.

227. **Sporophylls.**—The sporophylls are leaves set apart to produce sporangia, and in the pine they are arranged in a strobilus, as in the Horsetails and Club-mosses. As the group is heterosporous, however, there are two kinds of sporophylls and two kinds of strobili. One kind of strobilus is made up of megasporophylls bearing megasporangia; the other is made up of microsporophylls bearing microsporangia. These strobili are often spoken of as the "flowers" of the pine, but if these are flowers, so are the strobili of Horsetails and Club-mosses.

228. **Microsporophylls.**—In the pines the strobilus composed of microsporophylls is comparatively small (Figs. 308, *d*, 309). Each sporophyll is like a scale leaf, is narrowed at the base, and upon the lower surface are borne two prominent sporangia, which of course are microsporangia, and contain microspores (Fig. 309).

These structures of Seed-plants all received names before they were identified with the corresponding structures of the lower groups. The microsporophyll was called a *stamen*, the microsporangia *pollen-sacs*, and the microspores *pollen-grains*, or simply *pollen*. These names are still very convenient to use in connection with the Spermatophytes, but it should be remembered that they are simply other names for structures found in the lower groups.

FIG. 308. *Pinus Laricio,* showing tip of branch bearing needle-leaves, scale-leaves, and cones (strobili): *a*, very young carpellate cones, at time of pollination, borne at tip of the young shoot upon which new leaves are appearing; *b*, carpellate cones one year old; *c*, carpellate cones two years old, the scales spreading and shedding the seeds; *d*, young shoot bearing a cluster of staminate cones.—CALDWELL.

The strobilus composed of microsporophylls may be called the *staminate strobilus*—that is, one composed of stamens; it is often called the staminate cone, "cone" being the English translation of the word "strobilus." Frequently the staminate cone is spoken of as the "male cone," as it was once supposed that the stamen is the

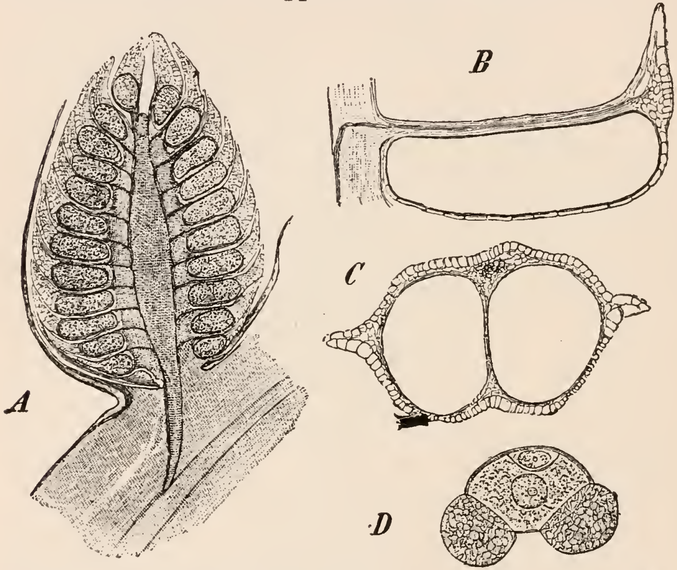


FIG. 309. Staminate cone (strobilus) of pine (*Pinus*): *A*, section of cone, showing microsporophylls (stamens) bearing microsporangia; *B*, longitudinal section of a single stamen, showing the large sporangium beneath; *C*, cross-section of a stamen, showing the two sporangia; *D*, a single microspore (pollen grain) much enlarged, showing the two wings, and a male gametophyte of two cells, the lower and larger (wall cell) developing the pollen tube, the upper and smaller (generative cell) giving rise to the sperms.—After STRASBURGER.

male organ. This name should, of course, be abandoned, as the stamen is now known to be a microsporophyll, which is an organ produced by the sporophyte, which never produces sex organs. It should be borne distinctly in mind that the stamen is not a sex organ, for the literature of botany is full of this old assumption, and the beginner is in danger of becoming confused and of forgetting that pollen grains are asexual spores.

229. **Megasporophylls.**—The strobili composed of megasporophylls become much larger than the others, forming

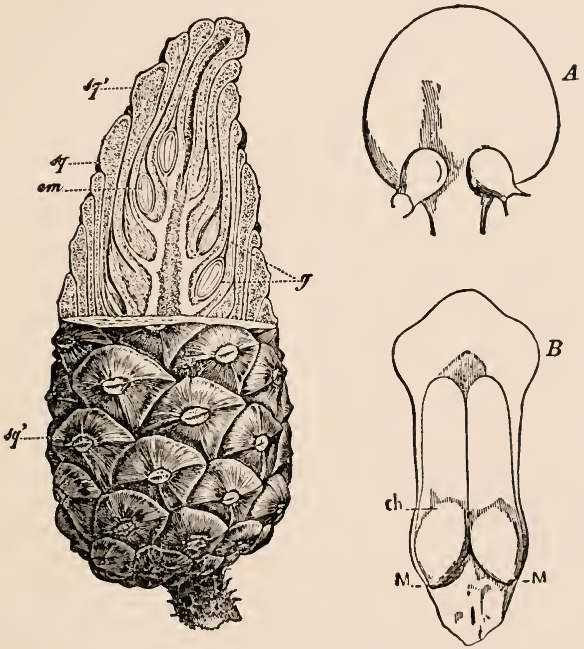


FIG. 310. *Pinus sylvestris*, showing mature cone partly sectioned, and showing carpels (sq, sq^1, sq^2) with seeds in their axils (g), in which the embryos (em) may be distinguished; A, a young carpel with two megasporangia; B, an old carpel with mature seeds (ch), the micropyle being below (M).—After BESSEY.

the well-known cones so characteristic of pines and their allies (Fig. 308, *a*, *b*, *c*). Each sporophyll is somewhat leaf-like, and at its base upon the upper side are two megasporangia (Fig. 310). It is these sporangia which are peculiar in each producing and retaining a solitary large megaspore. This megaspore resembles a sac-like cavity in the body of the sporangium (Fig. 311, *d*), and was at first not recognized as being a spore.

These structures had also received names before they were identified with the corresponding structures of the lower groups. The megasporophyll was called a *carpel*, the megasporangia *ovules*, and the megaspore an *embryo-sac*, because the young embryo was observed to develop within it (Fig. 310, *em*).

The strobilus of megasporophylls, therefore, may be called the *carpellate strobilus* or *carpellate cone*. As the carpel enters into the organization of a structure known as the *pistil*, to be described later, the cone is often called the *pistillate cone*. As the staminate cone is sometimes wrongly called a "male cone," so the carpellate cone is wrongly called a "female cone," the old idea being that the carpel with its ovules represented the female sex organ.

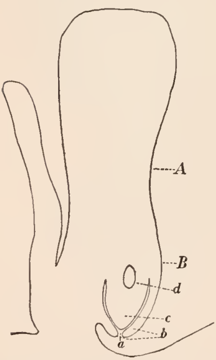


FIG. 311. Diagram of the carpel structures of pine, showing the heavy scale (*A*) which bears the ovule (*B*), in which are seen the micropyle (*a*), integument (*b*), nucellus (*c*), embryo-sac or megaspore (*d*).—MOORE.

The structure of the megasporangium, or ovule, must be known. The main body is the *nucellus* (Figs. 311, *c*, 312, *nc*); this sends out from near its base an outer membrane (*integument*) which is distinct above (Figs. 311, *b*, 312, *i*), covering the main part of the nucellus and projecting beyond its apex as a prominent neck, the passage through which to the apex of the nucellus is called the *micropyle* ("little gate") (Fig. 311, *a*). Centrally placed within the body of the nucellus is the conspicuous cavity called the embryo-sac (Fig. 311, *d*), in reality the retained megaspore. The relations between integument, micropyle, nucellus, and embryo-sac should be kept clearly in mind. In the pine the micropyle is directed downward, toward the base of the sporophyll.

230. **The gametophytes.**—The male and female gametophytes are so small that they develop entirely within the spores (pollen-grain and embryo-sac), and therefore can only be observed by the microscope.

The female gametophyte (often called "endosperm") fills up the large embryo-sac, and on its surface toward the micropyle develops regular flask-shaped archegonia (Fig. 312).

The male gametophyte is still more reduced, and is represented by a very few small cells which appear within the pollen-grain, two of which are sperm-cells. These sperm-cells must reach the archegonia, and accordingly the pollen-grain sends out a tube (*pollen-tube*), into which the sperm-cells enter, and are thus brought to the archegonia (Fig. 110).

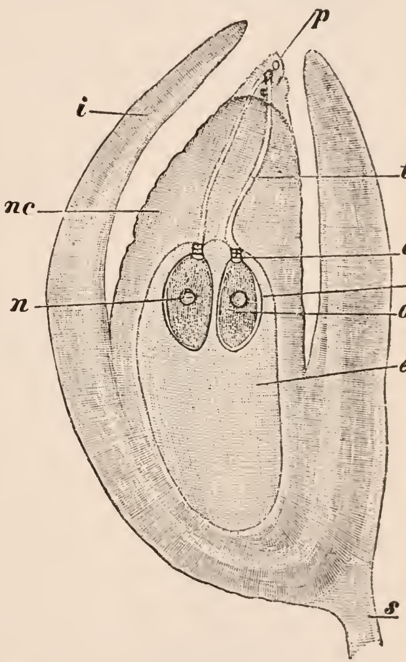


Fig. 312. Diagrammatic section through ovule (megasporangium) of spruce (*Picea*), showing integument (*i*), nucellus (*nc*), endosperm or female gametophyte (*e*) which fills the large megaspore imbedded in the nucellus, two archegonia (*a*) with short neck (*c*) and venter containing the egg (*o*), and position of germinating pollen-grains or microspores (*p*) whose tubes (*t*) penetrate the nucellus tissue and reach the archegonia.—After Schimper.

231. **Fertilization.** — Before fertilization can take place the pollen-grains (microspores) must be brought as near as possible to the female gametophyte with its archegonia. The spores are formed in very great abundance,

are dry and powdery, and are scattered far and wide by the wind. In the pines and their allies the pollen-grains are winged (Fig. 309, *D*), so that they are well organized for wind distribution. This transfer of pollen is called *pollination*, and those plants that use the wind as an agent of transfer are said to be *anemophilous*, or "wind-loving."

The pollen must reach the ovule, and to insure this it must fall like rain. To aid in catching the falling pollen the scale-like carpels of the cone spread apart, the pollen-grains slide down their sloping surfaces and collect in a little drift at the bottom of each carpel, where the ovules are found (Fig. 310, *A*, *B*). The flaring lips of the micropyle roll inward and outward as they are dry or moist, and by this motion some of the pollen-grains are caught and pressed down upon the apex of the nucellus.

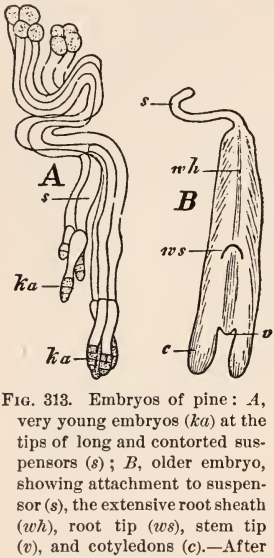


FIG. 313. Embryos of pine: *A*, very young embryos (*ka*) at the tips of long and contorted suspensors (*s*); *B*, older embryo, showing attachment to suspensor (*s*), the extensive root sheath (*wh*), root tip (*ws*), stem tip (*v*), and cotyledons (*c*).—After STRASBURGER.

In this position the pollen-tube develops, crowds its way among the cells of the nucellus, reaches the wall of the embryo-sac, and penetrating that, reaches the necks of the archegonia.

232. **The embryo.**—By the act of fertilization, an oospore is formed within the archegonium. As it is on the surface of its food supply (the endosperm), it first develops a long cylindrical process (*suspensor*), which penetrates the endosperm and develops the embryo at its tip. In this way the embryo lies imbedded in the midst of its food supply (Fig. 313).

233. **The seed.**—While the embryo is developing, some important changes are taking place in the ovule outside of the endosperm. The most noteworthy is the change which

transforms the integument into a hard bony covering, known as the *seed coat*, or *testa* (Fig. 314). The development of this testa hermetically seals the structures within, further development and activity are checked, and the living cells pass into the resting condition. This protected structure with its dormant cells is the *seed.*

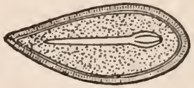


Fig. 314. Pine seed.

The organization of the seed checks the growth of the embryo, and this development within the seed is known as

Fig. 315. Pine seedlings, showing the long hypocotyl and the numerous cotyledons, with the old seed case still attached.—After Atkinson.

the *intra-seminal development*. In this condition the embryo may continue for a very long time, and it is a question whether it is death or suspended animation. Is a seed alive? is not an easy question to answer, for it may be kept in a dried-out condition for years, and then when placed in suitable conditions awaken and put forth a living plant.

This "awakening" of the seed is spoken of as its "germination," but this must not be confused with the germination of a spore, which is real germination. In the case of the seed an oospore has germinated and formed an embryo, which stops growing for a time, and then resumes it. This resumption of growth is not germination, but is what happens when a seed is said to "germinate." This second period of development is known as the *extra-seminal*, for it is inaugurated by the escape of the sporophyte from the seed coats (Fig. 315).

234. **The great groups of Gymnosperms.**—There are at least four living groups of Gymnosperms, and two or three extinct ones. The groups differ so widely from one another in habit as to show that Gymnosperms can be very much diversified. They are all woody forms, but they may be trailing or straggling shrubs, gigantic trees, or high-climbing vines; and their leaves may be needle-like, broad, or "fern-like." For our purpose it will be only necessary to define the two most prominent groups.

235. **Cycads.**—Cycads are tropical, fern-like forms, with large branched (compound) leaves. The stem is either a columnar shaft crowned with a rosette of great branching leaves, with the general habit of tree-ferns and palms (Figs. 16, 316); or they are like great tubers, crowned in the same way. In ancient times (the Mesozoic) they were very abundant, forming a conspicuous feature of the vegetation, but now they are represented only by about eighty forms scattered through both the oriental and occidental tropics.

Fig. 316. *Cycas revoluta*, showing the foliage at the summit of the stem. In the center is the nearly erect cluster of young foliage leaves, below are the scale leaves which covered them in bud, and below these are the widely spreading old foliage leaves.—Caldwell.

236. **Conifers.**—This is the great modern Gymnosperm group, and is characteristic of the temperate regions, where it forms great forests. Some of the forms are widely distributed, as the great genus of pines (*Pinus*) (Fig. 57), while some are now very much restricted, although formerly very widely distributed, as the gigantic redwoods (*Sequoia*) of the Pacific slope. The habit of the body is quite characteristic, a central shaft extending continuously to the very top, while the lateral branches spread horizontally, with diminishing length to the top, forming a conical outline (Figs. 56, 57). This habit of firs, pines, etc., gives them an appearance very distinct from that of other trees.

Fig. 317. Arbor-vitæ (*Thuja*), showing a branch with scaly overlapping leaves, and some carpellate cones (strobili).—After Eichler.

Another peculiar feature is furnished by the characteristic "needle-leaves," which seem to be poorly adapted for foliage. These leaves have small spread of surface and very heavy protecting walls, and show adaptation for enduring hard conditions (Fig. 308). As they have no regular period of falling, the trees are always clothed with them, and have been called "evergreens." There are some notable exceptions to this, however, as in the case of the common larch or tamarack, which sheds its leaves every season (Fig. 56).

FIG. 318. The common juniper (*Juniperus communis*); the branch to the left bearing staminate strobili; that to the right bearing staminate strobili above and carpellate strobili below, which latter have matured into the fleshy, berry-like fruit. —After BERG and SCHMIDT.

CHAPTER XXIV

SPERMATOPHYTES: ANGIOSPERMS

237. **Summary of Gymnosperms.**—Before beginning Angiosperms it is well to state clearly the characters of Gymnosperms which have set them apart as a distinct group of Spermatophytes, and which serve to contrast them with Angiosperms.

(1) The microspore (pollen-grain) by wind-pollination is brought into contact with the megasporangium (ovule), and there develops the pollen-tube, which penetrates the nucellus. This contact between pollen and ovule implies an exposed or naked ovule and hence seed, and therefore the name "Gymnosperm."

(2) The female gametophyte (endosperm) is well organized before fertilization.

(3) The female gametophyte produces archegonia.

238. **General characters of Angiosperms.**—This is the greatest group of plants, both in numbers and importance, being estimated to contain about 100,000 species, and forming the most conspicuous part of the vegetation of the earth. It is essentially a modern group, replacing the Gymnosperms which were formerly the dominant Seed-plants, and in the variety of their display exceeding all other groups. The name of the group is suggested by the fact that the seeds are inclosed in a seed case, in contrast with the exposed seeds of the Gymnosperms.

These are also the true flowering plants, and the appearance of true flowers means the development of an elaborate symbiotic relation between flowers and insects, through which pollination is secured. In Angiosperms, therefore, the wind is abandoned as an agent of pollen transfer and insects are used; and in passing from Gymnosperms to Angiosperms one passes from anemophilous to *entomophilous* ("insect-loving") plants. This does not mean that all Angiosperms are entomophilous, for some are still wind-pollinated, but that the group is prevailingly entomophilous. This fact, more than anything else, has resulted in a vast variety in the structure of flowers, so characteristic of the group.

239. **The plant body.**—This of course is a sporophyte, the gametophytes being minute and concealed, as in Gymnosperms. The sporophyte represents the greatest possible variety in habit, size, and duration, from minute floating forms to gigantic trees; herbs, shrubs, trees; erect, prostrate, climbing; aquatic, terrestrial, epiphytic; from a few days to centuries in duration.

Roots, stems, and leaves are more elaborate and variously organized for work than in other groups, and the whole structure represents the highest organization the plant body has attained. As in the Gymnosperms, the leaf is the most variously used organ, showing at least four distinct modifications: (1) foliage leaves, (2) scales, (3) sporophylls, and (4) floral leaves. The first three are present in Gymnosperms, and even in Pteridophytes, but floral leaves are peculiar to Angiosperms, making the true flower, and being associated with entomophily.

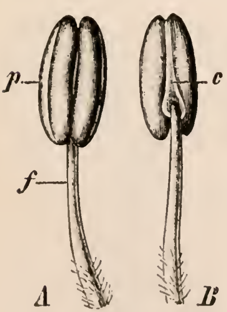


FIG. 319. Stamens of henbane (*Hyoscyamus*): *A*, front view, showing filament (*f*) and anther (*p*); *B*, back view, showing the connective (*c*) between the pollen-sacs. —After SCHIMPER.

240. **Microsporophylls.**—The microsporophyll of Angiosperms is more definitely known as a "stamen" than

that of Gymnosperms, and has lost any semblance to a leaf. It consists of a stalk-like portion, the *filament*, and a sporangia-bearing portion, the *anther* (Figs. 319, 321, *A*).

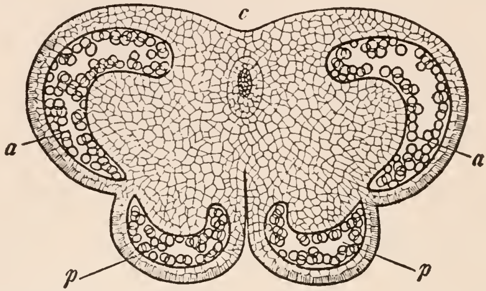


Fig. 320. Cross-section of anther of thorn apple (*Datura*), showing the four imbedded sporangia (*a*, *p*) containing microspores; the pair on each side will merge and dehisce along the depression between them for the discharge of pollen.—After Frank.

The filament may be long or short, slender or broad, or variously modified, or even wanting. The anther is simply the region of the sporophyll which bears sporangia, and is

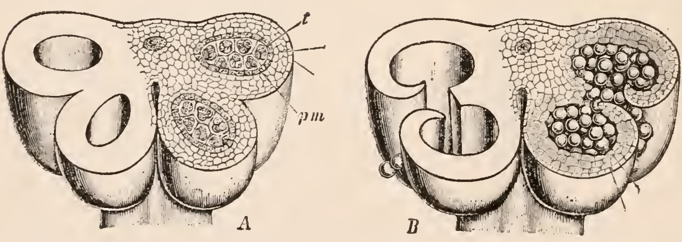


Fig. 321. Diagrammatic cross-sections of anthers: *A*, younger stage, showing the four imbedded sporangia, the contents of two removed, but the other two containing pollen mother cells (*pm*) surrounded by the tapetum (*t*); *B*, an older stage, in which the microspores (pollen grains) are mature, and the pair of sporangia on each side are merging together to form a single pollen-sac with longitudinal dehiscence.—After Baillon and Luerssen.

therefore a composite of sporophyll and sporangia and is often of uncertain limitation. Such a term is convenient, but is not exact or scientific.

If a young anther be sectioned transversely four sporangia will be found imbedded beneath the epidermis, a pair on each side of the axis (Figs. 320, 321). When they reach maturity, the paired sporangia on each side usually merge together, forming two spore-containing cavities (Fig. 321, *B*). These are generally called "pollen-sacs," and each anther is said to consist of two pollen-sacs, although each sac is made up of two merged sporangia, and is not the equivalent of the pollen-sac in Gymnosperms, which is a single sporangium.

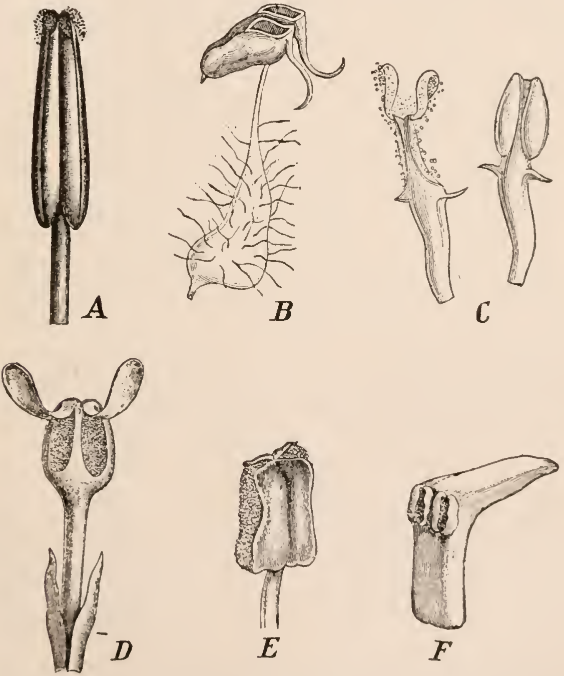


Fig. 322. Various forms of stamens: *A*, from *Solanum*, showing dehiscence by terminal pores; *B*, from *Arbutus*, showing anthers with terminal pores and "horns"; *C*, from *Berberis*; *D*, from *Atherosperma*, showing dehiscence by uplifted valves; *E*, from *Aquilegia*, showing longitudinal dehiscence; *F*, from *Popowia*, showing pollen-sacs near the middle of the stamen.—After Engler and Prantl.

The opening of the pollen-sac to discharge its pollen-grains (microspores) is called *dehiscence*, which means "a splitting open," and the methods of dehiscence are various (Fig. 322). By far the most common method is for the wall of each sac to split lengthwise (Fig. 323), which is called *longitudinal dehiscence;* another is for each sac to open by a terminal pore (Fig. 322), in which case it may be prolonged above into a tube.

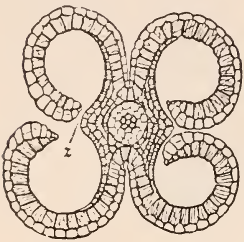


FIG. 323. Cross-section of anther of a lily (*Butomus*), showing the separating walls between the members of each pair of sporangia broken down at *z*, forming a continuous cavity (pollen-sac) which opens by a longitudinal slit.—After SACHS.

241. **Megasporophylls.** — These are the so-called "carpels" of Seed-plants, and in Angiosperms they are organized in various ways, but always so as to inclose the megasporangia (ovules). In the simplest cases each carpel is independent (Fig. 324, *A*), and is differentiated into three regions: (1) a hollow bulbous base, which contains the ovules and is the real seed case, known as the *ovary;* (2) surmounting this is a slender more or less elongated process, the *style;* and (3) usually at or near the apex of the style a special receptive surface for the pollen, the *stigma*.

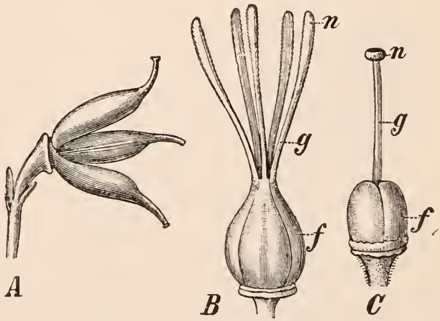
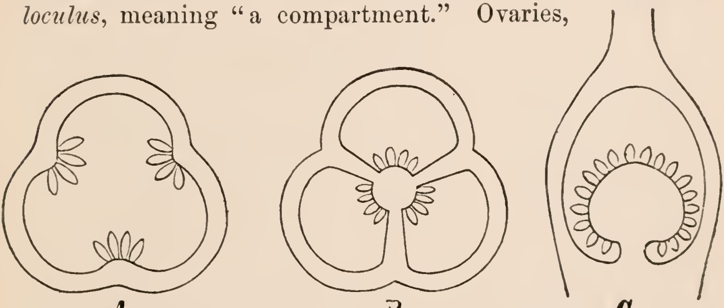


FIG. 324. Types of pistils: *A*, three simple pistils (apocarpous), each showing ovary and style tipped with stigma; *B*, a compound pistil (syncarpous), showing ovary (*f*), separate styles (*g*), and stigmas (*n*); *C*, a compound pistil (syncarpous), showing ovary (*f*), single style (*g*), and stigma (*n*).—After BERG and SCHMIDT.

In other cases several carpels together form a common ovary, while the styles may also combine to form one style (Fig. 324, *C*), or they may remain more or less distinct (Fig. 324, *B*). Such an ovary may contain a single chamber, as if the carpels had united edge to edge (Fig. 325, *A*); or it may contain as many chambers as there are constituent carpels (Fig. 325, *B*), as though each carpel had formed its own ovary before coalescence. In ordinary phrase an ovary is either "one-celled" or "several-celled," but as the word "cell" has a very different application, the ovary chamber had better be called a *loculus*, meaning "a compartment." Ovaries,



A **B** **C**

Fig. 325. Diagrammatic sections of ovaries: *A*, cross-section of an ovary with one loculus and three carpels, the three sets of ovules said to be attached to the wall (parietal); *B*, cross-section of an ovary with three loculi and three carpels, the ovules being in the center (central); *C*, longitudinal section showing ovules attached to free axis (free central).—After Schimper.

therefore, may have one loculus or several loculi. Where there are several loculi each one usually represents a constitutent carpel (Fig. 325, *B*); where there is one loculus the ovary may comprise one carpel (Fig. 324, *A*), or several (Fig. 325, *A*).

There is a very convenient but not a scientific word, which stands for any organization of the ovary and the accompanying parts, and that is *pistil*. A pistil may be one carpel (Fig. 324, *A*), or it may be several carpels organized together (Fig. 324, *B*, *C*), the former case being a *simple pistil*, the latter a *compound pistil*. In other words, any organization of carpels which appears as a single organ with one ovary is a pistil.

The ovules (megasporangia) are developed within the ovary (Fig. 325) either from the carpel wall, when they are foliar, or from the stem axis which ends within the ovary, when they are cauline (see § 89). They are similar in structure to those of Gymnosperms, with integument and micropyle, nucellus, and embryo-sac (megaspore), except that there are often two integuments, an outer and an inner (Fig. 326).

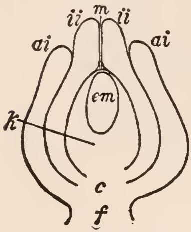


FIG. 326. A diagrammatic section of an ovule of Angiosperms, showing outer integument (*ai*), inner integument (*ii*), micropyle (*m*), nucellus (*k*), and embryo-sac or megaspore (*em*).—After SACHS.

242. **Modifications of the flower.**—In general, the flower may be regarded as a modified branch bearing sporophylls and usually floral leaves. Its representative among the Pteridophytes and Gymnosperms is the strobilus, which has sporophylls but not floral leaves. In Angiosperms it begins in a simple and somewhat indefinite way, gradually becomes more complex, until finally it appears as an elaborate and very efficient structure.

The evolution of the flower has proceeded along many lines, and has resulted in great diversity of structure. These diversities are largely used in the classification of Angiosperms, as it is supposed that near relatives are indicated by similar floral structures, as well as by other features. Some of the lines of evolution may be indicated as follows:

1. *From naked flowers to those with distinct calyx and corolla.*—In the simplest flowers floral leaves do not appear, and the flower is represented only by the sporophylls. When the floral leaves first appear they are inconspicuous, scale-like bodies. In higher forms they become more prominent, but are still all alike. At last the floral leaves become differentiated, the outer set (calyx) remaining scale-like or

like small foliage leaves, and the inner set (corolla) becoming more delicate in texture, larger, and generally brightly colored (Fig. 71).

2. *From spiral to cyclic flowers.*—In the simplest flowers the sporophylls and floral leaves (if any) are distributed about an elongated axis in a spiral, like a succession of leaves. As this axis is elongated and capable of continued growth, an indefinite number of each floral organ may appear. The spiral arrangement and indefinite numbers, therefore, are regarded as primitive characters.

In higher forms the axis becomes shorter, the spiral closer, until finally the sets of organs seem to be thrown into rosettes or cycles. These cycles may not appear in all the organs of a flower, but finally, in the highest forms, all the floral organs are in definite cycles. All through this evolution from the spiral to the cyclic arrangement there is constantly appearing a tendency to "settle down" to certain definite numbers, and when the complete cyclic arrangement is finally established these numbers are established, and they become characteristic of great groups. For example, in the cyclic Monocotyledons there are nearly always just three organs in each cycle, while in the cyclic Dicotyledons the number five prevails.

3. *From hypogynous to epigynous flowers.*—In the simpler flowers the sepals, petals, and stamens arise from beneath the ovary or ovaries (Fig. 72, *1*), and as in such cases the ovary may be seen distinctly above the origin (*insertion*) of the other parts, such a flower is often said to have a "superior ovary," or to be *hypogynous*, meaning in effect "under the ovary," referring to the fact that the insertion of the other parts is under the ovary.

There is a distinct tendency, however, for the insertion of the outer parts to be carried higher up, until finally it is above the ovary, and sepals, petals, and stamens seem to arise from the top of the ovary (Fig. 72, *3*), such a flower being *epigynous*. In such cases the ovary does not appear within the flower, but below it (Fig. 132), and the flower is often said to have an "inferior ovary."

4. *From apocarpous to syncarpous flowers.* — In the simpler flowers the carpels are entirely distinct, each carpel organizing a simple pistil, a single flower containing as many pistils as there are carpels (Fig. 324, *A*). Such a flower is said to be *apocarpous*, meaning "carpels separate." There is a very strong tendency, however, for the carpels of a flower to organize together and to form a single compound pistil (Fig. 324, *B*, *C*), such a flower being called *syncarpous*, meaning "carpels together."

5. *From polypetalous to sympetalous flowers.*—While the petals are entirely distinct from one another in the lower forms, a condition described as *polypetalous*, in the highest Angiosperms they are coalescent, the corolla thus becoming a more or less tubular organ (Figs. 73, 74). Such flowers are said to be *sympetalous*, meaning "petals united."

6. *From regular to irregular flowers.*—In the simplest flowers all the members of one set are alike, and the flower is said to be regular (Fig. 74, *a*, *b*). In certain lines of advance, however, there is a tendency for some of the members of a single set, particularly the petal set, to become unlike. For example, in the common violet one of the petals develops a spur; while in the sweet pea the petals are remarkably unlike. Such flowers are said to be *irregular* (Fig. 74, *c*, *d*, *e*), and as a rule irregularity is associated with adaptations for insect pollination.

These various lines appear in all stages of advancement in different flowers, so that it would be impossible to determine the relative rank in all cases. However, if a flower is naked, with indefinite numbers, hypogynous, and apocarpous, it would rank very low; but if it has a calyx and corolla, is completely cyclic, epigynous, syncarpous, sympetalous, and irregular, it would rank very high.

243. **The gametophytes.**—As in the case of the Gymnosperms, the gametophytes of Angiosperms are exceedingly

simple, being developed entirely within the spores which produce them.

The male gametophyte is represented by a few cells which appear within the pollen grain, two of which are male cells.

When pollination occurs, and the pollen has been transferred from the pollen-sacs to the stigma, it is detained by the minute papillæ of the stigmatic surface, which also excretes a sweetish sticky fluid. This fluid is a nutrient solution for the microspores, which begin to put out their tubes. A pollen-tube penetrates through the stigmatic surface, enters among the tissues of the style, which is sometimes very long, slowly or rapidly traverses the length of the style supplied with food by its cells but not penetrating them, enters the cavity of the ovary, passes through the micropyle of an ovule, penetrates the tissues of the nucellus (if any), and finally reaches and pierces the wall of the embryo-sac, within which is the egg awaiting fertilization (Fig. 327).

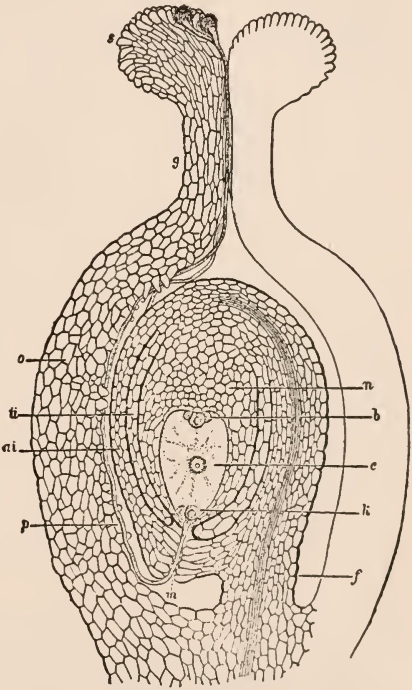


FIG. 327. Diagram of a longitudinal section through a carpel, to illustrate fertilization with all parts in place: *s*, stigma; *g*, style; *o*, ovary; *ai*, *ii*, outer and inner integuments; *n*, base of nucellus; *f*, funiculus; *b*, antipodal cells; *c*, endosperm nucleus; *k*, egg and one synergid; *p*, pollen-tube, having grown from stigma and passed through the micropyle (*m*) to the egg.—After LUERSSEN.

The female gametophyte develops within the embryo-sac, and consists at first of seven independent cells, one of which is the egg, no archegonium being formed. The

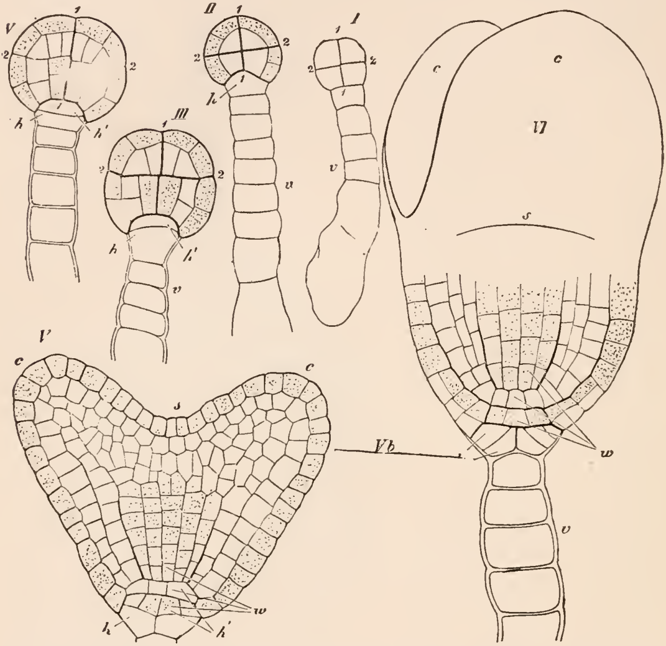


FIG. 328. Development of embryo of shepherd's purse (*Capsella*), a Dicotyledon; beginning with *I*, the youngest stage, and following the sequence to *VI*, the oldest stage, *v* represents the suspensor, *c* the cotyledons, *s* the stem-tip, *w* the root, *h* the root-cap. Note the root-tip at one end of the axis and the stem-tip at the other between the cotyledons.—After HANSTEIN.

egg is in the end of the sac nearest the micropyle, in the most convenient position for the entering tube. When the tip of the pollen-tube enters the sac it discharges the two male cells. One of these unites with the egg and forms the oospore, which germinates and forms the embryo. The other male cell unites with one of the other free cells of the female gametophyte and forms the "endosperm cell," which divides and begins the formation of the endosperm, a tissue that feeds the embryo and is often the nutritive part of seeds. In Angiosperms, therefore, there are two simultaneous acts of fertilization, one starting the embryo, the other the endosperm, and hence in this group "double fertilization" is said to occur.

244. **The embryo.**—When the oospore germinates, a more or less distinct suspensor is usually formed, but never so prominent as in Gymnosperms; and at the end of the suspensor the embryo is developed, which, when completed, is more or less surrounded by nourishing endosperm, or has stored up within its seed-leaves an abundant food supply.

The two groups of Angiosperms differ widely in the structure of the embryo. In Monocotyledons the axis of the embryo develops the root-tip at one end and the "seed-leaf" (cotyledon) at the other, the stem-tip arising from the side of the axis as a lateral member (Fig. 329).

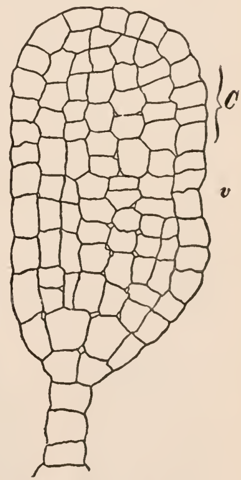


FIG. 329. Young embryo of water plantain (*Alisma*), a Monocotyledon, the root being organized at one end (next the suspensor), the single cotyledon (*C*) at the other, and the stem-tip arising from a lateral notch (*v*). — After HANSTEIN.

In Dicotyledons the axis of the embryo develops the root-tip at one end and the stem-tip at the other, the cotyledons (usually two) appearing as a pair of opposite lateral members on either side of the stem-tip (Fig. 328). As the cotyledons are lateral members their number may vary.

The axis of the embryo between the root-tip and the cotyledons is called the *hypocotyl* (Figs. 143, 315, 331), which means "under the cotyledon," a region which shows peculiar activity in connection with the escape of the embryo from the seed. Formerly it was called either *caulicle* or *radicle.* In Dicotyledons the stem-tip between the cotyledons often organizes the rudiments of subsequent leaves, forming a little bud which is called the *plumule.*

Embryos differ much as to completeness of their development within the seed. In some plants, especially those which are parasitic or saprophytic, the embryo is merely a small mass of cells, without any organization of root, stem, or leaf. In many cases the embryo becomes highly developed, the endosperm being used up and the cotyledons stuffed with food material, the plumule containing several well-organized young leaves, and the embryo completely filling the seed cavity. The common bean is a good illustration of this last case, the whole seed within the integument consisting of the two large, fleshy cotyledons, between which lie the hypocotyl and a plumule of several leaves.

245. **The seed.**—As in Gymnosperms, while the processes above described are taking place within the ovule, the integument or integuments are becoming transformed into the testa (Fig. 330). When this hard coat is fully devel-

FIG. 330. The two figures to the left are seeds of violet, one showing the black, hard testa, the other being sectioned and showing testa, endosperm, and imbedded embryo; the figure to the right is a section of a pepper fruit (*Piper*), showing modified ovary wall (*pc*), seed testa (*sc*), nucellus tissue (*p*), endosperm (*en*), and embryo (*em*).—After ATKINSON.

oped, the activities within cease, and the whole structure passes into that condition of suspended animation which is so little understood, and which may continue for a long time.

The testa is variously developed in seeds, sometimes being smooth and glistening, sometimes pitted, sometimes rough with warts or ridges. Sometimes prominent appendages are produced which assist in seed-dispersal, as the wings in *Catalpa* or *Bignonia* (Fig. 115), or the tufts of hair on the seeds of milkweed, cotton, or fireweed.

246. **The fruit.**—The effect of fertilization is felt beyond the boundaries of the ovule, which forms the seed. The ovary is also involved, and becomes more or less modified. It enlarges more or less, sometimes becoming remarkably enlarged. It also changes in structure, often becoming hard or parchment-like. In case it contains several or numerous seeds, it is organized to open in some way and discharge them, as in the ordinary *pods* and *capsules* (Fig. 122). In case there is but one seed, the modified ovary wall may invest it as closely as another integument, and a seed-like fruit is the result—a fruit which never opens and is practically a seed. Such a fruit is known as an *akene*, and is very characteristic of the greatest Angiosperm family, the Compositæ, to which sunflowers, asters, golden-rods, daisies, thistles, dandelions, etc., belong. Dry fruits which do not open to discharge the seed often bear appendages to aid in dispersal by wind (Figs. 116, 117), or by animals (Fig. 129).

Capsules, pods, and akenes are said to be dry fruits, but in many cases fruits ripen fleshy. In the peach, plum, cherry, and all ordinary "stone fruits," the modified ovary wall organizes two layers, the inner being very hard, forming the "stone," the outer being pulpy, or variously modified (Fig. 330). In the true berries, as the grape, currant, tomato, etc., the whole ovary becomes a thin-skinned pulpy mass in which the seeds are imbedded.

In some cases the effect of fertilization in changing structure is felt beyond the ovary. In the apple, pear, quince, and such fruits, the pulpy part is the modified calyx (one of the floral leaves), the ovary and its contained seeds being represented by the "core." In other cases, the end of the stem bearing the ovaries (receptacle) becomes enlarged and pulpy, as in the strawberry. This effect sometimes involves even more than the parts of a single flower, a whole flower-cluster, with its axis and bracts, becoming an enlarged pulpy mass, as in the pineapple.

The term "fruit," therefore, is a very indefinite one, so far as the structures it includes are concerned.

247. **The germination of the seed.**—It is wrong to apply the term "germination" to the renewal of activity by the young plantlet within the seed, as has been shown before (page 354), but in the absence of a better word it will be used. This "awakening of the seed" is a phenomenon so easily observed that it can hardly escape the attention of any one.

Just how long different seeds may retain their vitality—that is, live in a state of suspended animation—is not very definitely known. Some seeds have germinated after having remained in a dried-up condition for many years, but such stories as that wheat taken from the wrappings of Egyptian mummies has been made to germinate are myths.

If the structures of the seed are normal, its germination will follow its exposure to certain conditions, prominent among which are water, heat, and oxygen. Seeds vary in the amount of water and heat absolutely needed, but for terrestrial plants all the suitable conditions are supplied by burial in loose, moist soil, at the temperatures which prevail during the growing season.

This so-called germination is merely a renewal of the growth of the embryo, which results in freeing it from the seed coats, and in enabling it to establish itself for independent living. All the conditions for growth are present, namely, *food material*, stored within the seed, most commonly as starch or oil; *oxygen*, to be used in respiration; *water*, to put the cells in proper condition for work, and to act as an agent of transfer; and a *suitable tempera-*

ture, necessary for the chemical changes about to be made.

The first conspicuous change noted in the seed after the absorption of water is the softening of the contents, the solid and insoluble starch, if that be the form of the food storage, being converted by a process of digestion into soluble sugar, ready for transfer. The digestive substance is known as *enzyme*, and the most abundant enzyme in seeds is *diastase*, which has the power of transforming starch into a sugar. Accompanying these changes there is to be noted a marked evolution of heat, so that if a large mass of seeds is set to germinating, as in the process known as malting, the amount of heat generated may be very great.

The first part of the embryo to protrude from the seed is the tip of the hypocotyl, thrust out by the rapid elongation of the upper part of the hypocotyl (Fig. 143, *B*). This protruding and rapidly elongating tip, which is to develop the root, now rapidly elongates and is very sensitive to the influence of gravity, responding by developing any curvature necessary to reach the soil. Penetrating the soil, and beginning to put out lateral branches, it secures the grip necessary for the extrication of other regions of the embryo.

After some anchorage has thus been obtained, the upper part of the hypocotyl again begins a period of rapid elongation, which results in the development of a curvature known as the "hypocotyl arch" (Figs. 143, *C*, and 143, *a*). In the case of the germinating bean this arch is the first structure to appear above ground, and its pull upon the seed is very apt to bring it to the surface.

Finally, the arch, in its effort to straighten, pulls the cotyledons out of the seed-coats and with them the stem tip, the axis of the plant straightens up (Fig. 143, *a*), the seed-leaves and sometimes other leaves expand, and germination is over; for with roots in the soil, and green leaves expanded to the air and sunlight, the plantlet has become independent (Fig. 331).

It must not be supposed that all of the details just given apply to the germination of all seeds, for there are certain notable variations. For example, in the pea and acorn the cotyledons, so gorged with food as to have lost all power of acting as leaves, are never extricated from the seed-coats, but the stem tip, which lies between the cotyledons, is pushed out by the elongation of the cotyledons at base into short or sometimes long stalks. In the cereals, as corn, wheat, etc., the embryo lies close against one side of the seed, so that it is completely exposed by the splitting of the thin skin which covers it. In such a case the cotyledon is never unfolded, but remains as an absorbing organ, while the root extends in one direction, and the stem, with its succession of unsheathing leaves, develops in the other.

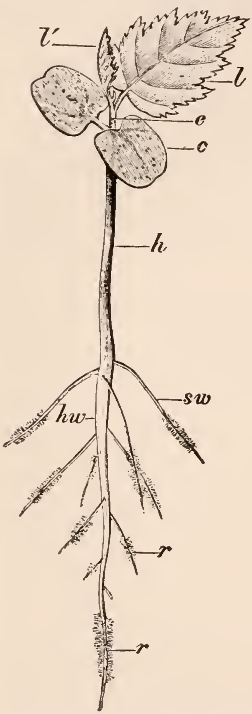


Fig. 331. Seedling of hornbeam (*Carpinus*), showing primary root (*hw*) bearing rootlets (*sw*) upon which are numerous root hairs (*r*), hypocotyl (*h*), cotyledons (*c*), young stem (*e*), and first (*l*) and second (*l′*) true leaves. —After Schimper.

248. **Summary from Angiosperms.** —At the beginning of this chapter (§ 237) the characters of the Gymnosperms were summarized which distinguished them from Angiosperms, whose contrasting characters may be stated as follows:

(1) The m i c r o s p o r e (pollen-grain), chiefly by insect pollination, is brought into contact with the stigma, which is a receptive region on the surface of the carpel, and there de-

velops the pollen-tube, which penetrates the style to reach the ovary cavity which contains the ovules (megasporangia). The impossibility of contact between pollen and ovule implies inclosed ovules and hence seeds, and therefore the name "Angiosperm."

(2) The female gametophyte is but slightly developed before fertilization, the egg appearing very early.

(3) The female gametophyte produces no archegonia, but a single naked egg.

CHAPTER XXV

MONOCOTYLEDONS AND DICOTYLEDONS

249. **Contrasting characters.**—The two great groups of Angiosperms are quite distinct, and there is usually no difficulty in recognizing them. The monocotyledons are usually regarded as the older and the simpler forms, and are represented by about twenty thousand species. The Dicotyledons are much more abundant and diversified, containing about eighty thousand species, and form the dominant vegetation almost everywhere. The chief contrasting characters may be stated as follows:

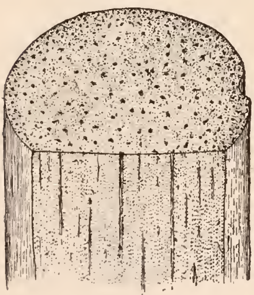


FIG. 332. Section of stem of corn, showing the scattered bundles, indicated by black dots in cross-section, and by lines in longitudinal section. —From "Plant Relations."

Monocotyledons. — (1) Embryo with terminal cotyledon and lateral stem-tip. This character is practically without exception.

(2) Vascular bundles of stem scattered (Fig. 332). This means that there is no annual increase in the diameter of the woody stems, and no extensive branching, but to this there are some exceptions.

(3) Leaf veins forming a closed system (Fig. 333, figure to left). As a rule there is an evident set of veins which run approximately parallel, and intricately branching between them is a system of minute veinlets not readily seen. The vein system does not end freely in the

margin of the leaf, but forms a "closed venation," so that the leaves usually have an even (*entire*) margin. There are some notable exceptions to this character.

(4) Cyclic flowers trimerous. The "three-parted"

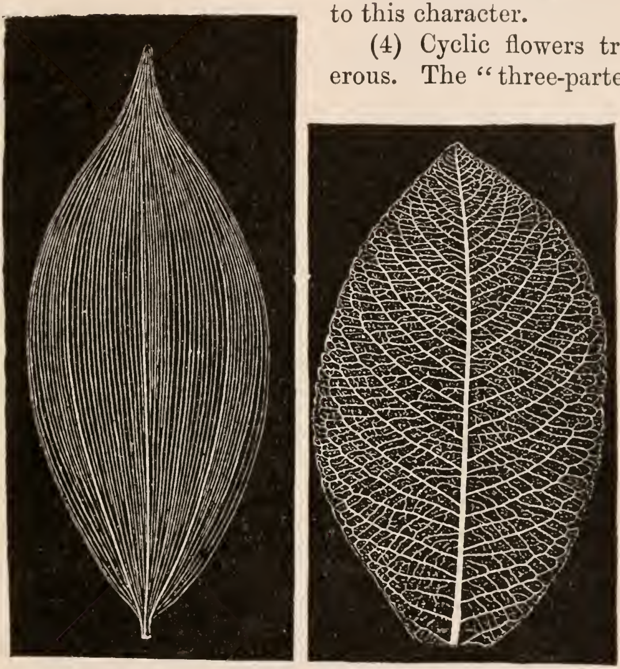


FIG. 333. Two types of leaf venation: the figure to the left is from Solomon's seal, a Monocotyledon, and shows the principal veins parallel, the very minute cross veinlets being invisible to the naked eye; that to the right is from a willow, a Dicotyledon, and shows netted veins, the main central vein (midrib) sending out a series of parallel branches, which are connected with one another by a network of veinlets.—After ETTINGSHAUSEN.

flowers of cyclic Monocotyledons are quite characteristic, but there are some trimerous Dicotyledons.

Dicotyledons.—(1) Embryo with lateral cotyledons and terminal stem-tip.

(2) Vascular bundles of stem forming a hollow cylinder (Fig. 334, *w*). This means an annual increase in the diam-

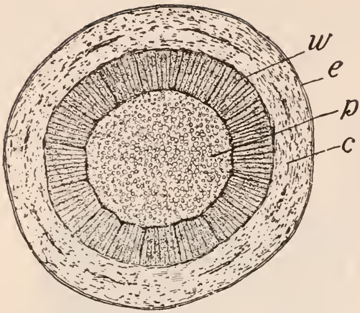


FIG. 334. Section across a young twig of box elder, showing the four stem regions: *e*, epidermis, represented by the heavy bounding line; *c*, cortex; *w*, vascular cylinder; *p*, pith.—From "Plant Relations."

eter of woody stems (Fig. 335, *w*), and a possible increase of the branch system and foliage display each year.

(3) Leaf veins forming an open system (Fig. 333, figure to right). The network of smaller veinlets between the larger veins is usually very evident, especially on the under surface of the leaf, suggesting the name "net-veined" leaves, in contrast to the "parallel-veined" leaves of Monocotyledons. The vein system ends freely in the margin of the leaf, forming an "open venation." In consequence of this, although the leaf may remain entire, it very commonly becomes toothed, lobed, and divided in various ways. Two main types of venation may be noted, which influence the form of leaves. In one case a single very prominent vein (*rib*) runs through the middle of the blade, and is called the *midrib*. From this all the minor veins arise as branches (Fig. 336), and such a leaf is said

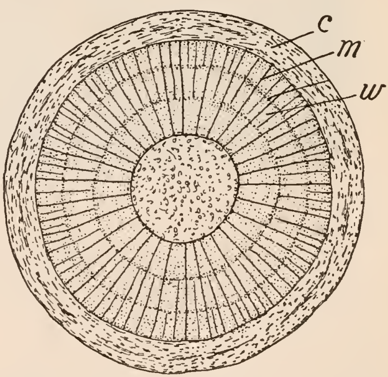


FIG. 335. Section across a twig of box elder three years old, showing three annual rings, or growth rings, in the vascular cylinder; the radiating lines (*m*) which cross the vascular region (*w*) represent the pith rays, the principal ones extending from the pith to the cortex (*c*).—From "Plant Relations."

to be *pinnate* or *pinnately veined*, and inclines to elongated forms. In the other case several ribs of equal prominence enter the blade and diverge through it (Fig. 336). Such a leaf is *palmate* or *palmately veined*, and inclines to broad forms.

(4) Cyclic flowers pentamerous or tetramerous. The flowers "in fives" are greatly in the majority, but some

FIG. 336. Leaves showing pinnate and palmate branching; the one to the left is from sumach, that to the right from buckeye.—CALDWELL.

very prominent families have flowers "in fours." There are also dicotyledonous families with flowers "in threes," and some with flowers "in twos."

It should be remembered that no one of the above characters, unless it be the character of the embryo, should be depended upon absolutely to distinguish these two groups.

It is the combination of characters which determines a group.

250. **Monocotyledons.**—In the Monocotyledons about forty families are recognized, containing numerous genera, and among these genera the twenty thousand species are distributed. It is evident that it will be impossible to consider such a vast array of forms, even the families being too numerous to mention.

Prominent among the families are the aquatic pondweeds of various kinds, the marshy ground cat-tails, the grasses and sedges, the tropical palms, the aroids, the lilies, and the orchids. Of these, the grasses form one of the largest and one of the most useful groups of plants. It is world-wide in its distribution, and is remarkable in its display of individuals, often growing so densely over large areas as to form a close turf. If the grass-like sedges be associated with them there are about six thousand species, representing nearly one third of the Monocotyledons. Here belong the various cereals, sugar-canes, bamboos, and pasture grasses, all of them immensely useful plants.

The palms and the aroids each number about one thousand species, and are conspicuous members of tropical vegetation.

In temperate regions, however, the lilies and their allies stand as the best representatives of Monocotyledons, with their usually conspicuous and well-organized flowers.

In number of species the orchids form the greatest family among the Monocotyledons, the species being variously estimated from six thousand to ten thousand. In display of individuals, however, the orchids are not to be compared with the grasses, or even with the lilies, for in general they are what are called "rare plants." Orchids are the most highly developed of Monocotyledons, and their brilliant coloration and bizarre forms are associated with marvellous adaptations for insect visitation.

251. **Dicotyledons.**—Dicotyledons form the greatest group of plants in rank and in numbers, being the most highly organized, and containing about eighty thousand species. They represent the dominant and successful vegetation in all regions, and are especially in the preponderance in temperate regions. They are herbs, shrubs, and trees, of every variety of size and habit, and the rich display of leaf forms is notably conspicuous.

Two great groups of Dicotyledons are recognized, the *Archichlamydeæ* and the *Sympetalæ*. In the former there is either no perianth or its parts are separate (polypetalous); in the latter the corolla is sympetalous. The Archichlamydeæ are the simpler forms, beginning in as simple a fashion as do the Monocotyledons; while the Sympetalæ are evidently derived from them and become the most highly organized of all plants. The two groups each contain about forty thousand species, but the Archichlamydeæ contain about one hundred and sixty families, and the Sympetalæ about fifty.

(1) *Archichlamydeæ.*—In this great division of Dicotyledons are such groups as the great tree alliance which includes poplars, oaks, hickories, elms, willows, etc.; the buttercup alliance, which includes buttercups, water-lilies, poppies, mustards, etc.; the rose family, one of the best known and most useful groups of the temperate regions; the pea family, by far the greatest family of the Archichlamydeæ, containing about seven thousand species; the parsley family, or umbellifers, containing numerous useful forms, and being the most highly organized family of the Archichlamydeæ.

(2) *Sympetalæ.*—These are the highest and the most recent Dicotyledons. While they contain numerous shrubs and trees in the tropics, they are by no means such a shrub and tree group in the temperate regions as are the Archichlamydeæ. The flowers are constantly cyclic, the number five or four is established, and the corolla is

sympetalous, the stamens usually being borne upon its tube.

Among the numerous families the following are prominent: the heaths, mostly shrubs of temperate and arctic or alpine regions; the convolvulus alliance, with corolla in the form of conspicuous tubes, funnels, trumpets, etc.; the aromatic mint family, with more than ten thousand species, and its allies the nightshades, the figworts, and the verbenas; and, last and highest, the family of composites, the greatest and ranking family of Angiosperms, estimated to contain at least twelve thousand species, more than one seventh of all known Dicotyledons, and more than one tenth of all Seed-plants. Not only is it the greatest family, but it is the youngest. Composites are distributed everywhere, but are most numerous in temperate regions, and are mostly herbs.

GLOSSARY

[The definitions of a glossary are often unsatisfactory. It is much better to consult the fuller explanations of the text by means of the index. The following glossary includes only frequently recurring technical terms. Those which are found only in reasonably close association with their explanation are omitted.]

AKENE: a one-seeded fruit which ripens dry and seed-like.

ALTERNATION OF GENERATIONS: the alternation of gametophyte and sporophyte in a life history.

ANEMOPHILOUS: applied to flowers or plants which use the wind as agent of pollination.

ANTHER: the sporangium-bearing part of a stamen.

ANTHERIDIUM: the male organ, producing sperms.

APETALOUS: applied to a flower with no petals.

APOCARPOUS: applied to a flower whose carpels are free from one another.

ARCHEGONIUM: the female, egg-producing organ of Bryophytes, Pteridophytes, and Gymnosperms.

ASCOCARP: a special case containing asci.

ASCOSPORE: a spore formed within an ascus.

ASCUS: a delicate sac (mother-cell) within which ascospores develop.

ASEXUAL SPORE: one produced usually by cell-division, at least not by cell-union.

CALYX: the outer set of floral leaves.

CAPSULE: in Bryophytes the spore-vessel; in Angiosperms a dry fruit which opens to discharge its seeds.

CARPEL: the megasporophyll of Spermatophytes.

CHLOROPHYLL: the green coloring matter of plants.

CHLOROPLAST: the protoplasmic body within the cell which is stained green by chlorophyll.

CONJUGATION: the union of similar gametes.

COROLLA: the inner set of floral leaves.

Cotyledon: the first leaf developed by an embryo sporophyte.

Cyclic: applied to an arrangement of leaves or floral parts in which two or more appear upon the axis at the same level, forming a cycle, or whorl, or verticil.

Dehiscence: the opening of an organ to discharge its contents, as in sporangia, pollen-sacs, capsules, etc.

Dichotomous: applied to a style of branching in which the tip of the axis forks.

Diœcious: applied to plants in which the two sex-organs are upon different individuals.

Dorsiventral: applied to a body whose two surfaces are differently exposed, as an ordinary thallus or loaf.

Egg: the female gamete.

Embryo: a plant in the earliest stages of its development from the spore.

Embryo-sac: the megaspore of Spermatophytes, which later contains the embryo.

Endosperm: the nourishing tissue developed within the embryo-sac, and thought to represent the female gametophyte.

Entomophilous: applied to flowers or plants which use insects as agents of pollination.

Epigynous: applied to a flower whose outer parts appear to arise from the top of the ovary.

Fertilization: the union of sperm and egg.

Filament: the stalk-like part of a stamen.

Foot: in Bryophytes the part of the sporogonium imbedded in the gametophore; in Pteridophytes an organ of the sporophyte embryo to absorb from the gametophyte.

Gametangium: the organ within which gametes are produced.

Gamete: a sexual cell, which by union with another produces a sexual spore.

Gametophyte: in alternation of generations, the generation which bears the sex organs.

Heterogamous: applied to plants whose pairing gametes are unlike.

Heterosporous: applied to those higher plants whose sporophyte produces two forms of asexual spores.

Homosporous: applied to those plants whose sporophyte produces similar asexual spores.

Host: a plant or animal attacked by a parasite.
Hypha: an individual filament of a mycelium.
Hypocotyl: the axis of the embryo sporophyte between the root-tip and the cotyledons.
Hypogynous: applied to a flower whose outer parts arise from beneath the ovary.

Inflorescence: a flower-cluster.
Integument: in Spermatophytes a membrane investing the nucellus.
Isogamous: applied to plants whose pairing gametes are similar.

Male cell: in Spermatophytes the fertilizing cell conducted by the pollen-tube to the egg.
Megasporangium: a sporangium which produces only megaspores.
Megaspore: in heterosporous plants the large spore which produces a female gametophyte.
Megasporophyll: a sporophyll which produces only megasporangia.
Mesophyll: the tissue of a leaf between the two epidermal layers which usually contains chloroplasts.
Microsporangium: a sporangium which produces only microspores.
Microspore: in heterosporous plants the small spore which produces a male gametophyte.
Microsporophyll: a sporophyll which produces only microsporangia.
Micropyle: the passageway to the nucellus left by the integument.
Monœcious: applied to plants in which the two sex organs are upon the same individual.
Mycelium: the mat of filaments which composes the working body of a fungus.

Naked flower: one with no floral leaves.
Nucellus: the main body of the ovule.

Oogonium: the female, egg-producing organ of Thallophytes.
Oosphere: the female gamete, or egg.
Oospore: the sexual spore resulting from fertilization.
Ovary: in Angiosperms the bulbous part of the pistil, which contains the ovules.
Ovule: the megasporangium of Spermatophytes.

Parasite: a plant which obtains food by attacking living plants or animals.
Perianth: the set of floral leaves when not differentiated into calyx and corolla.

Petal: one of the floral leaves which make up the corolla.

Photosynthesis: the process by which chloroplasts, aided by light, manufacture carbohydrates from carbon dioxide and water.

Pistil: the central organ of the flower, composed of one or more carpels.

Pistillate: applied to flowers with carpels but no stamens.

Pollen: the microspores of Spermatophytes.

Pollen-tube: the tube developed from the wall of the pollen grain which penetrates to the egg and conducts the male cells.

Pollination: the transfer of pollen from anther to ovule (in Gymnosperms) or stigma (in Angiosperms).

Polypetalous: applied to flowers whose petals are free from one another.

Prothallium: the gametophyte of Ferns.

Protonema: the thallus portion of the gametophyte of Mosses.

Receptacle: in Angiosperms that part of the stem which is more or less modified to support the parts of the flower.

Rhizoid: a hair-like process developed by the lower plants and by independent gametophytes to act as a holdfast or absorbing organ, or both.

Saprophyte: a plant which obtains food from the dead bodies or body products of plants or animals.

Scale: a leaf without chlorophyll, and usually reduced in size.

Sepal: one of the floral leaves which make up the calyx.

Sexual spore: one produced by the union of gametes.

Sperm: the male gamete.

Spiral: applied to an arrangement of leaves or floral parts in which no two appear upon the axis at the same level; often called alternate.

Sporangium: the organ within which asexual spores are produced (except in Bryophytes).

Spore: a cell set apart for reproduction.

Sporogonium: the leafless sporophyte of Bryophytes.

Sporophore: a special branch bearing asexual spores.

Sporophyll: a leaf set apart to produce sporangia.

Sporophyte: in alternation of generations, the generation which produces the asexual spores.

Stamen: the microsporophyll of Spermatophytes.

Staminate: applied to a flower with stamens but no carpels.

Stigma: in Angiosperms that portion of the carpel (usually of the style) prepared to receive pollen.

STOMA (pl. STOMATA): an epidermal organ for regulating the communication between green tissue and the air.

STROBILUS: a cone-like cluster of sporophylls.

STYLE: the stalk-like prolongation from the ovary which bears the stigma.

SYMBIONT: an organism which enters into the condition of symbiosis.

SYMBIOSIS: usually applied to the condition in which two different organisms live together in intimate and mutually helpful relations.

SYMPETALOUS: applied to a flower whose petals have coalesced.

SYNCARPOUS: applied to a flower whose carpels have coalesced.

ZOOSPORE: a motile asexual spore.

ZYGOTE: the sexual spore resulting from conjugation.

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THE END