Frontispiece.

Forest in the Southern Appalachian Mountains.

BOTANY

FOR HIGH SCHOOLS

BY

GEORGE FRANCIS ATKINSON, PH.B.

PROFESSOR OF BOTANY IN CORNELL UNIVERSITY

NEW YORK
HENRY HOLT AND COMPANY
1910

Pres' Office

10-14504

Stanhope Press
F. H. GILSON COMPANY
BOSTON, U.S.A.

PREFACE.

This book is addressed to pupils in their first or second year in the high school. It assumes that Botany may be the first science they study, and that therefore it should provide plenty of individual work within their powers, and should give this work unity of effect and make it evidently worth while. In keeping with the modern scientific spirit, nutrition, reproduction, and relation to man are made the dominant aspects of the subject. What plants are is made to appear in terms of what they do. Structures and processes are then interpreted both from the plant's point of view and from man's. The problems set before the pupil call for definite and continued effort on his part, and for the independent interpretation of observations. The economic relations of plant life are noted as the study proceeds, and the concluding chapters are intended to leave the pupil with a general view of the larger general applications of the science.

Especial importance is given to the study of seeds and seedlings, the parts of the full-grown plant and the principal types or forms of the root, stem and leaf, including the work performed by these parts in providing food and water, building material, and food storage. Since the flower is an important structure designed for the purpose of facilitating seed production, with principal and subordinate organs for this work, especial interest is attached to a careful study of its parts and their structure. As the different kinds of flowers and the different modes of their association on the flower shoot are the result of the operation of natural laws, floral structures and groupings naturally indicate plant relationship. Several of these different types are therefore studied, not for the primary purpose of plant analysis leading to the naming of plants, but in order to stimulate the student to recognize some of the general facts indicating the bond which unites the very diverse elements of the natural world. This should be one of the chief aims in all studies of nature, not because it is the scientific method, but because of the unconscious and wholesome influence which it has upon the formation of character and the development of a taste for the things beautiful in nature, in art, and in life's best work.

Several chapters are devoted to a study of the peculiar and unusual forms of nutrition by certain plants that have become closely associated in this respect with other organisms, and by the fungi and bacteria, which, lacking chlorophyll, must obtain certain food by other means than that employed by the green plants. In this connection special attention is given to some of the more important micro-organisms which are beneficial to man because of certain products of their activity, or which are harmful as causal agents in disease. One chapter is devoted to the study of the more useful plants of the farm, orchard and garden or of those employed in industrial operations. Chapters are also devoted to the principles of plant development and plant breeding, subjects which are of absorbing interest to all and of special practical importance to the farmer and horticulturist.

In schools where attention can be given to a study of representative plants in the different branches of the Plant Kingdom (in most schools at least a few can be studied) the chapters on the algæ, fungi, mosses and ferns will furnish the material and outline. Footnotes at the beginning of these chapters suggest one or two plants in each group which can be studied where there is not time for all. In these chapters several more plants are treated than can under ordinary circumstances be studied in the high-school course. Their inclusion in the book, however, aids in rounding out the subject, and in most cases they will serve a purpose for special assignment for reading, or for reference or for illustration.

Chapters XXXIV and XXXV, on the Gymnosperms and Angiosperms, as well as the latter portions of the chapters on the algæ, fungi, mosses and ferns, are not intended for study except in advanced classes. Some few students, however, will be interested in the life histories, with the illustrative formulæ and graphic representations of life cycles, together with the reviews showing progression in the evolution of plant structures. The author believes it is a good principle in pedagogy to present now and then ideas and inferences upon the work which may be beyond the comprehension of the majority of the members of the class, of course without holding the students answerable in any way for it. It is stimulating and suggestive to most students especially if it is not required work, and serves now and then to lift their minds out of the "humdrum" of the regular course. A few will catch glimpses of principles and processes in nature which will be decidedly beneficial in the development of thought and reasoning power.

Since it is neither practicable nor desirable to lay down a hard and fast course for all high schools, there are suggested below several courses which are suitable for different conditions.

For short courses, one half year or less: Part I, and Chapter XXXVI (Economic or Useful Plants) with parts of Chapters XXXVII, XXXVIII and XXXIX. For a full half-year course the study of an alga (Spirogyra), a mold (Bread mold), a moss (Polytrichum or other type) and a fern may be added.

For courses in agricultural botany: Part I, and Chapters XXVI–XXIX (Fungi), Chapter XXXVI (Economic or Useful Plants), and parts of Chapters XXXVII, XXXVIII and XXXIX.

For two half-year courses: *First course:* Part I, and Chapter XXXVI (Economic or Useful Plants) and parts of Chapters XXXVII, XXXVIII and XXXIX. *Second course:* Chapters XXII–XXXV. Several algæ and fungi, a lichen, a liverwort and moss (with a few additional types for illustration), a fern (with several additional ones, with horsetails, club-mosses and quillwort for illustration), a pine (with other conifers and Cycas, Zamia and Ginkgo for illustration).

Many of the illustrations are new and were made especially for this book, the photographs being made by the author and the drawings by Mr. Frank Rathbun under the author's supervision. Acknowledgments are due to Messrs. Ginn and Company for the use of a few illustrations from Bergen and Davis's *Principles of Botany* and from the author's *First Studies in Plant Life;* to D. Appleton & Co. for the use of a few illustrations from Coulter's *Botany;* and to the Bureau of Forestry and the Bureau of Plant Industry, U. S. Dept. of Agriculture, for some photographs which are acknowledged in connection with the illustrations.

G. W. A.

CORNELL UNIVERSITY, *April*, 1910.

TABLE OF CONTENTS.

PART I. GROWTH AND WORK OF PLANTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER XV.

CHAPTER XVI.

CHAPTER XVII.

CHAPTER XVIII.

CHAPTER XIX.

CHAPTER XX.

CHAPTER XXI.

PART II. GENERAL MORPHOLOGY AND CLASSIFICATION OF PLANTS.

CHAPTER XXII.

CHAPTER XXIII.

CHAPTER XXIV.

CHAPTER XXV.

CHAPTER XXVI.

CHAPTER XXVII.

CHAPTER XXVIII.

CHAPTER XXIX.

CHAPTER XXX.

CHAPTER XXXI.

CHAPTER XXXII.

CHAPTER XXXIII.

CHAPTER XXXIV.

CHAPTER XXXV.

CHAPTER XXXVI.

CHAPTER XXXVII.

CHAPTER XXXVIII.

CHAPTER XXXIX.

CHAPTER XL.

CHAPTER XLI.

PART I.

GROWTH AND WORK OF PLANTS.

CHAPTER I.

PARTS OF SEEDS AND HOW SEEDS GERMINATE.

THE BEAN.

1. Seed of the common garden bean.—There are many varieties of garden beans but the form of the seed is often slightly curved or kidney-shaped as seen in side view. Upon the concave side there are distinct markings. There is a scar (= hilum) about the middle line. This is the point where the seed was attached to the wall of the bean pod as can easily be seen in the case of young beans by opening the pods. On either side of the scar is a minute mark. One of these is slightly larger than the other and often appears when examined under a hand lens to be somewhat heart-shaped. It is continuous with a short elevated line on that end of the bean. This slightly elevated line is the *raphe* (fig. 1). It is formed by the stalk of the ovule (the very young stage of the seed in the pod) which is attached at the end of the bean and here is bent around and joined to the edge. On the other side of the scar and near it is a minute opening, the *micropyle.* The root of the embryo lies beyond this just underneath the seed coats. Its position is often manifest by a prominent elongated elevation especially when the bean is swollen after soaking in water.

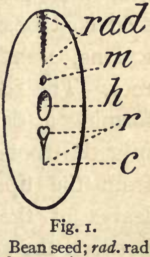


Fig. 1.
Bean seed; *rad.* radicle as primary root; *m.* micropyle; *h.* hilum; *r.* raphe; *c.* chalaza.

2. Parts of the bean seed.—When beans are soaked for a few hours in water the seed coats take up the water faster than the embryo and consequently swell faster and become much wrinkled. The seed coats thus become loosened from the embryo within and can be easily slipped off. After a time the embryo swells by imbibition of water and the seed becomes plump again. When the seed is split in two lengthwise by cutting the seed coats along the convex side, the two halves can be laid open. These two fleshy bodies are the *seed leaves* or *cotyledons*, and the rest of the embryo is attached at one end to one of the halves, its attachment being broken away from the other. The root or radicle lies at one end next the seed coats and in the entire bean seed causes the short elevated line at this end of the seed. At the opposite end is the *plumule*, consisting of two or four membranous leaves now somewhat triangular in form and marked with fine lines or veins. The stem of the embryo is short, and is that part of the embryo to the upper end of which the cotyledons are attached, and to the lower end of which the radicle is attached. This part of the stem is the *hypocotyl*.

Fig. 2.
Bean seeds soaking and swelling; read from left to right.

3. Germination of the bean.—In germination the radicle elongates more rapidly at first than the other parts, soon pierces the seed coat near the scar and forms a long, slender, conical, primary root. The root hairs soon appear, forming a dense velvety covering over the root a little distance back from the tip. As the stem, and leaves of the plumule, which lie between the cotyledons, increase in size the seed coats are ruptured by the pressure and are usually cast off in the soil. The part of the stem which lies between the cotyledons and the root now elongates very rapidly

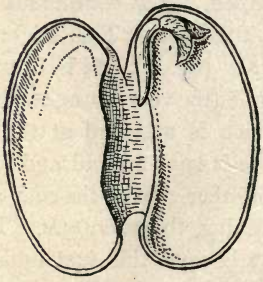


Fig. 3.
Bean seed split in two, showing plantlet (radicle and plumule) at one end.

and arches up in the form of a loop. It is this loop which breaks the way through the soil, since it would be a difficult task for the slender stem to push the bulky cotyledons up ahead of it. The cotyledons are therefore pulled from the ground as the loop straightens up after emerging from the soil. This portion of the stem (hypocotyl) becomes quite long in the bean, but is quite short in the corn. The cotyledons are thus lifted above the ground. They become more or less shrivelled and shrunken because of the food substance withdrawn for the growth of the seedling, and finally fall away, as the young membranous leaves expand and the stem elongates.

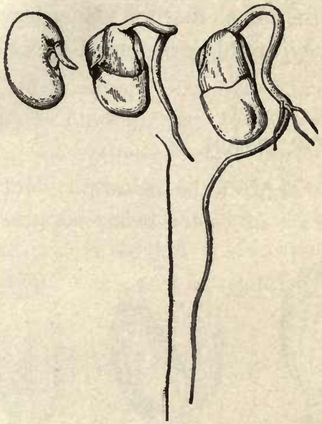


Fig. 4.
Bean seeds germinating, seed coat slipping off.

Fig. 5.
Beans germinating, one cotyledon removed, showing expanding plumule.

Fig. 6.
How the garden bean comes out of the ground. First the looped hypocotyl, then the cotyledons pulled out, next casting off the seed coat, last the plant erect, bearing thick cotyledons, the expanding leaves, and the plumule between them.

4. In the scarlet runner bean, and in the pea, the hypocotyl remains short so that the cotyledons are left in the ground. The portion of the stem above the cotyledons elongates and forms the loop as the seedling emerges from the soil so that the tender leaves and plumule are not injured, as they would be if pushed up while they are standing erect.

THE CASTOR BEAN.

5. The castor-oil bean.—The seed of the castor-oil plant is often called a bean, castor-oil bean, or castor bean, because it resembles a bean somewhat in shape. It is, however, not a true bean, but belongs to the Spurge family. At the smaller end of the seed there is a mass of spongy tissue which covers the hilum. This is called the *caruncle.* Its function is to absorb moisture and thus provide for the passage of water through the hilum end of the seed, where it passes more readily than through the outer parts of the hard seed coats, which are smooth as if varnished, and not so absorbent as the dull more porous part of the coat which lies under the caruncle. When the seed is cut open there is seen a mass of white mealy substance, the

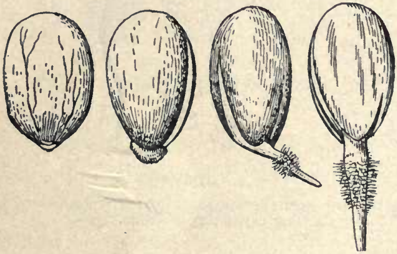


Fig. 7.
Castor bean seeds sprouting.

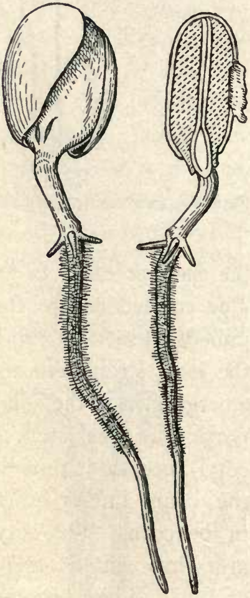


Fig. 8.
Castor bean germinating. At right, section showing the two thin cotyledons lying between the endosperm.

endosperm,* which is covered by a thin papery material.† The embryo lies within the endosperm; its radicle at the end next the caruncle. The two cotyledons are thin and covered by the endosperm.

6. Germination of the castor bean.—The spongy substance of the caruncle becomes much swollen by absorption of water. In germination the swelling of the embryo and endosperm by the absorption of water bursts the rigid seed coat causing it to crack lengthwise, so that a portion of the endosperm can be seen through the crack. The radicle emerges from the end where the caruncle is located. The hypocotyl, which is very short in the embryo stage, now elongates. The seed being bulky is not readily pushed up through the soil. The hypocotyl part of the stem arches upward forming a loop and as it elongates and endeavors to straighten up it pulls the "seed" from the ground. Figure 9 shows different stages. The hard seed coat gradually slips off. The white endosperm is now very distinct and is seen to cover up the cotyledons which remain closed. It can be seen, however, that the endosperm is "wasting away," that it is being absorbed through the outer faces of the cotyledons. By this means, they are exposed to the light and take on a green color. The mass of the endosperm becomes less and less, until finally there is but a thin

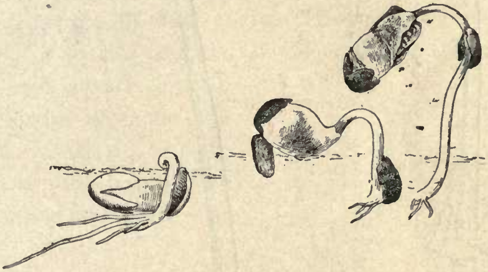


Fig. 9.
Germination of castor-oil bean.

---

* The endosperm is food stored in the seed outside of the embryo.

† This papery lining is the dead remnant of the nucellus which was used up in the growth of the endosperm. See Chapter XXXV.

film or remnant which dries. The food stored in the seed here has, therefore, been completely used up by the embryo during germination, and the cotyledons have served as the absorptive organs for this food.

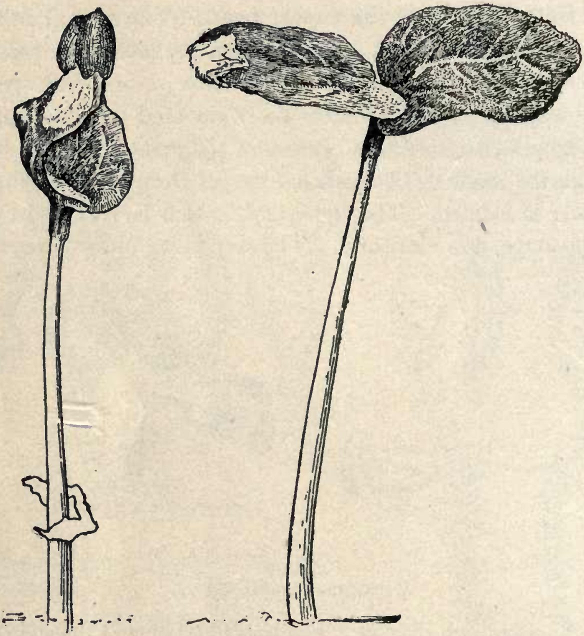


Fig. 10.

Seedlings of castor-oil bean casting the seed coats, and showing papery remnant of the endosperm.

7. The embryo of the castor-oil bean presents a type very different from that of the bean as we can readily see by a comparison. Yet the two types so different in form and structure are very similar when we consider the relation of the food substance to the cotyledons and the function of the latter in absorption of this stored food. It should not be difficult now to understand how the embryo of the bean and pea during the formation of the seed can absorb the endosperm through the cotyledons though it is stored in the cotyledons as food for the embryo during germination and the early stage of the seedling.

side to the stem or caulicle and this point of connection can be seen quite clearly. This is the *scutellum* of the embryo, so called because of its form and the central attachment at one side which resembles a little shield. The stem or caulicle, the leaf bud, or plumule, the root or radicle, the root sheath, and the scutellum or cotyledon, make the young embryo in the corn seed. There is still a large bulk of the content of the grain which lies against the scutellum. This is known as the *endosperm*. In the corn it is largely made up of starch which is stored food for the young embryo when the seed germinates.

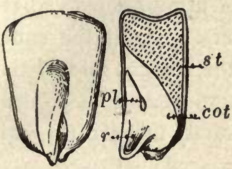


Fig. 15.
Corn grains sprouting; *st.* starch; *cot.* cotyledon; *pl.* plumule; *r.* radicle in root sheath, the sheath still covering the root.

12. Germination of the corn.—The root sheath usually emerges first with the radicle of the embryo still enclosed. While the root sheath is still short, lengthwise sections will show that it has ceased to elongate, and the root has pushed through it at one end.

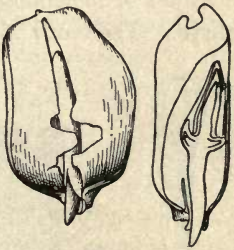


Fig. 16.
Germination of corn grains, showing origin of first lateral roots. Note the radicle (primary root) emerging from the root sheath. In right-hand seedling note the remains of root sheath from which the radicle emerged.

Fig. 17.
Germinating corn grains. Plumule and primary root have emerged.

At this stage sections also show, when made through the middle line of the embryo, the origin of the first two lateral roots. One of them lies inside in the axis of the scutellum and the leaf, while the other lies opposite underneath the coat of the groove (see fig. 16). They are really adventitious roots since they arise from the stem. The true lateral roots arise from the primary root and extend in a nearly horizontal direction, and the branching of these finally results in a great mass of fibrous roots radiating in all directions in the upper soil layers. About the same time or very soon after the root emerges, the conical fold of the leaves emerges from the other end of the groove. This conical form of the folded leaves wedges its way directly upward through the soil. The leaves elongate and unfold.

THE PINE.

13. The pine seed.—The seeds of the pine are formed on the upper (inner) surface of the scales of the pine cone (see paragraph 529 on cones of the pine). The seeds are oval and somewhat compressed and flattened, and attached to the lower end of the scale, two on each scale. As they become freed from the scale a long, thin and broad strip of the scale splits off and remains attached to the seed as a wing. A section of the seed shows the thin papery remnant of the nucellus lying between the seed coats and the white mass of the endosperm. Within this lies the embryo. The root and stem together form a straight cylindrical portion, and at the stem end there is a crown of small needlelike leaves, the seed leaves or cotyledons. The cotyledons are numerous in the pines. The embryo is entirely destitute of chlorophyll, but during germination, even if the seedlings are grown in the dark the leaves become green. In germination the radicle emerges from the micropylar end of the seed. The hypocotyl elongates and forms a loop which pulls the leafy end of the stem and the cotyledons from the ground.

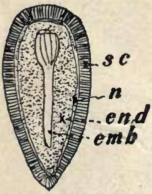


Fig. 18.
Pine seed, section of. *sc.* seed coat; *n*, remains of nucellus; *end.* endosperm (= female gametophyte); *emb.* embryo = young sporophyte. Seed coat and nucellus = remains of old sporophyte.

Fig. 19.
Embryo of white pine removed from seed, showing several cotyledons.

Fig. 20.
Pine seedling just emerging from the ground.

CONCLUSIONS

14. The seed.—A seed is a plant structure composed of the embryo plant surrounded by the seed coats. The seed coats are formed from the walls of the ovule. The seed is capable, by the growth of the embryo, of producing a plant similar to the parent.

The embryo is made up of the three principal parts of the plant, the root, stem and leaf, but these parts are in a very rudimentary form. Squash, pea, bean, castor bean and apple seeds are examples of clearly defined seeds. The "shell" of the squash or apple seed or the membrane which can be slipped off from a pea or bean after being thoroughly soaked in water, is made up of the seed coats. The entire content of the squash or almond seed is the embryo.

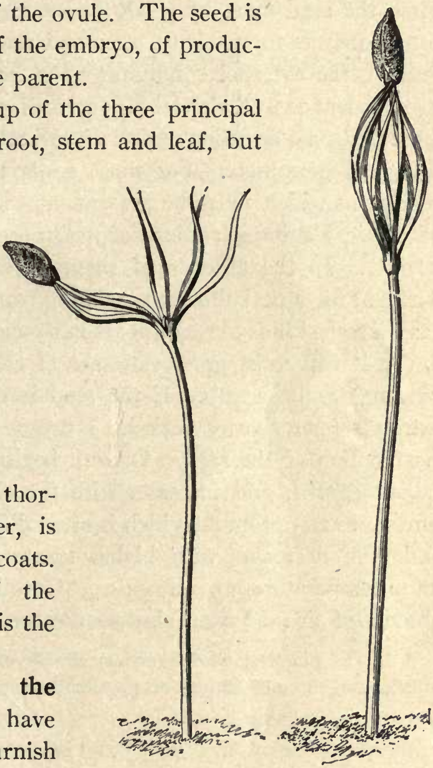


Fig. 21.
White-pine seedling casting seed coats.

15. Food stored in the seed.—Nearly all seeds have food stored in them to furnish nutriment for the embryo plant from the time of germination until the seedling has established itself in the earth, where it can obtain its food from the outside. In the squash, bean, pea, etc., the food is stored up in the two first seed leaves (cotyledons) which make the bulk of the embryo and are easily recognized as the two fleshy halves. In other seeds, as in the castor bean, the corn, wheat, etc., the food is stored around, or at one side of the embryo, within the seed coats, and is then known as *endosperm* (literally the inside of the seed).

16. Conditions of germination of seeds.—In order that the seeds of plants may germinate, certain conditions must be fulfilled. First, the seed must be good; i.e., it must meet certain internal conditions, as to maturity, age, and the vitality of the embryo. Second, the external conditions must be favorable. Seeds vary a great deal as to their viability according to age, etc.; some seeds must first pass a resting period of several weeks or months before they will germinate. For most seeds there are three external conditions which must be present in order that they may germinate; *air*, a suitable amount of *moisture*, and a suitable degree of *warmth*. In the absence of these conditions the seeds remain dormant for a period of time ranging from a very few days in the case of some kinds to many years in the case of others. If the seed is dry it will resist great extremes of cold (many degrees below freezing) and warmth. If the seed is moist it will resist these extremes for a shorter period. Extreme cold prevents or retards germination of the seed. Growth begins slowly at about 6° C. (about 43° F.), and increases with the elevation of the temperature up to an optimum, which is often different in different plants, and then decreases with higher temperatures until at a maximum temperature growth ceases. Germination may begin in the absence of air (of oxygen) but soon ceases.*

---

* In the practical work exercises can be arranged to demonstrate the influence of these conditions on germination.

CHAPTER II.

NATURE OF FOOD STORED IN SEEDS AND OTHER PLANT PARTS.*

17. In the study of the parts of the seed it was found that the seedlings are able to make considerable growth when not supplied with food from the outside. This growth goes on at the expense of food stored in the seed. This food was stored up in the seed during its formation in the ripening of the fruit. In some seeds it is laid down outside of the embryo and is called *endosperm*, as in the grain of corn, wheat, castor bean, etc. In others, while it was first formed as endosperm in the young seed, it was largely or completely absorbed by the embryo during the ripening of the seed, as in the bean, pea, squash, sunflower, etc., where it is stored in the cotyledons of the embryo. In the study of the seeds we have found the general location of the food substance. We wish now to learn more particularly the form in which it is stored, its nature, as well as the special receptacles and their arrangement. The special receptacles are the *cells*† of the endosperm, the cotyledons, etc., where the food is stored.

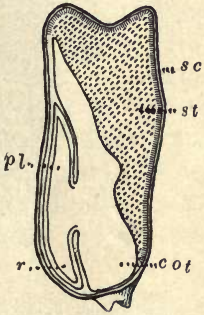


Fig. 22.

Section through grain of corn. *s.c.* seed coats; *st.* starch, the aleurone layer lies between the starch and seed coats; *cot.* cotyledon (here the *scutellum*); *r.* radicle enclosed root sheath; *pl.* plumule.

---

* It will probably be found convenient to study the nature and location of food substances while the student is studying the various seeds, bulbs, shoots, roots, etc., but this short chapter is introduced here in order to avoid the unnecessary description of them with each different object studied.

† A *cell* is a unit of microscopic structure in plants. It is like a minute box with cellulose for its walls. Living and growing cells contain the life substance (protoplasm) which has a complicated structure. In some plants

18. Minute structure of the coats and outer layer of food reservoir in corn and wheat grains.—This structure is determined by a study of a thin section cut from a grain and extending through the outer surface and a short distance into the interior or flour part, and magnified by the use of the microscope. Figure 23 is from a wheat grain, and the parts are as follows: the outer layer of cells (*ep*) is the epidermis, and upon this is the cuticle (*c*); next are a few layers of cells (*m*) the middle layer of brown, and next (i, i_1) comes the inner layer of brown.* Together these are some-

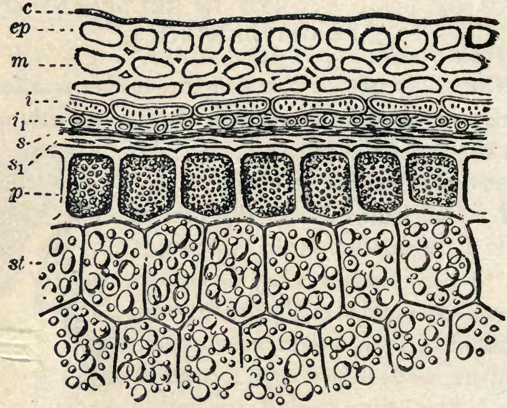


Fig. 23.

Section through exterior part of a grain of wheat. *c*, cuticle, or outer layer of bran; *ep*, epidermis; *m*, middle layer; *i*, i_1, layers of hull next to seed coats; *s*, s_1, seed coats; *p*, layer containing proteid grains; *st*, cells of the endosperm filled with starch. Greatly magnified. — After Tschirch.

the protoplasmic units are not bounded off by cell walls, still in general we can say that the cell is the unit of structure, at least of the tissues of the higher plants. A *tissue* is a group of cells of one kind, or in some cases of different kinds united together.

* These three portions of the brown layers are not a part of the seed. They are a part of the fruit and are in reality the wall of the ovary inside of which the seed is formed. If this brown layer could be entirely removed from the grain of corn and wheat the remaining part of the grain would be the seed. While then we speak of the grain of corn and wheat as seeds we should remember that this usage is not technically correct, for the walls of the seed capsule are consolidated with those of the seed.

times called the bran layer. The two layers of cells (s, s_1) are the two seed coats (the outer and the inner seed coats. See the formation of the seed, paragraph 305.) At *p* is the aleurone layer, the cells containing proteid grains, and at *st* are the starch containing cells.

19. The aleurone layer. — Lying just within the seed coats is a single layer of very regular cells rectangular in outline and nearly cuboidal in form. They are packed with fine granular content. This layer of cells is the *aleurone* layer. The granules in the cells are *proteid* grains or aleurone grains. These proteids form one of the food substances stored in many seeds. The aleurone layer is rich in nitrogenous food, the proteids being a nitrogenous substance containing nitrogen (N), carbon (C), hydrogen (H), oxygen (O), sulphur (S) and sometimes phosphorus (P). This forms the most nutritious part of the flour, and it is well known that nitrogenous foods, both for plants and animals, are much less abundant and more costly than most other foods. These proteids are in composition very much like the albumen, or white of egg.

20. The starch in the endosperm.—Just inside of the aleurone layer is a tissue of large angular cells filled with coarse whitish grains. These are starch grains. Starch does not contain nitrogen. It consists of three elements, C, H, and O.* The starch grains vary greatly in size, and in some plants they are much larger than in others. If the section of a grain of wheat or corn is treated with iodine the starch is stained blue while the aleurone layer is stained brownish yellow.

21. Starch.—Starch is stored in plants usually in the form of grains which are deposited inside the cells. While these grains are microscopic in size, they vary a great deal in different plants. Commercial starch, while it will give the reactions for starch, is not suitable for the study of the grains, since they are destroyed in its preparation. Starch becomes blue by treatment with a few drops of a tincture of iodine, or, better, a solution of iodine in potassium iodide. Sometimes the color is more

---

* $C_6H_{10}O_5$.

or less of a purple or violet shade. We should distinguish between reserve starch and transitory starch. Reserve starch is that which is stored in special receptacles for future use and is that which is utilized by man for commercial purposes. Transitory starch is that which is formed during the day, and at night is transported to the reserve organs. Reserve starch grains are usually much larger than transitory starch grains.

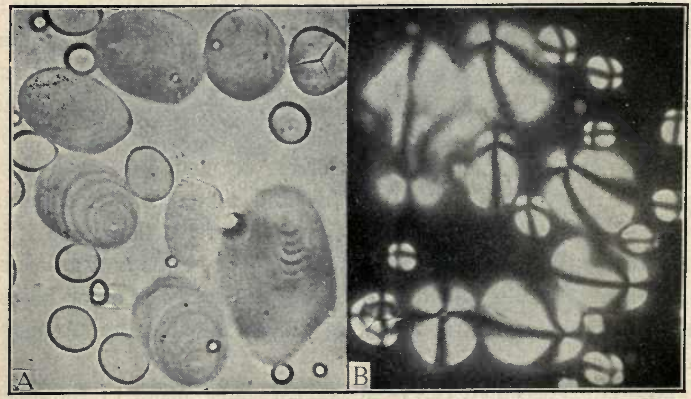


Fig. 24.

A. Photomicrograph of starch grains from potato.

B. Photomicrograph of starch grains from potato, polarized light.

22. Form and appearance of starch grains.—In the potato tuber the starch grains are packed in the cells. The grains are of quite large size as compared with many other kinds of starch. They present a very interesting and characteristic structure. The grain appears to be stratified, the strata often being in excentric layers. In potato starch these strata are usually in excentric rings about a single spot called the hilum. These layers are supposed to be made up of alternate dense and less dense layers of the substance. Potato starch grains are oval to rhombic in form. Starch grains of the corn are more or less angular and are much smaller than those of the potato. Those of the bean and other legumes are more or less kidney shaped. In the corn and bean starch grains there are often radiating lines from the hilum, which appear like fissures. The starch grains of wheat are of two kinds, very small ones, and quite large ones mixed in with them.

23. The starch grains are surrounded by a thin coating of cellulose, a substance similar to that of which the cell walls of plants are made. This must be dissolved before the plant can use the starch for food. The plant dissolves it by the use of certain cellulose ferments manufactured by it, and then the starch is dissolved by the diastase ferment (paragraph 180). A similar diastase is present in the saliva of man, but this will not act on the starch grains unless the cellulose coat is broken, or dissolved by some ferment. Heat causes the starch grains to swell. If they are mixed with water, gentle heat changes the grains to a paste. If dry, the cellulose coat is ruptured as the starch swells. Thorough cooking of starchy vegetables and fruits makes them easier of digestion.

24. Corrosion of starch grains during germination.— Since plants cannot absorb solid particles of food, the embryo in the seed cannot use the starch for food until after it is dissolved. The embryo has the power to excrete a juice or ferment (diastase) which acts on the starch grains, dissolving them and changing them to a sugar. During this process the starch grains become corroded. To see the corroded starch grains, take some of the endosperm of the grain of corn at different stages of germination and examine under the microscope. In comparing the appearance of these starch

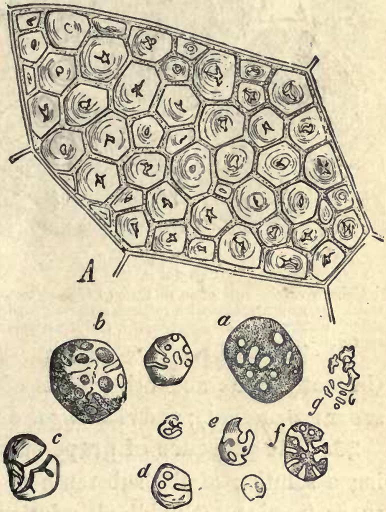


Fig. 25.

Cell of endosperm of Indian corn, containing polygonal starch grains, separated by thin plates of protoplasm. In the figures *a* to *g*, the starch grains, taken from a germinating Indian corn grain, are becoming dissolved and disintegrated.—After Sachs.

grains with those in ungerminated seeds, the results of the corrosion are clearly seen.

25. Sugar.—Sugar is a substance closely related to starch. Commercial sugar is usually in the form of crystals, or when liquid it is known as syrup or molasses. In the plant it occurs in the liquid form since it is dissolved in a quantity of water. If it were thick like molasses, or in the form of crystals like commercial sugar, it would be so strong as to kill the plants because it would draw so much water, by absorption, from the surrounding tissue, that the protoplasm would be destroyed. The sugars found in plants are of three general kinds: *cane sugar* or *sucrose* abundant in sugar cane, sugar beet, sugar maple, etc.; *fruit sugar* or glucose found in the fruit of a majority of plants, and abundant in some, as in apples, pears, grapes, etc., (in many fruits and other parts of plants both glucose and cane sugar are present); and *malt sugar* or maltose, as in malted barley.

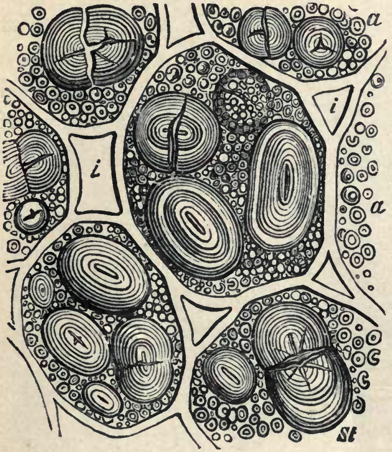


Fig. 26.

Cells from the cotyledon of the pea (*Pisum sativum*). *st.* starch grains with nucleus and concentric striæ; *a*, granules of aleurone; *i*, *i*, intercellular spaces.— After Sachs.

26. The presence of grape sugar can be determined by adding a solution of the substance to "Fehling's solution." Grape sugar "reduces" Fehling's solution. It causes the precipitation of copper and cuprous oxide, a reddish substance. The presence of cane sugar can be determined by adding a solution of cobaltous nitrate (5 grains cobalt nitrate in 100 cc. distilled water) to a solution containing the cane sugar, followed by the addition of a strong sodium hydrate solution. A beautiful violet color appears. Grape sugar treated in the same way gives a blue color which gradually changes to green. Cane sugar can be changed to grape sugar (or invert sugar, as it is sometimes called) by adding a few drops of strong hydrochloric acid to a solution of cane sugar and boiling for a minute or two. By neutralizing this with sodium carbonate, Fehling's solution can be used to show that it is grape sugar. If Fehling's solution is added to a solution of cane sugar, and boiled, it will be inverted to grape sugar as the red precipitate will show. Both kinds of sugar are sometimes found in the same plant tissue. Both are apt to be present in the branches of the sugar maple during the autumn, winter or spring.

27. Proteids.—Proteids have been mentioned as being present in the aleurone layer of wheat. They also occur in the seeds of other cereals. They are present in considerable quantity in beans and other legumes. They form the principal food storage in the thick leaves of the onion. Their presence can be determined by adding a small quantity of strong nitric acid to portions of the tissue and then heating. A pale yellow color appears. If a small quantity of ammonium hydrate is now added the color is changed to orange.

28. Experience shows that several food substances are present in the same object studied. For example, starch, sugar and proteids are present in the potato tuber, but starch is more abundant than the other substances.

29. Oil.—Oil occurs in the tissues of various plants, but especially in certain seeds as cotton seed, flax seed, and in many nuts. The fatty oils occur in the form of small translucent drops in certain cells. The oil is obtained from seeds and nuts by subjecting them to great pressure. Osmic acid blackens the oil and its presence in tissue can be detected by the use of this reagent, or by soaking pieces of the tissue in Flemming's solution which contains osmic acid.

30. Inulin.—The food substance stored in the roots of certain composite plants, like the Jerusalem artichoke (*Helianthus tuberosus*) and the dahlia, is in solution. Inulin is precipitated into sphaero-crystals by prolonged immersion of the tissue in alcohol. Many of them are sometimes present in a single cell. They show peculiar radiate and concentric markings.

CHAPTER III.

GROWTH OF ROOT AND STEM.

31. Direction of growth.—In studying the germination of seeds one fact becomes very evident which perhaps was familiar before, that the root grows downward and the stem upward. This is very important for the plant in order that its parts may establish a congenial relation to their surroundings, and be in a position to perform their work, the root in the ground and the foliage shoot in the air and light. When seeds are scattered by natural means or are sown by the farmer or gardener they fall in various positions. The seed may lie so that the embryo is upright and the root already pointing in a downward direction, or it may be horizontal or inverted. Nevertheless, the root when it emerges from the seed turns downward to enter the soil, and the stem turns upward. Some seeds which are carried by the wind are so balanced that the root end of the embryo hangs downward (many composites, the clematis, etc., see chapter on seed distribution).

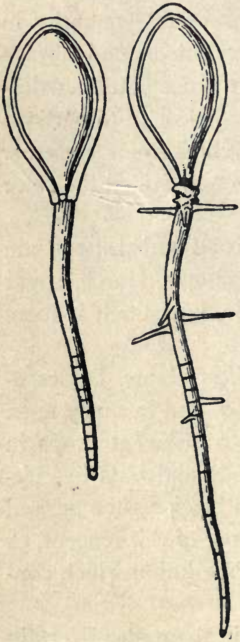


Fig. 27.
Pumpkin seedlings, the root marked in left. Right one showing where growth took place in twenty-four hours.

32. Region of elongation in roots.—The region where elongation takes place in roots is determined by a careful plotting of the root into a number of small sections, and by keeping the seedling in an upright position in moist air. Subsequent observations and a careful plotting of the root from day to day shows that the elongating part of the root occupies a certain area back of the tip. This elongation is due to the elongation of individual cells which are constantly being formed in the growing point of the tip, and are left behind. These cells elongate slowly at first, then rapidly and then slowly again until they cease to elongate. All of the cells in one cross area of the root grow at about the same rate at the same time. Their united action then is manifest in the slow elongation of the root just back of the tip, its more rapid elongation further back, followed by the slow elongation again until elongation finally ceases.

33. Region of elongation in stems.—The region of elongation in stems is determined in a similar way. It occurs just back of the growing point, but covers usually a greater area than in the root.

34. The motor zone in roots, or region of curvature.—After a seedling or a plant has been growing in one direction for a time, if its position be changed so that the root and stem are in a horizontal position, or at any angle from the upright, the root and stem will curve so that the root grows downward and the stem upward. The region of curvature of the root under these circumstances corresponds with the region of elongation. This curvature is made possible because the cells in the region of the root are all elongating. Those on the upper side of the root elongate more than those on the underside and bring about the curvature.

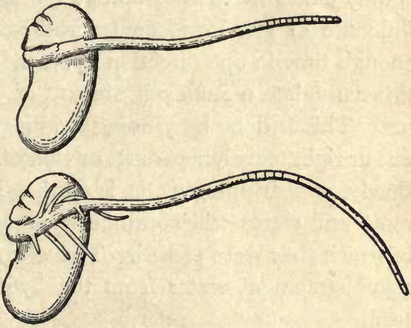


Fig. 28.
Bean seedling placed horizontally and marked to show where the root bends.

35. The perceptive zone in roots.—The perceptive zone in roots is that part of the root which receives the *stimulus* causing it to turn downward. It is, therefore, a sense organ.

The stimulus which causes the root to turn downward is initiated by gravity. We must be careful, however, not to confuse this *stimulus* from gravity with the *pull* which gravity exerts on all bodies. For example, if we lift a seedling and then "let go" of it, it will fall to the ground, or until it meets some object which intercepts it. It is not this force of gravity which causes the roots of plants to grow in a downward direction. Gravity merely initiates a stimulus in response to which the root turns downward. It has been found that this *perceptive zone*, which *perceives* the stimulus, is in the root tip. While the root tip receives the stimulus, this is not the part of the root which curves. The curvature takes place in the motor zone, or region of growth by elongation. The stimulus received by the sense organ in the root tip is carried back to the growth region, and the cells on the upper side of the horizontal root elongate faster than those on the under side, and the curving results.

36. How it is determined that gravity stimulates the root to grow in a downward direction.—This is shown by constantly changing the position of the root, so that the stimulating influence of gravity is neutralized and does not act for a long enough time in one direction upon the sense organ in the root tip to accumulate a sufficient amount of excitation from the stimulus. This is done by pinning seedlings in various positions upon an upright revolving disk or wheel. The wheel is revolved slowly, and dripping water is used to keep the roots moist. The roots and stems will continue to elongate in the same direction in which they were placed. The wheel can be revolved by a slow small stream of water from the hydrant, or by clock arrangement.

37. Geotropism.—The direction of growth of stems and roots, when uninfluenced by light, as shown in the preceding paragraphs, is caused by the stimulus from the influence of gravity. This stimulus causes a turning of the stem or root in a definite direction in relation to the earth. This phenomenon is called, therefore, *geotropism*, which name means literally *earth turning*, since the earth in this case is the body which provides the gravitation influence. The turning of the root towards the earth is *positive* geotropism, or *progeotropism.* The turning of the stem away from the earth is *negative* geotropism, or *apogeotropism.* The primary root is therefore *progeotropic*, the primary stem is *apogeotropic.* Lateral roots show transverse geotropism, or *diageotropism*, since their direction of growth is sideways or lateral.

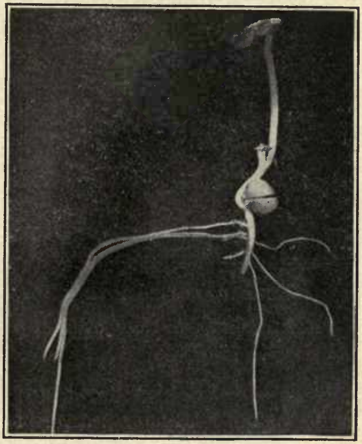


Fig. 29.

Pea seedling; lateral roots turning downward after primary root has been cut off.

38. Change in the direction of growth of lateral branches.— This takes place when the main shoot or "leader" is destroyed or removed. One or more branches change from growth in a lateral direction to an upright direction. This is very striking in certain trees like some conifers (pines, spruces, etc.). When the top of a young pine is cut off one or two of the lateral branches gradually curve upward and take the place of the leader. This is sometimes very common in the white pine where the larva of a beetle kills the top of the main shoot or leader. Pine or spruce trees struck by lightning in such a way that a large part of the top is broken off, present a few years later a very singular appearance, the topmost lateral branches remaining spread out for some distance. They are too old and firm for one or two of them to turn upward and take the place of the "leader." But a number of small branchlets on the upper surface of several of these lateral branches grow directly upward making a small forest or grove of trees in the top of a single tree.

39. Work performed by roots in penetrating the soil.— One of the important kinds of work which the roots perform is the penetration of the soil or substratum where the plant is growing. Even where the soil is quite hard and compact we often find it permeated with a perfect maze of delicate roots. The action of the root in penetrating the soil is much like that of a wedge, except that the driving force is different, and the forward movement of the root lies in a short section just back of the tip which is constantly shifting from old cells to new ones. The driving force for forward movement in the root comes from the growth of the cells in the zone of elongation, while the widening force comes mainly from growth in thickness. Since the driving force comes from elongation of cells near the tip of the root, the older part of the root must be held in place, otherwise the root would simply be pushed backward out of the ground. If the seed germinated when on the surface of the ground the root could not well enter. In case of the seedling the root hairs serve to anchor the young root until the lateral roots are formed, when the young root system as a whole furnishes the anchorage. The tip of the root is pushed with considerable force against the soil particles in advance, and being conical in form turns them to one side. The rigidity of the older parts of the young root, as well as the wall of earth around it, prevents the root from bending.

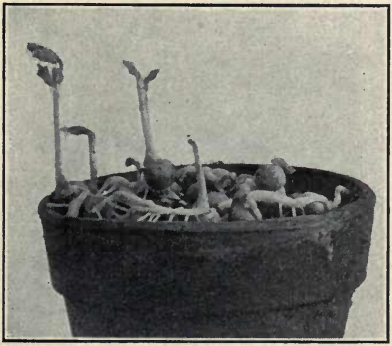


Fig. 30.

Roots of peas entering soil after anchorage by root hair.

40. Force exerted by growth.—The force exerted by roots and stems as a result of growth is remarkable. Even in the case of young seedlings the hard crust of the soil is often broken as the stem rises. In rocky places it is a common thing to see small crevices in rocks, where the slender roots of trees enter, broaden, and the rock is split apart as the root enlarges. The force exerted by such delicate plants as mushrooms is seen where they burst through hard dry ground. One should improve the opportunities for observing all such phenomena when occasion offers.

41. Influence of light on the direction of growth of stems and roots.—Besides the stimulus of gravity there is the stimulus of light which influences the direction of growth of stem and root. Roots are mostly in the dark and therefore are rarely influenced by light. When seedlings of certain plants are grown in water cultures and have a one-sided illumination the roots turn away from the light, but since geotropism is also acting on them they are turned obliquely to one side. In the same way when the stems have come above ground they are still under the influence of the stimulus of gravity. But the stimulus of light is usually more powerful and has more influence in determining the direction of growth of the stem and its branches. Light thus has a very important influence in determining the form of the stem. The stimulus of light causes the stem to turn toward the light.

42. Heliotropism.—The turning of plant parts under the influence of light is called *heliotropism*, a turning toward the sun, or light, or more properly speaking, a turning influenced by the stimulus of light. Heliotropism then is the name given to the phenomenon in its broadest sense. Positive heliotropism or *proheliotropism* is a turning toward the light; negative heliotropism or *apoheliotropism* is a turning away from the light; and transverse heliotropism or *diaheliotropism* is a lateral turning under the influence of light.

CHAPTER IV.

ROOTS, THEIR KINDS, MECHANICAL WORK AND STRUCTURE.

43. There are two kinds of work which nearly all roots perform: First, the absorption of water and food solutions; second, that of attachment and support for the plant. In addition there are cases where roots of certain plants serve other purposes as well, for example, where they serve as storehouses for food. In some of these the root takes on a special form which enables it to hold large reserves of food. Such food reservoirs are seen in the sweet potato, the tuber-rooted sunflower, dahlia, carrot, parsnip, etc. In other cases food materials are held in reserve during certain seasons in large roots of trees, or in roots of perennial or biennial plants, where they are not specialized as food reservoirs.

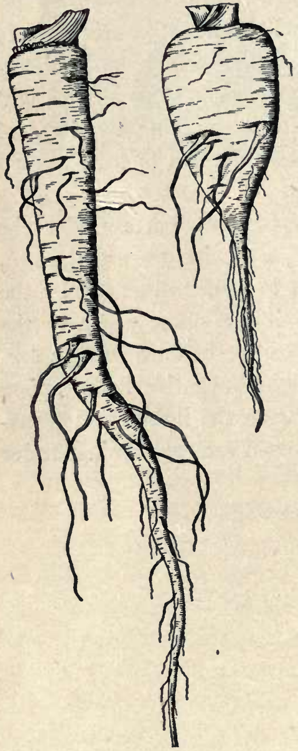


Fig. 31.
Tap roots of parsnip and carrot. Such fleshy ones are also called crown tubers.

ROOT SYSTEM.

44. The root system of a plant includes all the roots of a single plant, but has special reference to the form, the branching of the system as a whole determined by the mode, extent, direction and character of the branching. There are several types of root systems, and these are seen to be peculiar to certain plants. For example:

45. The tap-root system.—Plants possessing a tap-root system are those which have a prominent root called the tap root, which is stout and extends downward to some depth in the soil, as in the dandelion. This is usually developed from the primary root. There are numerous lateral roots but they are usually slender. The carrot, parsnip, etc., are other examples. The *fibrous-root system* is very different. The roots are comparatively slender and much branched, as in the bean, corn, etc. *Fascicled roots.* Thickened or fleshy roots developed in clusters or fascicles are called *fascicled roots.* A good example is seen in the dahlia with a tuft of stout fusiform roots.

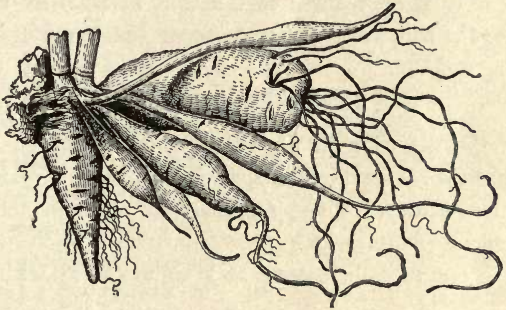


Fig. 32.
Fascicled roots of the dahlia.

46. Relation of root system to the soil.—The relation of the root system of plants to the soil is a very important one, and is governed to some extent by the nature of the soil, the moisture content and distribution of the plant food. Plants with a tap-root system have an advantage over those with a shallow fibrous-root system in dry soils or in dry weather, since the roots are able to reach the moisture at the lower levels in the soil. Evaporation removes the moisture from the surface layers rapidly in dry soil and in dry periods, and plants with a root system developed near the surface are the first to suffer. Hickory and walnut trees have a tap root which extends to great depths in the soil, and have little difficulty in obtaining the necessary water in dry soils or in dry seasons. Cone-bearing trees, the pines, spruces, etc., have a shallow root system, and are especially suited to growing in regions where plant food is chiefly confined near the surface of the ground. Plants growing in the desert, except the annuals, which grow only during the rainy season, usually have a root system which extends to a considerable depth in the soil.

47. The mesquite tree of the Southwestern States and Mexico is a remarkable example of the relation of the roots to the soil under different conditions. Where the soil is not very dry it forms a large tree and the roots do not extend very deeply into the soil. In the very dry regions, however, the tree attains a height of only two or three feet and it extends its roots very deeply into the soil, sixty feet or more, to obtain water.

KINDS OF ROOTS.

Besides the variation in the root system of plants, there are several kinds of roots which do special work for the plant.

48. Aerial roots.—These are most common in the case of many tropical plants which grow on trees. Such plants are epiphytes. The roots here serve as grapplers to attach the plants to the limbs and trunks of trees. Good examples of these can be seen in the case of many tropical orchids which are grown in so many greenhouses. Some of the roots dangle in the air and are provided with a special sheath of spongy tissue (the *velamen*)

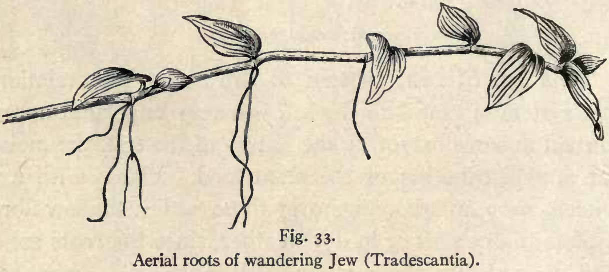


Fig. 33.
Aerial roots of wandering Jew (Tradescantia).

which absorbs moisture from the air. Another example common in greenhouses is the wandering Jew (*Tradescantia*). The aerial roots grow from the joints, usually two roots from each joint. Good examples of aerial roots can be seen in the case of the climbing poison ivy, English ivy, trumpet creeper, etc. These serve to hold the vine to the tree or other support on which it is climbing.

49. Bracing roots, or prop roots.—In some plants where the fibrous-root system in the soil is not sufficient to support the heavy plant upright, aerial roots are developed a short distance above the ground and as they reach the soil serve to prop or brace the plant. Good examples are seen in the Indian corn, and in the screw pine grown so commonly in greenhouses. A classic example of prop roots is seen in the banyan tree of India where numerous roots grow downward from the wide spreading branches. The mangrove along the coast in the subtropical regions of Florida is another example.

Fig. 34.
Bracing roots of Indian corn

50. Strangling roots.—In some tropical countries there are trees (*Clusia*) which begin their life as seedlings on other trees from seeds which have lodged in the fork of a branch or some other landing place. Slender roots grow down to the ground, one of which forms this part of the trunk. Other roots coil around the foster tree. When the *Clusia* becomes a large tree these roots wrapped around the foster tree tightly strangle and kill it.*

51. Fleshy roots, or root tubers.—There are roots or portions of roots which have become large and fleshy, as in the sweet potato or the dahlia. Such roots are reservoirs where plant food is stored to be used later by the plant for growth or

---

* See "A Tragedy of the Forest," Torreya 8, 253–259, 1908.

seed production or for starting new plants. In the sweet potato the food is stored as sugar, while in the dahlia it is stored as *inulin*, common in many composites. In the natural condition it is in solution, but by prolonged immersion of the tissue in alcohol the inulin is precipitated in the form of sphæro crystals.

52. External structure near and including the root tip.—The principal general features in the structure of roots can be obtained in the study of the roots of seedlings. The form of the extreme tip is conic, and it consists of a group of cells which are loosely held together, especially on the outer surface, where they constantly become free and die. This is the *root cap*, and it protects the delicate growing cells just back of the tip. A splendid example of the root cap is afforded by the screw pine. It is very large and can very readily be seen on the prop roots before they reach the soil. Another interesting example is found on the roots of the water hyacinth common in some of the streams of Florida and sometimes grown in aquaria in greenhouses. The root cap is long and can be very easily pulled from the root and then slipped on again. Just back of these loose cells and still near the tip, the surface of the root is smooth and the cells are united closely and firmly. The outer layer of cells, somewhat elongated and rectangular, forms the "skin" or *epidermis* as it is more properly called. When the young root is transparent this layer can be traced some distance underneath the root cap where it arises from the meristem (see paragraph 54), and the outline of the *central cylinder* can also be seen (fig. 37). A little farther back from the tip of the root some of the epidermal cells grow out into the long *root hairs*. The root hairs occupy a rather definite area of the root a little distance back from the tip. As the root elongates new

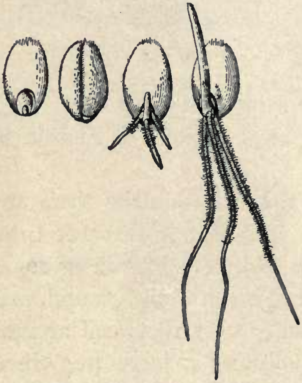


Fig. 35.
Germinating wheat, showing root hairs.

root hairs are constantly being developed from newly formed epidermal cells, while all the older root hairs behind are constantly dying and disappearing. They are long, slender, tubular cells, and since they serve the important purpose of absorbing water and mineral food solutions from the soil, they must be fresh and new.

53. Internal structure of the root.—Fig. 36 represents a cross section of a root. The outer layer of cells is the *epidermis* from which the root hairs arise. Just inside of the epidermis is the *cortex*, which consists of several layers of cells more or less rounded and with air spaces between where they touch adjacent cells. Inside of this is a ring of a single layer of rather thin cells (the *pericycle*). This can be located by observing that it lies just outside of groups of cells so highly differentiated in the center. These groups of cells, together with the thin-walled fundamental cells which are between them, make the *central cylinder* (fig. 37). There are often eight groups of special cells seen in cross section of a young root. Four of these, the more prominent ones, are the *fibro-vascular bundles* (paragraph 98). They are broad inward and narrowed outward as seen in cross section. The larger cells are the vessels or tubes through which the water or "sap" flows in the root. Besides the vessels there are thick-walled wood fibers, and on the outer side also some young thin-walled living cells which divide and grow to form additional cells for the bundle as the root increases in diameter. The tissue of these bundles is woody and is the *xylem* (paragraph 98). Alternating with these four radiating groups of wood cells are four other groups of bast cells (or *phloem*), which lie near the pericycle. The tissue of thin-walled cells lying between these groups is fundamental tissue, *parenchyma* (paragraph 94).

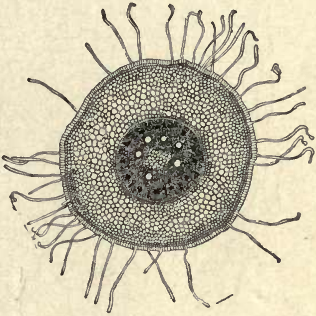


Fig. 36.
Section of corn root, showing root hairs formed from elongated epidermal cells.

54. Origin of the tissues of the root.—This can be studied in a longitudinal section of a young root including the tip. The epidermis is the outer layer of cells. Towards the root tip the rows of epidermal cells converge on a curve and meet near the middle in a tissue of cells rich in protoplasm and with thin walls (the meristem, a group of growing cells at the end of roots and stems). The cortex lies just inside of the epidermis and consists of several rows of cells on each side. Inside of the cortex is the central cylinder. By consulting fig. 37 the position and limits of these tissues can be seen. The meristem is the tissue from which the others arise. Its cells divide and the older ones pass back into epidermis cortex and central cylinder. In the central cylinder there is a great variety of cells. In the meristem where these cells arise they are all alike, but as they age and pass over into the different tissues they take on the special forms which make them suitable for their special kind of work. This is an interesting and important change, since economy and the highest utility are gained in this division of labor and specialization among the working cells of the root. In a similar way the specialized cells of stems, leaves and flowers arise from a meristem of simple undifferentiated cells. The plant body may thus be compared to a highly organized and developed community of individuals, each with its special work to do, and all working together for the common good.

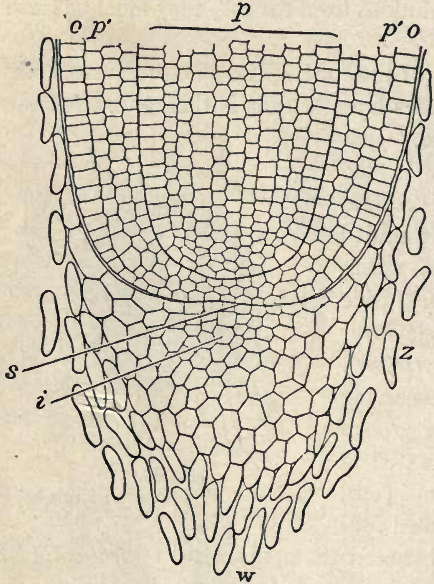


Fig 37.

Lengthwise section (somewhat diagrammatic) through root tip of Indian corn. *w*, root cap; *i*, younger part of cap; *z*, dead cells separating from cap; *s*, growing point; *o*, epidermis; *p'*, intermediate layer between epidermis and central cylinder; *p*, central cylinder, in which the fibro-vascular bundles arise. — After Wiesner.

CHAPTER V.

WORK OF ROOTS IN ABSORPTION OF WATER AND FOOD FROM THE SOIL.

55. Absorption of water and food substances from the soil.—Land plants absorb water and food solutions chiefly through the root hairs. In the study of seedlings we observed the form of the root hairs and their position on the roots. They are very slender, long cells developed in great numbers over the surface of the root a little distance back from the tip of the root. The root hairs are not permanent as in the case of most of the roots. As the root elongates, new root hairs are formed, while the older ones farther back on the stem die. Thus the root hairs are fresh and in good condition for their work of absorption.

56. How the root hairs absorb water from the soil.—Each root hair is a plant cell which is very much elongated. It is formed by the lateral elongation of one of the cells of the skin or epidermis of the root. The outer part or boundary of the root hair is its cell wall. It is thin and white. Inside of the root hair is a granular, whitish, slimy substance. This is the living substance of the cell, and is called *protoplasm*. It is the living protoplasm in the root hair which enables it to take up water and food solutions.

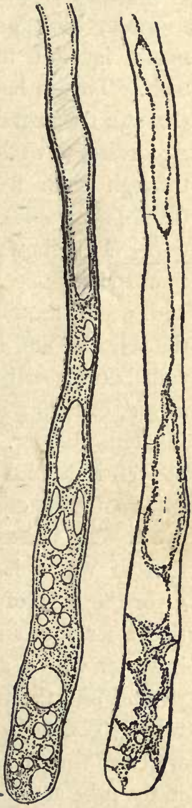


Fig. 38.

Root hair of corn before and after treatment with 5 per cent salt solution.

There is a thin and continuous membrane of protoplasm which lines the wall. Inside of this membrane the entire space of the cell is not filled with protoplasm. There are large spaces filled with a watery fluid called *cell sap*, which is a solution of certain salts, sugars, etc., in water. If the root hairs are placed in a 5 per cent salt solution, the membrane of protoplasm lies between the cell sap inside of the cell and the salt solution. The cell wall permits the water and solutions to filter through easily. But the protoplasmic membrane is of a closer and different texture, so that soluble substances do not pass through so readily. The water of the solution, however, passes through the membrane easily. The result is that the protoplasm contracts away from the cell wall. This is because some of the water in the cell sap flowed through the protoplasmic membrane into the salt solution outside. According to well-known laws of physics, the greater flow of water through such a membrane, which is only half-way permeable (semi-permeable), is always in the direction of the stronger solution. This shows then that the 5 per cent salt solution is stronger than the cell-sap solution. But when the salt solution is replaced with water, the membrane of protoplasm moves out again against the cell wall and is pressed firmly against it, so that the elastic cell wall becomes slightly stretched while the cell becomes firm and *turgid*, or is in a state of *turgescence*, or tension, something like an inflated bladder. This action of the protoplasmic membrane, the cell wall, and the cell sap explains to us how it is that the delicate root hairs can take up water and food solutions from the soil.

57. The behavior of a root hair or other cell in the absorption of water is sometimes illustrated in the following way.* Over the bulb of a thistle tube a piece of a bladder membrane is tied after thoroughly soaking it. A saturated solution of sugar in water with a small quantity of a red analine dye to color it is poured into the tube to fill the bulb and a short distance into the tube. The bulb of the thistle tube is lowered into a bottle of water so that the height of the water in the bottle and the solution in the tube are at the same level. In a few hours or in a day or so, if the experiment is properly set up, the solution in the tube will

---

* Or by the well-known egg experiment.

rise above the surface of the water in the bottle. Water then flows through the membrane into the sugar solution, but the sugar and the dye do not pass through the membrane to any great extent unless left for a long time.

58. Turgor in the plant cell is sometimes illustrated in the following way. A medium-sized vial is filled with a saturated solution of sugar. Over the open end a piece of bladder membrane which has been thoroughly soaked is securely tied in such a way as to exclude the air. The vial is then immersed in a vessel of water and allowed to stand for a day or two. It is then taken from the vessel of water. The membrane is arched upward as if by a pressure within. If the membrane is pricked with a needle, and the instrument quickly withdrawn, a stream of water spurts out because of the inside pressure.

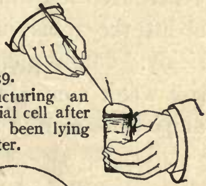


Fig. 39. Puncturing an artificial cell after it has been lying in water.

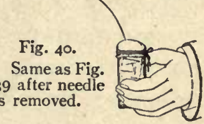


Fig. 40. Same as Fig. 39 after needle is removed.

59. How the root hairs get water from the soil.—Most land plants get their water and food solutions from soil which is moist or sometimes even appears dry. How can they take up water from moist soil or from soil which is so dry that no water can be pumped from it? The soil is composed of very finely pulverized rock, in the form of minute angular grains. Mixed with these fine grains is more or less matter of an organic nature, the disintegrated remains of plants. When soil is not saturated with water, the water present is in the form of a thin film which surrounds the soil particles. The soil particles touch each other, but because of their form there are spaces between them just as there are spaces between the stones in a pile. The film of water which surrounds the soil particles meets and joins with adjacent soil particles at their points of contact, thus making a continuous film for a great extent through the soil, reaching down to the ground water below. The spaces between the soil particles are filled with air, which is very necessary for the health of the plant. The root hairs of plants being attached very closely and firmly to some of these soil particles are thus brought into very close contact with the water film in the soil, and absorb it, while fresh water is drawn through the film from the ground water below. Where free soil water is present in the soil for any length of time about the roots of most dry land plants, the plants become sickly. Many plants, however, grow in soil where there is free soil water continually, or for a great portion of the time. Examples are seen in the swamp plants, semiaquatics, etc.

CHAPTER VI.

TYPES AND KINDS OF STEMS.

60. Kinds of plants with reference to the length of their life.—There are three kinds of plants as regards the normal duration of their life, *annuals*, *biennials*, and *perennials*. An *annual* is a plant which makes its entire growth in one year or season, from the germination of the seed to maturity, when new seed is ripened and the plant dies. Some may accomplish this in a few weeks, others require the entire season from early spring to late autumn. There are many examples of annuals among our common plants, as the corn, buckwheat, oats, morning glory, sunflower, bean, peas, etc. A *biennial* is a plant which starts from the seed one season and lives over to the season of the second year before the ripening of its seed and death. In many of these there is strong root and leaf development the first year with very little stem, while the second year the stem development is more prominent, the flowers and seed are formed, and the plant dies. Examples are the carrot, turnip, beet, cabbage. The evening primrose is sometimes a biennial. Winter wheat is usually a biennial. When sown in the autumn or late summer it forms strong " stools" by producing numerous branches near the ground. When sown in the spring it becomes an annual, grows more quickly into the long stems, and stools but little. For this reason spring wheat is generally used for spring sowing. Those plants which are sometimes annual, sometimes biennial, are often called transition forms. *Perennials* are plants which normally live several or many years. Examples are found in most of the grasses, the golden-rod, wild aster, and all shrubs and trees. Some plants have a perennial root stalk and an annual aerial shoot, as in the mandrake, jack-in-the-pulpit, wake-robin, etc.

61. Principal functions of the stem.—The stem has several kinds of work to do. The two principal functions of ordinary stems are, first, support for the leaves, so that they can be well exposed to the light and air, and second, conduction of water and food substances from the roots to the leaves, and of food substances from the leaves to the roots and different parts of the stem. Other functions of stems will be seen in studying the specialized kinds of stems.

62. Stems respond to the influence of light.—They are sensitive to light and under its stimulus they turn toward the light. This is well seen in growing plants like beans, peas, sunflower, etc., especially in young plants when all the leaves are removed and the plant is placed near a well-lighted window, or in a dark box with a small window at one side.

63. Peculiarities of stems grown in continued darkness.—Stems grown in the dark are very different from those grown in the light. They lack chlorophyll, the green coloring matter in leaves and many young stems. The leaves on many such stems are very small, and the stems of many plants are long, more slender, more watery and contain less plant substance than the same plants grown in the light. In the light, building material is formed in the green parts, especially in the leaves. This furnishes the substance for building material especially of the cell wall, the firm and hard parts of the stem. Thus under the influence of light the stems are stockier, shorter and firmer.

64. Types of stems.—There are several types of stems as regards the form or habit of the stem system. Some of these types are well shown by different trees. Observations can be made on these in the fields, parks and woods. The *conical* type is very characteristic of many spruces, the larch, and some other coniferous trees. The main stem or trunk is straight, continuous through to the topmost part of the tree, and is often called the leader, or the trunk is said to be excurrent. The branches are all lateral to this and much smaller. The lower branches are the longer, and successive branches upward are successively shorter, so that the outline of the tree as a whole is that of a tall cone. The *oval* type is represented by certain oaks especially when they grow in the open where they are not crowded and the branch system is free to develop freely. The *columnar* type is represented by the Lombardy poplar, where there is a central shaft, the leader, and numerous small branches which are nearly erect and nearly parallel with the main axis. The *diffuse* or *deliquescent* type is well expressed in the elm. The branching is somewhat dichotomous and diffuse, the main trunk being soon lost. The branching is only an apparent, not a true dichotomy. The buds on the young shoots are alternate and two-ranked, that is, regularly in two rows on opposite sides of the stem. The young shoots tend to be somewhat zigzag, with a bud on the outside of each angle. The axillary terminal bud develops in one direction, while the second bud develops a shoot which diverges in the other direction, thus forming an apparent dichotomy.

65. Kinds of stems.—The great variety of stems may be grouped together under the head of *kinds of stems.* For example, the *floral stem* or *floral shoot* is that part of the stem whose work it is to bear the flower or flowers. The *foliage shoot* is the portion of the stem which bears the leaves or foliage, and is often very extensive. *Specialized stems*, or *specialized shoots*, are those stems which are unusual either because of their peculiar form or because of the work which they perform, as the cactus, the potato tuber, etc. In fact all stems properly speaking are specialized for certain kinds of work. *Bud shoots*, or *buds*, form another kind of stem. Within each of these kinds of stems there is a considerable variety. The pupil should study a number of each kind. In the study of the *floral shoot* we are concerned chiefly with the flower, and this topic will be taken up in Chapter XVI.

FOLIAGE SHOOT.

66. Erect stems.—The erect stems are self-supporting. Trees, the vast majority of shrubs, and many herbs belong to this kind. The main axis is erect for a greater or lesser distance, but the branching often soon displaces the main trunk, and the various stems of an individual plant may extend in various directions. The general position, however, of the plant is erect. Where a number of individuals start very close together, in age the outer ones may lean more or less under the influence of light and the need for room. This is true with many shrubs which branch near the ground or send up many stems from the underground portion. Erect stems are self-supporting, the woody and supporting tissues being sufficiently developed to give great strength and rigidity, while the proportion in size and height is in harmony with the supporting tissues.

67. Climbing stems.—Climbing stems are not self-supporting; they climb upon or around other objects. The pumpkin, the morning glory, the grape, Japanese and English ivy, climbing bitter sweet, climbing poison ivy, the rattan, etc., are examples. The rattan grows in India, often attaining several hundred feet in length. The more slender species are used for wickerwork, etc. Climbing stems secure themselves to the object of support in various ways. *Root climbers* develop numerous aerial roots from the stem which take hold in the crevices of the coarse bark of trees, as in the climbing poison ivy, or they can lay hold of smoother surfaces of trees or walls, as the English ivy. *Tendril climbers* take hold of the object of support by long slender outgrowths. In many cases these tendrils are modified leaves or portions of leaves. In the pea the terminal portion of the leaf and leaflets (the midribs) forms the tendrils which coil around the object of support. In the squash and some other cucurbits it appears that the tendrils are the main veins of reduced leaves. In the clematis, or virgin's bower, the petiole of the leaf acts as the tendril and coils around the object. The dwarf tropæolum climbs in a similar way. In the Japanese (or Boston) ivy the ends of the branched tendril are broadened into thin, flat, disk-like objects, which are applied closely to the smooth surface of the wall and

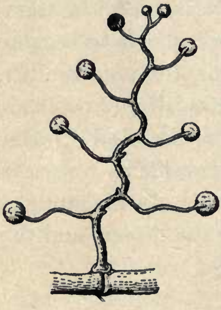


Fig. 41.
Japanese ivy with disk-like hold-fasts.

hold tightly to it. The tendrils of the American ivy (*Ampelopsis quinquefolia*) behave in a similar way. *Twining*, or *coiling climbers*, coil around the object of support, as the hop, morning glory, climbing bean. All twining stems do not coil around the object of support in the same direction, but a given species always coils in the same direction. The morning glory coils from right to left, i.e., against the sun, while the hop coils in the opposite direction, i.e., with the sun. In the tropical forests climbing stems reach their greatest development. Some of the lianas (as these climbing plants are called) have stems the diameter of large trees. One curious one (*Copernicia tectorum*) forms a network of anastomosing branches around palms.

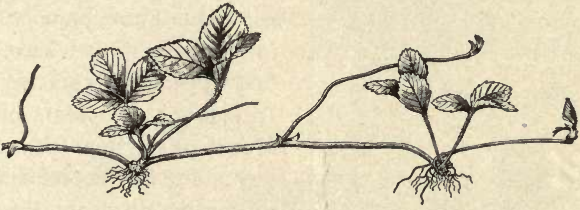


Fig. 42.
Stolon, or runner, of strawberry.

68. Prostrate stems.—Prostrate stems trail or " creep " on the ground. The dewberry and strawberry are examples of climbing land plants. These are also called *stolons* from the habit of creeping on the ground for a distance, then striking root and developing a cluster of leaves, while the main stem continues as a creeper and strikes root again, and so on. The water fern (Marsilia) is a good example of a prostrate aquatic plant.

69. Root stocks, burrowing stems, or rhizomes.—These are subterranean stems. They may be long and extend for a considerable distance in the ground as in the mandrake, false Solomon's seal, many grasses, the bracken fern and sensitive fern; or the stem may be short and thick like the underground stem of the wake robin (*Trillium*). Such underground stems are called *root-stocks*. Most of them, as in the case of the mandrake, false Solomon's seal, wake robin and grasses, have erect stems which arise as branches from the root-stock and bear the flowers and foliage leaves, while scale leaves are borne on the subterranean stem. Grasses with subterranean stems (root-stocks) are in some descriptive works said to be "stoloniferous." But this is not in accordance with the strict use of the term stolon since it does not apply to subterranean stems. The root-stocks of the bracken fern and sensitive fern do not bear aerial branches, but the large leaves which arise from the subterranean stem have stout, long, leaf stalks which serve to lift them up into the air and light.

70. Root-stock of Iris.—The root-stocks of Iris are irregularly club-shaped, with prominent concentric rings and stout, fleshy roots. Branching of the root-stock takes place near the upper end. These branches arise in the axils of old leaves and first appear as conical buds. In plants a few years old the branching system is readily seen. In the depressions the concentric rings are the scars formed by the falling away of the leaves, the scars marking the point where the leaf bases were attached. In these leaf scars are numerous minute pits, the scars of the fibro-vascular bundles of the leaf.

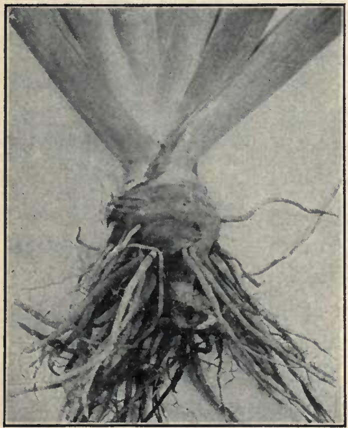


Fig. 43.
Root-stock of iris.

71. Decumbent stems.—These are stems which arise in an ascending manner and then curve or droop to the ground, where they often take root at the tip and form here a new decumbent stem, so that the plant slowly travels and spreads over the ground. The blackberries and raspberries are decumbent stems. The "walking" fern travels in a similar way but it is the long narrow leaf which is decumbent. The tip of the leaf strikes the ground and organizes a stem which develops roots and new leaves.

72. Crown stems, or acaulescent plants.—The dandelion is a good example of this kind of stem. These are sometimes called "stemless" plants, and this is the meaning of *acaulescent plants.* The plant appears to be composed only of root and leaves. But there is a very short section of the stem, difficult to define its limits, between the root and leaves and to which they are attached. It is at the *crown* of the root, and for this reason such a stem may be called a *crown stem.* Many biennials have crown stems. The beet, turnip, parsnip and carrot are also examples, but because of the large, fleshy root of these plants they are sometimes called *crown tubers.* The crown stem of the dandelion is perennial and bears the foliage leaves. But each year it develops one or more flower stems which die down after the seed ripens. In the fleshy roots mentioned above, during the second year a tall leafy stem is developed which bears flowers and seed. The fleshy roots are reservoirs for the storage of food material (see Chapter II).

SPECIALIZED STEMS.

73. Bulbs.—A bulb is a specialized shoot with a very short stem which is covered with numerous overlapping thick leaves, as in the onion, hyacinth, lily, tulip, etc. The onion is made up largely of broad, thick, short, fleshy leaves, or the leaf bases, which overlap very closely and make a more or less flattened circular or oval body. The outer leaves are usually dead, thin, papery and brown. A longitudinal section through the middle shows well the thickness and relation of the leaves. At the lower end can be seen the flattened very short stem to the upper surface of which the leaves are attached, while the roots extend from the

Fig. 44.
Section of onion "bulb," showing thick fleshy leaves.

lower side (fig. 44). The food is stored in the fleshy leaves. It is of a proteid or nitrogenous nature, i.e., it contains nitrogen in addition to carbon, hydrogen, and oxygen. The presence of proteids can be shown by heating portions of an onion in nitric acid. The liquid becomes pale yellow in color. Adding a small quantity of ammonium hydrate the color becomes orange. The lily bulb (easter lily, fig. 45) is similar to that of the onion but the thickened leaves are not so closely and compactly crowded.

Fig. 45.
Easter lily "bulbs."

74. The corm.—This is a short, thick, fleshy shoot in which food is stored. The Indian turnip, or Jack-in-the-pulpit, is a good example. This is circular and somewhat flattened or oval. It is perennial, increasing gradually in size usually each year on the upper side, while the lower side gradually dies off. Propagation of the corm usually takes place by the formation of small corms on the side. These eventually separate and form new plants. New corms are also formed by the germination of the seed.

75. Tubers.—A tuber is a fleshy thickened portion of a subterranean stem containing large quantities of plant food. There are rudimentary scale leaves, in the axils of which are buds. These buds often resemble an eye, as in the potato tuber, when they are called "eyes." The potato plant has slender underground stems as well as aerial stems. It is on the ends of these underground stems, which are thicker than the roots, that the potato tuber is formed. Some of the starch that is made in the leaves during the day is transported to these underground shoots and stored up in the tuber.

76. The potato is an interesting plant to study.—The potato plant is propagated by planting the tubers, or pieces of them containing the eyes. Tubers kept in a warm room during the winter often "sprout," the sprouts or shoots developing from the eyes. Sometimes when kept in a box or drawer, even in the absence of light, they will form colorless shoots and a new crop of small potatoes. If placed in a vessel in contact with a little water, and kept in a warm room in strong light, green shoots and leaves will develop, and many interesting experiments can be performed with them.*

77. The sweet potato is sometimes called a "*root tuber.*" It is not a true tuber since it is an enlargement of a root and not of a stem. Sweet potatoes are propagated by planting the potato to obtain the young shoots, large numbers of which spring from the fleshy root, not from true buds, but adventitious buds are formed in the tissue of the root.

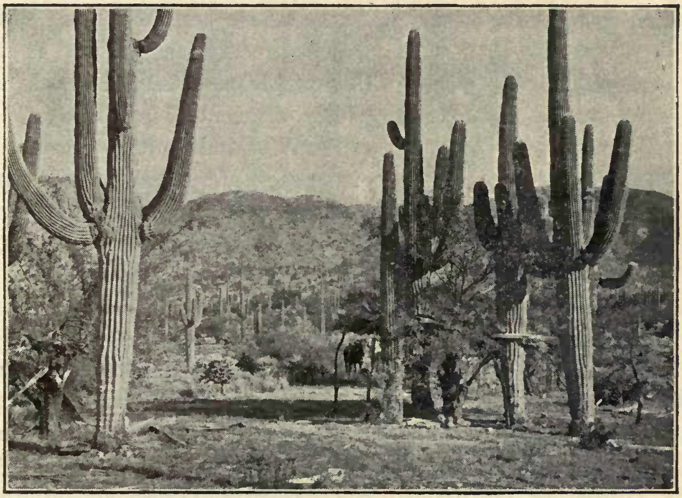


Fig. 46.

Desert vegetation, Arizona, showing large succulent trunks of cactus with shrubs and stunted trees. Open formation. (Photograph by Tuomey.)

78. Cacti.—The cacti embrace a great variety in the form of the stem. The stems are greatly specialized. They are succu-

---

* See "Water Culture Method for Experimenting with Potatoes," *Plant World*, **11**, 249–254, 1908.

lent (fleshy and contain quantities of water) stout and thick, with a thick waxy cuticle on the surface. The stomates are deeply sunk in depressions. These characters aid the plant in the conservation of water which is of great importance to these plants since they usually grow in desert or dry regions. They are further specialized in that they do not have green leaves, the function of the green leaves being performed by the stem which contains the chlorophyll. In some species the prickles or spines which are so numerous on the cacti are supposed to represent leaves since they are outgrowths of the stem. Some of the cacti have tall stout columnar stems, some are shaped like a melon as the "melon cactus," others have branched stems with flattened pear-shaped joints as in the prickly pear cactus. This is widely distributed in dry regions of the West and South. Examples of the cacti are usually to be found in greenhouses. Such stems are sometimes called *condensed* stems.

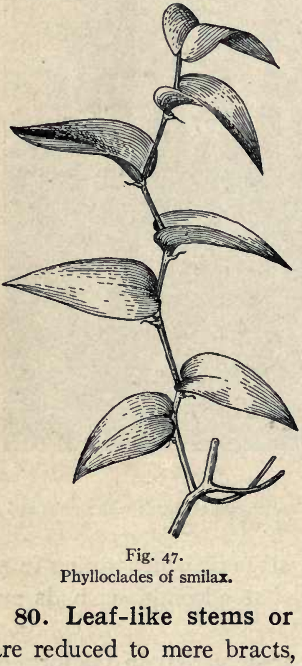


Fig. 47.
Phylloclades of smilax.

79. Other succulent stems.—Some succulent stems are common in regions which are not habitually dry. The purslane is a common weed in the northern and eastern United States. It has thick, smooth, watery stems, and thick, small, succulent leaves. It is very difficult to kill because of its power to conserve water. The houseleek, live-forever, stonecrops, etc., are other examples.

80. Leaf-like stems or phylloclades.—In these the leaves are reduced to mere bracts, and the stem or branches of it are broadened and flattened so that they resemble leaves. The gardener's "smilax" (*Myrsiphyllum*), so commonly grown in greenhouses, is a good example. The main stem is slender and cylindrical, but there are numerous branches which are leaf-like. They are known to be branches because they arise in the axils of small scale-like leaves. The asparagus is also an example of a plant in which the stem has taken on the function of leaves, while the latter are rudimentary.

BUDS OR BUD SHOOTS.

81. Buds are special types of shoots or branches containing the delicate growing point of the stem. This growing point is usually protected by closely overlapping scales, or hairs, or in some cases it lies in a depression. As such they exist in a resting condition through the winter in some climates, or through dry periods in climates where this is the resting period for vegetation. Distinct buds are also usually present at the end of the growing shoot or branch throughout the growing season. The delicate growing point organizes the young leaves which arise near its apex, and the stem tissues which are left behind. The growing point in these buds is protected by the overlapping young leaves, sometimes provided with numerous hairs, and sometimes in addition by a waxy or resinous or gummy substance. As to their means for protection buds are of two kinds, *covered* and *naked*. The covered buds have a coating of imbricated or overlapping scales, while buds protected by cork or hairs are said to be naked.

82. As to their position buds are *axillary* when they arise as usual in the axil of a leaf; *terminal* when they are formed at the apex of a shoot or branch; *accessory* when there are more than one at a given point, one above the other in the axil of a leaf; *adventitious* when they arise at other points on the stem than in the axils of the leaves or apex of shoots, i.e., at any point on the stem or root or leaf.

83. Protection of buds.—Since in our climate the trees and shrubs form the buds towards the end of the growing season, the winter is the resting period and this is the period through which the delicate growing point of the shoot needs protection in the bud. The covering of buds by the closely overlapping scales, and by the woolly or hair-like covering of the inner scales of many buds, or by hairs alone, as is the case in some buds, is generally supposed to be a protection against freezing. This is not strictly true, for ice is abundantly formed within the buds during very cold weather even in buds well covered with scales or hairs. It is rather a protection against the effects of freezing, or more properly speaking, it is a protection against the loss of water from the delicate tissues of the bud. This protection applies then to buds in climates where the resting season for vegetation is dry and hot as well as in climates where the resting season is very cold. When freezing takes place (in plant tissues a little below the freezing point for water outside) the ice is rarely formed inside of the cells in the protoplasm. The ice forms on the outside of the cells in the intercellular spaces. As freezing continues water is drawn from the cells and added to the ice crystals in the intercellular* spaces. The effect of freezing then is to draw water from the cells, i.e., it is a drying effect. If the buds had no protection on the outside, the ice would gradually vaporize and escape. The bud coverings, however, prevent excessive loss of water, and when warmer weather comes the ice crystals in the intercellular spaces melt and the water is drawn again into the protoplasm of the cells by osmosis (paragraph 352). Bud coverings probably protect the young growing plant from mechanical injury also.

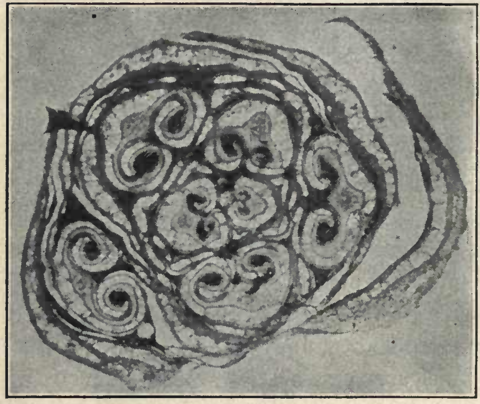


Fig. 48.

Section of frozen bud of Populus dilitata showing ice from water drawn from the bud leaves (from K. M. Wiegand). The white crescents are masses of ice between the bud scales.

For the study of buds see Chapter VIII.

---

* See "Some Studies Regarding the Biology of Buds and Twigs in Winter," *Bot. Gaz.*, 41, 373–423, 1906.

GROWTH OF STEMS.

84. Definite and indefinite growth.—In woody stems, shrubs and trees, there are two types of growth in length of the new shoots each year, *definite* growth, or determinate growth, and *indefinite* growth, or indeterminate growth. In the larger number of trees and shrubs of the North Temperate region the growth is definite. It is usually completed by the middle of July. A terminal bud is formed from which the following season the shoot continues its growth. In some of these buds all the leaves of this shoot for the coming season are already formed in miniature in the bud and are covered and protected by the outer dull colored scales. During the growth of the shoot the next season these leaves mature and unfold as the shoot elongates, and then a new terminal bud is formed. In other cases not only do the young leaves already formed in the bud expand, but new leaves are formed as the shoot elongates. In indefinite growth, however, growth in length of the shoot continues until late in the summer or autumn, and the terminal bud as well as the terminal portion of the twig dies. One of the lateral buds then acts as the terminal bud to continue the growth the following season. In the spice bush a considerable portion of the dead terminal shoot remains and the following year the new growth comes from the living lateral buds some distance back from the tip. In the elm the terminal portion of the shoot which dies is small, falls away, and the latest lateral bud to be formed appears to occupy the end of the shoot. This forms an axillary terminal bud.

85. Annual growth of stems.—Annual growth of most stems takes place in two directions, in length and in thickness.

86. Growth in length.—In the case of stems with definite growth there are external marks on the shoots which indicate each year's growth for several years until the bark becomes so old as to obscure the marks. These marks are formed by the scars of the bud scales when they fall off at the time of the opening of the buds in the spring. These are known as *scale scars* or *ring scars*, because they form closely crowded rings on the shoot. Stems with indefinite growth usually do not show these annual scale scars, though they are faintly shown in some stems with indefinite growth which have axillary terminal buds, as in the elm. In pine trees the annual growth in length is easily shown for many years since one whorl of branches is formed each year from a whorl of buds just below the terminal bud.*

87. Growth in thickness.—Growth in thickness of most shrubs and stems is marked by " annual rings " seen in a cross section of the stem, a new ring of tissue being added each year. These rings are made distinct by the variation in the compactness or porosity of the wood formed each season, those vessels (or " pores ") in the wood being larger which are formed in spring and early summer, while they are smaller and the wood more compact which is formed later in the summer. The age of trees or their branches can be determined by counting the number of these annual rings.

88. Nodes and internodes of the stem.—The point where each leaf is borne is called a *node*. The space between two successive nodes is called an *internode*. In some plants, especially the grasses, corn, wheat, etc., the nodes are very distinct since they coincide with the " joint."

---

* These buds are not in a true whorl since they arise in the axils of scale leaves arranged in a spiral on the stem, but the scale leaves are very numerous and crowded and so the buds appear to be in a whorl.

CHAPTER VII.

STRUCTURE OF STEMS AND THE WATER PATH IN STEMS.

89. In the study of seeds and their germination (Chapters I and II) it was found that certain seedlings, the corn, for example, has one cotyledon, while the pea, bean, etc., have two cotyledons, or seed leaves. Plants belonging to the first class are called *Monocotyledons*, while those belonging to the second class are called *Dicotyledons*. The fact that most plants of the first class have one cotyledon, and those of the second have two cotyledons, led to the adoption of these names. There are, however, other important distinctions. The anatomy or structure of the plants belonging to these two classes show certain points of agreement. Most of the members of the monocotyledons possess one type of structure, while the members of the dicotyledons possess another type of structure.

STRUCTURE OF THE STEMS OF MONOCOTYLEDONS.

90. The corn plant, the cereals like wheat, the grasses, etc., are good examples of monocotyledons; the stem is distinctly marked off into nodes, or joints, and internodes. The leaf is attached at a node. The three parts in a typical leaf, as in the corn, are as follows: The *sheath* surrounds the stem, the *blade* is the free part of the leaf, the *ligule* is a slight membranous

Fig. 49.
Corn plant, a monocotyledon.

projection at the junction of blade and sheath, and it partly surrounds the stem.

91. Gross structure of the corn stem as seen in cross section.—The outer hard layer is called the rind. The soft pithy portion of the interior forms the bulk of the stem. Scattered in the pith are minute firmer and more compact points as seen in cross section. In old corn stalks which have lain in the field during winter and a part of the following season, if cut through the rind with a knife and the pith within broken, these firm portions are apt to pull out in the form of fibers as shown in fig. 50. "Stalks" of celery (the petioles of the leaves) are excellent to show these bundles which make old or tough celery "stringy."

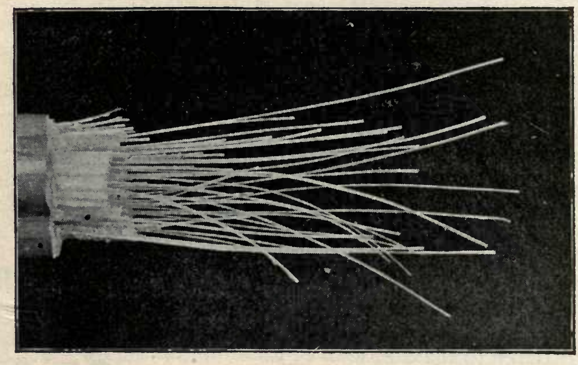


Fig. 50.
Broken corn stalk, showing fibro-vascular bundles.

92. Fibro-vascular bundles.—These fibrous portions are made up of several kinds of elongated cells united in the form of a bundle. Some of the cells are slender, have thick walls, and overlapping ends. They are woody fibers and give strength to the bundle. There are other elongated cells which are tubular and are joined end to end to form *vessels*. There are other kinds of cells too, but the bundle takes its name from these two sorts and is called a *fibro-vascular* bundle. The water which passes from the roots to the leaves largely passes through these vessels, hence the term *vascular*. If a young corn stalk or other leafy stem is cut and the cut end placed in red ink or in a solution of a red analin dye like eosin, the colored liquid rises in these bundles and colors them, while the pith or other parts remain uncolored.

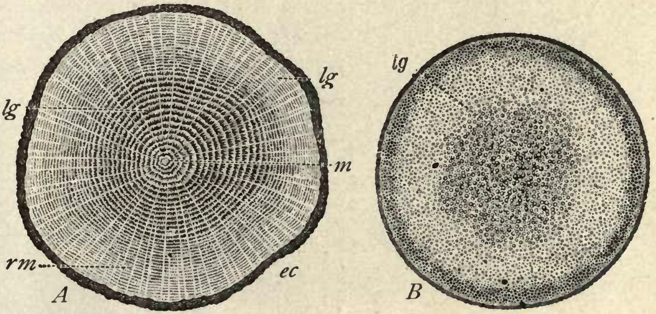


Fig. 51.

A, cross section of the stem of an oak tree thirty-seven years old, showing the annual rings. *rm*, the medullary rays; *m*, the pith (medulla). *B*, cross section of the stem of a palm tree, showing the scattered bundles.

93. The palm stem.—Palm trees are also monocotyledons. In fig. 51, B, is shown a cross section. The arrangement and distribution of the fibro-vascular bundles is similar to those in the corn.

94. Microscopic structure of the corn stem.—A microscopic study of a cross section of a corn stem shows that the pithy portion is made up of quite large cells with thin walls, the cells being equal in diameter. This kind of tissue is called *parenchyma*. In the fibro-vascular bundle there is a great variety in the size of the cells. Near the center of the bundle is a group of small cells with thin walls filled with protoplasm if the bundle is not too old. This group of cells is the *cambium* portion of the bundle. This is the growing part of the bundle so long as growth takes place. It is the region where the cells divide and multiply in number, i.e., growth by division and multiplication, and should be distinguished from those cells which have ceased to divide, but grow by enlargement. Upon one side of the bundle are seen the large vessels with the smaller fibers and some thin-walled parenchyma cells. This is the *woody portion of the* *bundle.* Upon the other side of the bundle is a group of small cells with thick whitish walls, the *bast portion of the bundle.* The dividing cells of the cambium furnish the cells to make these different elements of the bundle which soon cease to grow and form *permanent* tissue. The cambium then disappears; vessels, bast, and thick-walled fibers remain. This thick-walled fibrous tissue in the monocotyledons entirely surrounds or encloses the growing tissue and other elements of the bundle and soon prevents farther enlargement and expansion. Such a bundle in which the cambium is enclosed by and passes over into permanent tissue is called a *closed* bundle. Stems with closed bundles usually do not increase in thickness after the formation of the permanent tissue. Monocotyledonous trees like the palms, therefore, never attain the great diameter of dicotyledonous trees, because the trunks cease to increase in diameter. For this reason the trunks of palms are of nearly equal diameter while dicotyledonous trees and conifers which have open bundles (paragraph 98) have tapering trunks.

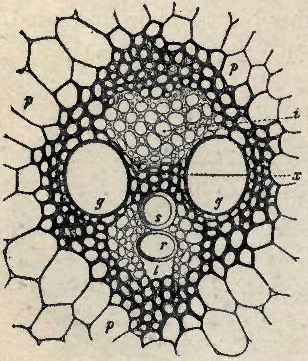


Fig. 52.

Transection of fibro-vascular bundle of Indian corn. *a*, toward periphery of stem; *g*, large pitted vessels; *s*, spiral vessel; *r*, annular vessel; *l*, air cavity formed by breaking apart of the cells; *i*, soft bast, a form of sieve tissue; *p*, thin-walled parenchyma. (Sachs.)

Fig. 53.

Uncoiled spiral ducts, from petioles of Indian lotus, supporting weight of section of petiole.

95. In a longitudinal section the vessels of the bundle are seen to be marked in various ways by thickenings on the wall. These markings are in the form of rings, spirals, pits, transverse thickenings. These vessels were derived from cells of the *fundamental* tissue (parenchyma) which of course originally came from the *cambium* or *meristem.* At first they elongate, and the cross walls at their adjacent ends dissolve and thus make long tubes or vessels of the connecting cells. These different kinds of vessels can often be found in the same bundle. In some plants the spiral thickenings on the vessels are so regular and so strong in contrast with the thinner portions of the wall and the other tissues that when the stem is broken the spiral will uncoil in long, delicate, cobweb threads. This is shown in a remarkable way in the flower stems and petioles of the Indian lotus (figs. 53–55). The rind of the stem is cut with a knife and the stem then broken.

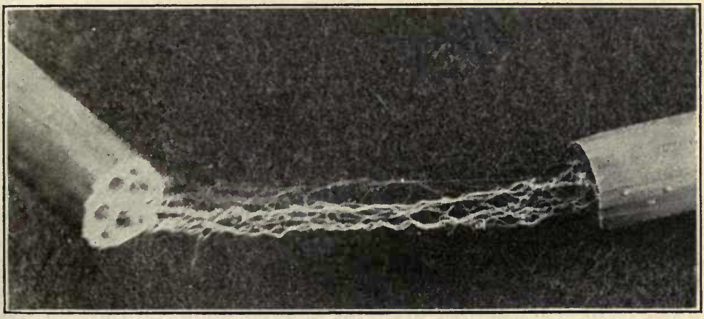


Fig. 54.
Uncoiled spiral ducts of Indian lotus.

Fig. 55.
Photomicrograph of uncoiled spiral ducts of Indian lotus.

The uncoiled spiral is strong enough to support by suspension a piece of the stem 2 cm. to 4 cm. long, and so delicate that one cannot see the means of support at a little distance unless held before a black object or the light. Examined under the microscope the beautiful spiral markings can be seen.

STRUCTURE OF THE STEM OF DICOTYLEDONS.

96. Gross structure of the stem of an annual.—A cross section of the stem of a dicotyledon shows a very different structure (fig. 51, A). Leafy shoots of dicotyledonous stems like the garden balsam or touch-me-not (*Impatiens*), bean, sunflower, etc., may be placed with the cut ends in red ink or a solution of a red analin dye. After several hours the loss of water from the leaf will draw the colored liquid up through the vascular ducts. This will stain the bundles, and also the veins of the leaves in many cases, so that the color is easily seen through the thin overlapping tissues. If shoots with white flowers are also placed in the dye the white petals will become stained. If the stems are now cut across the position of the bundles can be seen. Instead of being scattered without order through the

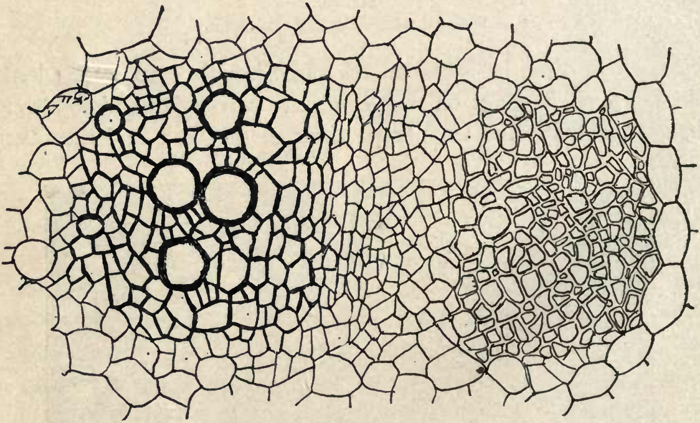


Fig. 56.

Xylem portion of bundle. Cambium portion of bundle. Bast portion of bundle. Section of vascular bundle of sunflower stem.

stem they are arranged in the form of a ring about midway between the center of the stem and the outside. They are arranged in a concentric ring with spaces between them. The central part of the stem is the *pith* or *medulla*. The portion outside of the rings of bundles is the *cortex*. The radiating strands of tissue lying between the bundles and connecting the pith with the cortex are the *medullary rays*.

97. Microscopic structure of an annual stem.—The pith cortex and medullary rays are composed of thin walled cells of nearly equal diameter and belong to the fundamental tissue or parenchyma. The outer layer of cells is the *epidermis*. In some stems just underneath the epidermis the cells for several layers have walls which are thickened at the angles. This gives additional strength to the stems.

98. The fibro-vascular bundle.—This should be studied in cross and longitudinal sections. In cross section each bundle is seen to be divided into two parts, an outer (toward the outside of the stem) and an inner one. The outer portion is the *bast* portion, while the inner is the *woody* portion. The bast portion is characterized by numerous bast cells, which have whitish thick walls, and form very long fibers. In the wood portion are the vessels which in cross section appear like large angular or circular cells with thick walls. Intermingled with the vessels are the thick walled wood fibers and some thin walled parenchyma. Between the bast and woody portions of the bundle there is a group of cells with very thin walls and rich in protoplasm. These cells are usually quite regularly arranged in rows and are rectangular in form. This is the *cambium* portion of the bundle. The cells of the cambium grow and divide, thus increasing in number. The older ones on the bast side of the bundle cease to grow and change into bast cells, others into sieve tubes, etc. The older ones on the wood side of the bundle cease to grow and change into vessels, wood fibers, etc. It will be noticed that the wood and bast at no point meet around the cambium but that the cambium itself extends across the medullary ray and is connected with the cambium in the adjacent bundles. In fact, the cambium forms a complete ring around in the stem, at this point separating the bast and wood of all the bundles. The bundle is not therefore closed but is open. This is characteristic of the bundles of the dicotyledons as distinguished from those of the monocotyledons. The stems of dicotyledons can therefore increase in diameter indefinitely as long as growth continues, since the cambium never completely passes over into permanent tissue, and extending through the bundle, across the medullary ray into the adjacent bundles, keeps them open. A longitudinal section of a bundle will show the same arrangement of the cells, and will give an idea of the length of the different elements, and show the markings of the vessels and the character of the sieve tubes.

Fig. 57.

Longitudinal section of vascular bundle of sunflower stem; spiral, scalariform and pitted vessels at left; next are wood fibers with oblique cross walls; in middle are cambium cells with straight cross walls; next, two sieve tubes, then phloem or blast cells.

99. Structure in cross section of perennial woody stems.—A cross section of a stem several years old will show the following structure. In trees like the oak the chief points in the structure can be seen readily with the eye or with the aid of a hand or pocket lens. The character of the " bark " will depend on the age and the kind of the tree. If the stem is only a few years old the bark will be green and soft. This soft bark is made up of the bast portion of numerous fibro-vascular bundles lying side by side, and in it are the sieve tubes. On older stems the outer bark is dead and often cracked into deep furrows. This is the true bark. It is formed by a layer of cells on the outside of the bast portion called *cork producer*. The soft " bark " lies underneath the coarse dead corky bark in the old stems. In the spring, the soft bark can be very easily stripped off from the stems, as in the willow, basswood, etc. The tissue where the bark parts from the stem when stripped off in this way is the young and delicate *cambium*, which, we found in paragraph 98, forms a continuous layer entirely around the stem between the bast and the wood of the bundle. The portion of the stem lying inside of this layer then is the wood, except the central portion or pith.* The wood portion of old trees consists of a whitish outer portion called the *sap* wood, while the darker inner portion is the *heart* wood. The heart wood is dead, but in the sap wood there are many living cells and it is here that the rise of water in the tree takes place. No rise of water takes place in the dead heart wood. There are three peculiarities of the woody portion of such a stem which are visible to the eye. *First*, the slender whitish lines which radiate from or near the pith to the outside. These are the medullary rays or pith rays which (paragraph 96) lie between the fibro-vascular bundles. They consist of parenchyma cells which are alive in the sap wood and usually dead in the heart wood.† The cells of the pith rays are very much elongated radially; they are flattened by the lateral pressure of the bundles and they present the smooth shining surfaces in radially split wood: *second*, the *porosity* of the wood, which appears to the eye (unless it is a very hard compact heavy wood) to have numerous minute pores: *third*, the presence of numerous concentric rings, called *annual rings*.

100. Growth in thickness and the formation of annual rings.—In woody stems the fibro-vascular bundles lie very closely side by side so that the woody part of one bundle practically touches that of the two adjacent ones. They do not quite touch,

---

* The pith varies greatly in extent in different trees and shrubs. In some it is very abundant, as in the elder, sumac. It may be continuous, chambered or diaphragmed, etc., in different species.

† In some trees the pith ray cells remain alive for many years.

however, for the pith ray is between. But the parenchyma of the pith rays is squeezed into thin plates by the crowding of the bundles. This brings the bundles of the first year's growth of the stem so near together that they form a ring visible to the eye. Since the bundle is an open one the cambium grows each year, adding on new wood on the inside and new bast on the outside. This causes the growth in thickness of woody stems since each successive year the cambium places on a new layer of wood on the outside * of the old and a new layer of bark on the inside of the old. As the stem increases in diameter new bundles arise in the cambium between the old ones so that the bundles are always crowded. The annual rings are not marked by rings of different bundles. Each bundle is thin and becomes very broad and flat radially, by the constant addition of new wood on the outer edge. The annual ring is due to different rates of growth of the wood during a single season. In the spring and early summer growth is more rapid and the vessels are larger. This gives great porosity to the new wood formed in spring and early summer. In late summer growth is slower and the vessels while present are very much smaller so that the late summer wood is quite compact. The annual rings are then made up of alternating rings of porous and compact wood, and rings of each, constituting an annual ring, since both are produced in one season.

Fig. 58.
Section of oak tree showing annual rings and medullary rays.

---

* For this reason dicotyledons are called by some *exogenous* (growing on the outside), while the monocotyledons are *endogenous* (growing on the inside).

CHAPTER VIII.

WINTER CONDITION OF SHOOTS AND BUDS.

101. A study of the winter habit of perennial plants shows some very interesting adaptations of plants to meet the severe conditions to which they are subjected during the season. The spring and summer is the growing season. The new growth is at first comparatively tender, with an abundance of water and a comparatively small amount of cell wall or building material in the shoots and leaves. In this condition vegetation is very susceptible to either extreme cold or extreme drought. This is occasionally seen in our climate (temperate zone) when there is an early, warm spring. The new shoots and leaves are developed rapidly. They are full of water and the tissues are soft and weak. When a severe frost follows it often works great injury to the new vegetation, the new leaves and shoots of hardy trees and shrubs being killed and drying up, presenting a very unsightly appearance. The same effect is sometimes produced in some plants when a strong, dry wind continuing for several days often withers up the leaves and shoots because of the excessive loss of water under these conditions.

102. If vegetation passes this critical period without injury the natural processes of maturity and ripening of the parts prepare the plants for the long, severe winter season. Different plants prepare to meet this season in different ways. The annuals, which form little wood or protecting bark, expend their energy in the production and ripening of seed, and then the plant dies. The seed, or fruit, possesses dry, hard walls, and the living substance in the embryo passes into a condition in which there is little danger from either dryness or extreme cold. In the case of the perennial herbs, the annual shoot produces its seed, and then dies to the ground, while the underground shoot or root is protected from either drought or cold. The evergreens like the pines, spruces, cedars, the laurels, rhododendrons, etc., have thick leaves which are protected by thick walled epidermal cells, which in turn are also protected by the cuticle, a coating of a waxy substance which largely checks the loss of water. The protoplasm also undergoes certain changes with the oncoming of winter, so that it is more resistant to the injuries accompanying extremely cold weather.

103. The deciduous trees and shrubs, those which shed their leaves in the autumn and winter, show a very interesting adaptation to meet the rigors of a winter season. The leaves are usually broad and thin, and are especially suited for the purpose of transpiration, that is, the loss of water. By the death and shedding of the leaves, deciduous trees and shrubs get rid of organs, which, if they remained alive and active during the winter, would drain so much water from them that they would dry out and die, since the roots during the cold season absorb but little water from the soil and could not replace that lost through the leaves. The shoots are protected by the maturing or ripening of the wood, the cell walls becoming thick and firm. The outer portion of the bark has thick walled cells which are dead and lose most of their water. With each year this bark becomes thicker. This, with the waxy cuticle on the surface, serves to protect the winter shoots. The young growing points, however, consist of delicate masses of cells rich in protoplasm and with an abundance of water. If these growing points, or buds, at the ends of the shoots and in the axils of the leaves were unprotected, they would lose a sufficient amount of water during the dry and freezing weather to kill them. But they are protected by coverings in the form of bud scales, hairs, or by both, and often by the abundant formation of a waxy or resinous substance between the scales and on the outside. The bud scales also afford protection to the delicate growing point from mechanical injuries.

104. The effect of freezing on plant tissue. — Very few plants are killed by actual cold or freezing of the tissues.* It was once thought that in the freezing of plant tissue ice was formed inside of the cells, and that the protoplasm was killed by the cold. But this rarely occurs. The water freezes on the outside of the cell wall, and additional water flows out from the inside of the cell and continues to freeze there building up ice crystals in the intercellular spaces (fig. 48). If the freezing continues long enough, so much water may be drawn from the protoplasm in the cell as to make it too dry and thus kill it. When the buds freeze the ice crystals are formed in the intercellular spaces. When the ice crystals thaw the water is slowly absorbed by the protoplasm in the cells again and is unharmed. Were it not for the bud scales and other means for bud protection, the water from the thawing ice crystals would evaporate and the protoplasm would be killed. The effect of freezing on plant tissue is, therefore, in most cases the same as that of excessive dryness.

105. Characters of winter buds and shoots.—Winter buds and shoots possess certain marks and other features which are characteristic of the different kinds, so that a careful student of these characters is enabled to tell the different kinds of trees and shrubs from the winter condition of the shoots and buds.† Some of these characters are as follows: The surface, whether smooth or rough, shiny or dull, the color, the form of the lenticels. The lenticels are minute elevations composed of corky tissue with a minute opening, which serves the purpose of an interchange of air and other gases, between the tissues of the shoots and the outside. The shape of the shoots is another character, also the form and arrangement of the leaf scars, with their markings, the form and other characters of the buds, etc. The characters of the following shoots will serve as illustrations.

106. Shoots of the horse chestnut.—*Terminal buds.* The terminal bud where well formed is larger than the lateral buds. This, as in other similar cases, is evidence that this bud will con-

---

* See "Some Studies Regarding the Biology of Buds and Twigs in Winter," *Bot. Gaz.*, 41, 373–423, 1906.

† See "A Key to the Genera of Woody Plants in Winter," 3rd edition, 1908, by Wiegand and Foxworthy. Andrus & Church, Ithaca, N. Y.

tinue the growth, the coming year, of the main shoot, and that the lateral shoots will be subordinate in size. The buds are well protected by brown, overlapping, external scales and a sticky, varnish-like substance, which covers them. If the scales are removed one by one their position and relation can be seen. They occur in pairs, the two of a pair being opposite, and each pair alternates with the pair above and below. Some of the buds are leaf buds while others are flower buds. As the buds open in the spring it can be seen that the leaves have a similar relation to each other, and to the scales, except that they are farther apart. As the scales fall away they leave transverse lines on the shoot, which are crowded and in the form of ringmarks. These are the *scale scars*. They mark the end of one year's growth of the shoot and the beginning of the next. By observing these ring scars on the shoot the age of the shoot can be determined for several years back. If the shoot is cut obliquely at different ages it will be seen that the annual rings indicate the same age of the shoot as the scale scars do. *Lateral buds*. The lateral buds are opposite and arise above the leaf scars. The larger buds are on the last year's growth, and those nearer the terminal bud are the larger and will develop into lateral branches. Those buds which do not ordinarily develop into shoots are *latent* buds, and if the terminal and larger lateral buds are removed by cutting off the part of the shoot which bears them, can develop into shoots. *The leaf scars*. The leaf scars are large and shaped something like the bottom of a horse's foot with a horseshoe and nails. The series of pits (bundle scars) mark the position of the vascular bundles which extend from the stem into the petiole of the leaf. Scattered over the surface of the shoot are numerous minute, grayish or dull white elevations, the lenticels.

Fig. 59.
Shoot of horse chestnut.

107. Shoots of the lilac.—The shoots of the lilac have the same arrangement of the lateral buds and leaf scars as those of the horse chestnut. They are opposite and in pairs, and each pair alternates in position with the pair above and below. The leaf scar is much smaller and semi-lunar in shape. The outer bud scales are brown, while the inner ones are green, and some of the intermediate ones have brown tips and green bases. There is one interesting point of difference, however, between the shoots of the lilac and those of the horse chestnut. The shoot appears to have a pair of terminal buds which stand slightly divergent. There is a leaf scar at the base of each one which shows that these buds are *axillary;* i.e., they arise in the axils of the leaves. They are, therefore, *axillary* terminal buds. This would indicate that the true terminal bud was subordinate. This is true. If we search carefully between the pair of axillary terminal buds there is found a minute dead terminal bud on the scar, left where it has fallen away. This indicates that the shoots of the lilac have indefinite or indeterminate growth. Those of the horse chestnut have determinate growth. The pair of axillary terminal buds of the lilac form, the following year, a pair of shoots which diverge, or fork. Some of these buds, however, are flower buds, as can be determined by dissecting them.


Fig. 60. Shoot of lilac.

108. Shoots of the elm.—The elm represents still another type of shoot, as shown by the position of the buds. The buds are *alternate*, and are situated in two rows on opposite sides of the shoot. The shoots are more or less zigzag in outline, the buds situated at the angles thus formed. On the ascending or horizontal shoots the rows of buds are lateral, so that as they develop into shoots the branching system of a limb presents a flattened outline, which is more marked when the leaves are present, since shoots and leaves lie in nearly the same plane. On either side of the leaf scar is a minute scar, the *stipule* scar, which marks the location of small delicate outgrowths (the stipules) at the base of the leaf stalk, which fall away soon after the opening of the leaves in the spring. The larger bud at the end of the stem is situated in the axil of a leaf scar. It is, therefore, an axillary terminal bud. Close to it and on the opposite side from its leaf scar is a small scar, which marks the point where the true terminal bud was seated and which has fallen away. The shoot of the elm has therefore indefinite growth. In the spring, when the new shoots develop, the axillary terminal bud and the bud next below but on the opposite side of the shoot, develop with nearly equal vigor, and thus diverge, producing a fork. The result of this is the diffuse or deliquescent stem of the elm (see types of stems, paragraph 64).

109. Shoots of the butternut.—The terminal young shoots of the butternut are of a dull brownish green color, while the older shoots are a darker brown. The surface is dotted with minute gray or whitish points, the lenticels. The terminal shoot can be determined by the prominent apical bud, which is long, conical and slightly curved. On vigorous shoots the annual growth can be determined by the presence of a band of small rings which mark the scale scars of the previous year's bud. The leaf scars on the shoot are very peculiar in form; they are somewhat triangular in outline. Upon the gray face of the scar are several dark marks, a V-shaped mark below, and a small round dot at each upper angle, giving to the scar the grotesque appearance of the face of some animal. These marks are the scars of the fibro-vascular bundles which extended into the leaf. Directly above each leaf scar is a bud. This is the bud which was formed in the axil of the leaf. Often above this is another bud, a supernumerary, or accessory, bud. The position of the scars shows that the leaf arrangement is alternate and spiral, for a string passed around the stem and passing over each leaf scar would extend in a spiral. The bud scales occupy similar positions but they are very much crowded.

110. Shoots of the peach.—The shoots of the peach tree have a shiny, smooth surface, which is usually reddish or reddish green in color. The extent of the year's growth varies from a few inches to several feet in length, according to the position of the shoot on the tree and the vigor of growth. The buds in the axils of the leaf are one to three on vigorous shoots, usually three. The middle one represents the main shoot; the lateral ones are branches from its base. Often the lateral ones develop shoots also, but when they are much stouter than the middle one they are usually flower buds. If not killed by extreme winter cold (say, −26°C. = −15° F. or lower), they will blossom in the spring. If they have been killed, the flower is black. This can be seen by removing the overlapping scales, or by cutting it open through the middle. In pruning, from one-third to one-half of the end of these new vigorous shoots is cut away in order to favor fruit development, and to admit sunlight to the forming fruit.

111. Shoots of the sumac.*—The shoots of the sumac also have indefinite growth, and the terminal portion therefore dies back some distance during the winter. This dead portion is very slender and short and very easily falls away. It is, however, often attached during late winter, and may have remnants of leaves clinging to it. Jarring the shoot usually causes the dead terminal portion to fall. Sometimes the shoot will die back

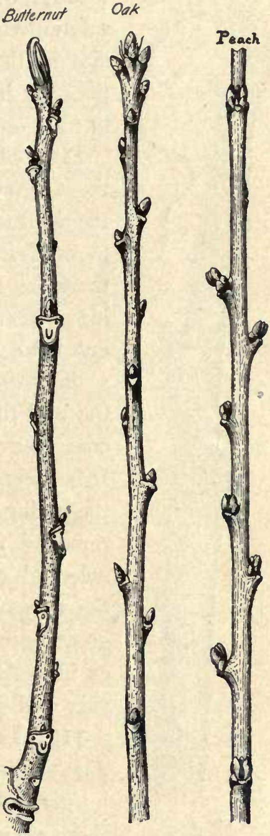


Fig. 61.
Shoots of butternut, oak and peach.

---

* The characters will vary with the species. The species dealt with here is the stag horn sumac, *Rhus typhina* = *R. hirta* of some books.

farther than this slender terminal portion. The sumac is further interesting because of the hairy condition of the shoots; the absence of bud scales, their function being performed by a dense woolly covering; by the resinous or gummy exudation where bruised or cut, and by the large size of the medulla or pith. The leaf scars are peculiar in that they nearly surround the buds, but are open above and nearly heart shaped.

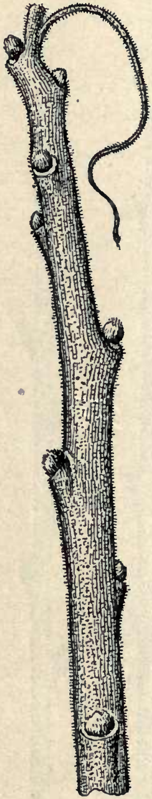


Fig. 62.

Shoot of sumac. Note axillary terminal bud by side of dead base of terminal portion and dead leaf.

112. Shoots of the willow.—The shoots of the willow possess an axillary terminal bud and the dead terminal portion of the shoot is crowded to one side. The growth of the willow shoot therefore is indefinite. The leaf scar is semilunar in form and there are three bundle scars, one below and one at each end. There is but a single brown scale on the bud, and it fits over the bud like a cap or hood. On removing it the character and condition of the bud within is seen. It is green and the young leaves are hairy. In the spring when growth begins the bark is easily removed from willow shoots. The willow is a splendid example of the formation of adventitious shoots and roots. They are developed in great numbers when a shoot is placed in water or in moist ground, and the willow is therefore very easily propagated from cuttings.

113. Leaf arrangement or phyllotaxy.—The arrangement of leaves on the shoot follows in general certain well-known systems. While there are certain variations and departures from the normal, on the individuals of a given species the arrangement is the same. The arrangement can be studied on leafy shoots, or on winter shoots, since the leaf scars and axillary buds mark the position of the leaves. Leaves are either opposite or alternate. The pairs of opposite leaves usually alternate at right angles with adjacent pairs. The alternate leaves are arranged in a spiral on the stem; i.e., a line drawn around the stem from left to right and passing over the leaf scars would form a spiral. The arrangement, whether on the opposite or alternate plan, is probably the result of natural causes in the origin of the leaves on the small growing point of the stem, where they are much crowded. The origin in some such regular order whether on the opposite or alternate plan, permits a large number in a given space. Either of these arrangements, however, gives the leaves a better light relation, as will be seen in the study of leaves, than if the leaves were arranged promiscuously, or all in a line one above another. The influence of light therefore may have had some influence through inheritance of a favorable position for the leaves.

114. In the case of the elm shoots, if the end of a cord is pinned on a leaf scar near the base of the last year's growth, and wound around the stem from left to right, passing over the successive leaf scars, it will pass once around the stem for every two scars. This arrangement is represented by the fraction $\frac{1}{2}$, the numerator denoting the number of turns around the stem, and the denominator indicating the number of leaf scars traversed in order to reach another leaf scar directly above the one at the starting point. In the sedges and in the American white hellebore (*Veratrum viride*) there will be one turn for every three leaves, and this is represented by $\frac{1}{3}$. In the butternut, oak, etc., there will be two turns of the spiral for every three scars or leaves, and this is represented by $\frac{2}{5}$. Now we find this curious relation. If we add together the numerators and denominators of the first two fractions, the result is as follows: $\frac{1}{2} + \frac{1}{3} = \frac{2}{5}$. Now if we add together the last two fractions in a similar way it gives a fraction which represents another plan of arrangement possessed by many shoots, thus $\frac{1}{3} + \frac{2}{5} = \frac{3}{8}$. In like manner $\frac{2}{5} + \frac{3}{8} = \frac{5}{13}$, which represents another, and so on for several other known systems.

CHAPTER IX.

LEAVES, THEIR FORM AND MOVEMENT.

1. THE GROSS PARTS OF THE LEAF.

115. Blade and petiole.—The majority of leaves consist of two rather distinct parts, — the *blade* and the *petiole.* The blade is the thin, expanded portion; the petiole is the stalk which attaches the leaf to the stem. The petiole is sometimes absent, in which case the blade is attached directly to the stem. The blade is the essential part of the leaf physiologically, and therefore in all plants where the leaf performs its normal work (see Chapter XI) the blade is usually present.

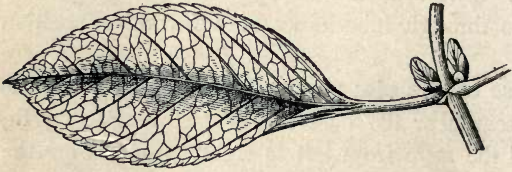


Fig. 63.
Leaf of hydrangea, showing blade and petiole.

116. Stipules.—With many leaves there are also present small or medium sized appendages which are attached one on each side at the base of the petiole, or they are attached to the stem at the junction of the petiole. These are the stipules. The stipules are either permanent and remain attached to the petiole during the life of the leaf, as in the apple, pea, etc. (figs. 65, 68), or they fall away early, as in the elm. In the former case they are usually green; in the latter they are often pale. The stipules are sometimes quite large, and the two together enclose the leaf in the bud, as in the tulip tree, and the point of attachment of the two extends entirely around the stem. In the false acacia the stipules are in the form of stout spines.

117. Parts of the leaf in the Indian corn and grasses.—In the grasses the part of the leaf attached to the stem folds completely or partly around the stem for some distance, and is called the *sheath*, while the blade is free. In the Indian corn and some other Gramineæ there is a membranous growth arising from the junction of the sheath and blade which lies close around the stem. This is the *ligule*.

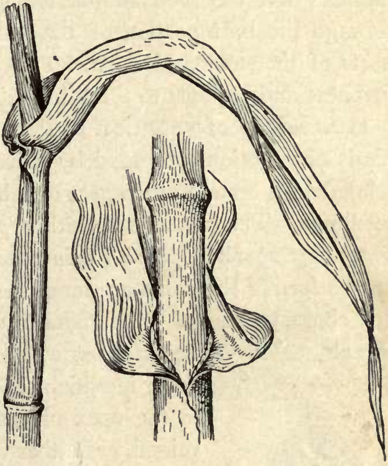


Fig. 64.
Leaf of corn, showing blade, sheath, and ligule.

118. Venation of leaves.—The blade of the leaf is prominently marked by lines, in the form, usually, of elevations, especially on the underside, while the lines are also seen distinctly on the upper side of the leaf. These are called *veins* of the leaf. Some of these veins are quite large and prominent, while others are smaller and less conspicuous. Within the veins are the vascular bundles, which are continuous through the petioles with

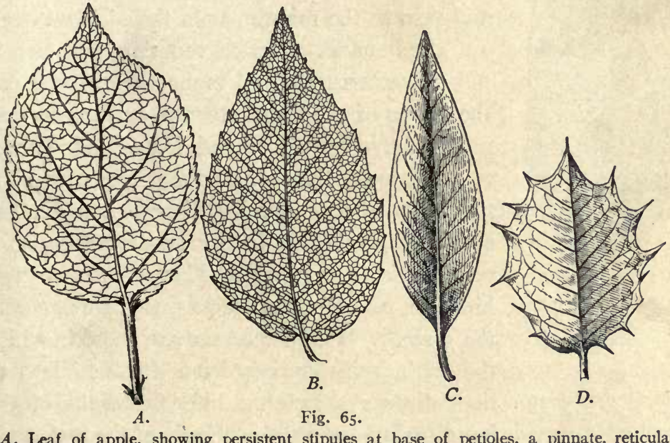


Fig. 65.
A. Leaf of apple, showing persistent stipules at base of petioles, a pinnate, reticulate, veined leaf, edge serrate. *B.* Leaf of beech, pinnate, reticulate venation, edge serrate. *C.* Leaf of laurel, edge plain. *D.* Leaf of holly, edge spiny.

the vascular system of the stem. Water and food substances are carried from the stem through them and distributed to all parts of the leaf, and the food assimilated in the leaves is carried back through the bast portion of the bundles to supply the growing parts of the stem and roots. The "veins" also assist in giving firmness and support to the thin and broadly expanded blade.

119. Kinds of venation in leaves.—In general there are two kinds of venation presented by leaves, which in general are correlated with certain characters of relationship noted in stems and seedlings. The venation is either *parallel* or *netted* (reticulate), so that we speak of *parallel veined* leaves and *netted veined* leaves. In the former the veins are long, regular and nearly parallel and are characteristic of most monocotyledons, as in the corn, the cereals, other grasses, palms, etc. There are two kinds: First, those in which the veins all run from the base to the apex of the leaf; second, the pinnately veined, or feather veined, those in which there is a mid-vein running from the base to apex, and the lateral veins are parallel and run from the mid-vein to the margin, as in the pickerel weed and the banana. Parallel venation, however, is not characteristic of all monocotyledons, since the leaves of the Indian turnip, or Jack-in-the-pulpit, have netted veined leaves. In *netted veined* leaves, the veins do not run with such regularity, the main veins diverge more or less and their branches finally anastomose into a very intricate network. There are also two kinds of netted veined leaves, the *palmate* and the *pinnate*. Palmate leaves are those in which the main veins spring from the petiole and then diverge something like the digits of the hand (palm) toward the margin of the leaf, as in the maple. In pinnate leaves there is a main vein which extends from the petiole directly through the middle line of the leaf, and the main branches from this arise at nearly

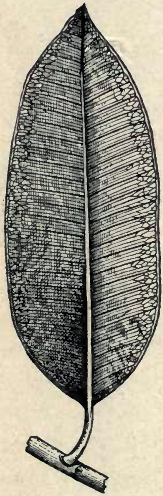


Fig. 66.

Leaf of rubber plant, a pinnately veined leaf, edge plane.

right angles and run nearly parallel toward the margin of the leaf, like the "veins" in a feather or *pinna*. Examples are seen in the oaks, apple, quince, beech, rubber plant, etc. Netted veined leaves are characteristic of the dicotyledons.

2. FORM OF LEAVES.

120. Leaves vary greatly in form, not only as to the general outline, but also as to the character of the margin and the division of the blade. The multitude of these variations it would be out of place to enumerate here, since a knowledge of them is chiefly of value in descriptive work and in the determination of species. Some of the more general types may, however, be mentioned. Some of the more aberrant variations are mentioned under *modifications of leaves*. There are two general kinds, *simple* leaves and *compound* leaves.

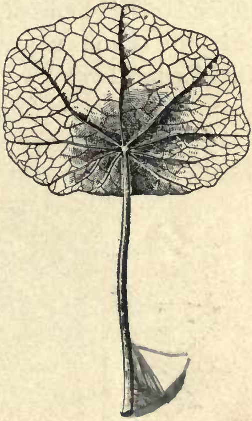


Fig. 67.
Leaf of Tropæolum, a peltate leaf with palmate venation.

121. Simple leaves.—Simple leaves are those which consist of a single blade. The blade may be oval in outline, or heart-shaped, elliptical, lanceolate, arrow-shaped, reniform (kidney-shaped), etc., and the edge may be plain, or irregular when the margin may have the appearance of being cut into minute teeth like the cutting edge of a saw (serrate leaves), as in the apple, or with more prominent teeth (dentate leaves), or with rounded teeth when the margin is scalloped (crenate leaves), etc. When the divisions extend deeper the leaf is *cut*, when nearly or quite halfway to the midrib the leaf is *lobed*, when halfway or more *cleft*, when nearly to the midrib *parted*, and when the divisions extend quite to the midrib the leaf is *divided*. The margins of the lobes or divisions may then be plane or serrate, etc. These divisions take place between the more prominent veins so that the leaf may be *pinnately lobed*, *parted*, *divided*, etc., or *palmately lobed*, etc., according to the kind of venation.

122. Compound leaves.—Compound leaves are those leaves in which the divisions of the blade are complete and regular and the divisions are set off distinctly from each other somewhat like distinct leaves, or *leaflets*.

123. Significance of leaf division.—The leaves are important organs for certain kinds of work for the plant. Within certain limits the work of the leaf is in proportion to its spread of surface. Beyond certain limits of spread, however, thin leaves are in danger of injury, since they would be whipped about more by the wind. Divisions of large leaves permit the currents of air to pass with less danger of injury. The work which leaves perform in conjunction with light is very important and the leaves must have a good light relation. Divided leaves permit the light to shine through to leaves below which otherwise would be too greatly shaded were the large leaves continuous.

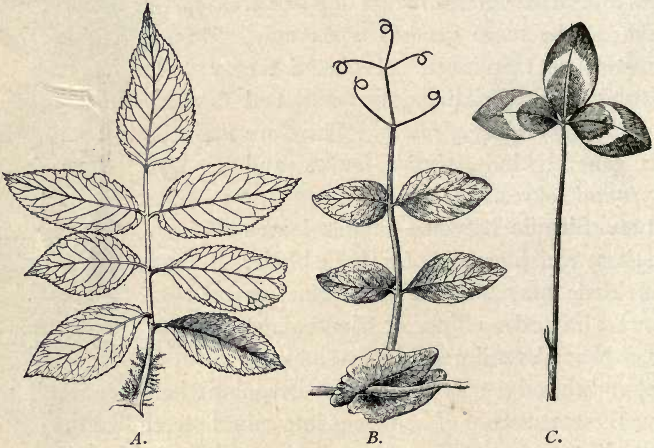


Fig. 68.

A. Rose leaf, pinnately compound, odd pinnate, hairy stipules. *B*. Leaf of pea, pinnately compound, terminal leaflets replaced by tendrils, leaf-like stipules. *C*. Clover leaf, palmately compound, persistent stipules.

3. FALL OF THE LEAF.

124. Leaves are not permanent outgrowths of the stem as most branches are. Their origin is superficial as compared with the origin of a branch, and they sooner or later fall away from the stem. In many trees and shrubs the leaves formed during the growing season fall at its close. These trees and shrubs are said to be *deciduous*. The stems remain bare during the resting season which in our climate is the winter season. In the spring new leaves are again formed on the new shoots. Other trees and shrubs hold each season's crop of leaves for several (two to four or more) years, and usually one crop, the oldest, falls away each year. These trees and shrubs are said to be *evergreen*, because they are holding several crops of green leaves during summer and winter, as in the pines, spruces, firs, balsams, rhododendrons, etc. When the time has come for the leaf to fall, a separation layer of cells is formed at the junction of the petiole with the stem, and the leaf falls away leaving a scar (the leaf scar) on the stem with a smooth surface (Chapter VIII). The scars, therefore, enable us to determine the position and arrangement of the leaves of deciduous shrubs and trees during the winter.

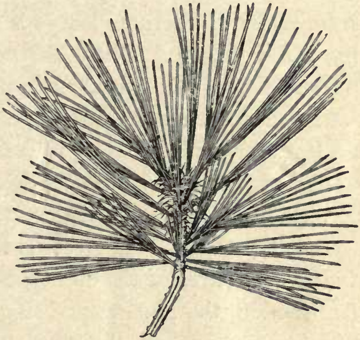


Fig. 69.
Shoot of white pine with "needle" leaves.

4. ARRANGEMENT OF LEAVES.

125. The arrangement of leaves on the stem seems to follow certain definite laws, and, barring accidents, is always the same for a given species.

126. Opposite leaves.—Leaves are opposite on the stem when two arise at the same level, or node, but on opposite sides. The milkweed (*Asclepias*) is a good example, but there are many others, as the horse chestnut, lilac, etc. In these examples each pair is at right angles to the pair above and below, so that looking down the axis of the stem there are seen four rows of leaves.

127. Whorled or verticillate leaves.—Leaves are whorled where three or more arise at the same level, or node, on the stem, and they are usually equidistant around the circumference of the stem. The Joepye-weed (*Eupatorium*) is an example.

128. Alternate leaves.—By far the larger number of plants have alternate leaves. There is but one leaf at the same level or node. Not only do the majority of plants have alternate leaves, but there is a great variety in their arrangement, though they all are arranged spirally around the stem. The simplest arrangement of alternate leaves is seen in such an example as the elm, iris, corn, etc. There are two rows of leaves, one each on opposite sides of the stem. If a pin is thrust through the end of a string and then stuck at the point of attachment of a leaf, or in a leaf scar, and the string is wound around the stem in a spiral, passing across each successive leaf scar or point of attachment, the string will cross two leaf scars for each complete revolution around the stem. This gives us the law or plan of arrangement of alternate leaves of the elm type which is expressed in the form of a fraction, the numerator being the number of revolutions the string makes around the stem until it reaches a leaf directly above the leaf at the starting point, while the denominator is represented by the number of leaf scars, or points of attachment, over which the string passes in making the same number of revolutions, not counting the leaf scar which served as the starting point. In the case of the elm, therefore, the plan of arrangement is expressed by the fraction $\frac{1}{2}$ which represents also the angle of divergence of successive leaves from each other around the stem. This is the two ranked arrangement. The next higher arrangement is the three ranked, shown in the sedges, the *Veratrum* or American white hellebore (*Veratrum viride*) in swamps and damp woods. The leaves are in three rows, and the arrangement is expressed by the fraction $\frac{1}{3}$. The five ranked arrangement is shown in the apple, poplar, etc. Here the spiral makes two revolutions for five leaves, and the fraction is $\frac{2}{5}$.

129. Practical studies on the arrangement of leaves.—This study can be carried on in the winter by the leaf scars, though a study during the growing season is preferable if it is possible. It will be found profitable, if possible, to prosecute this study in the fields or parks, when the students can make their observations and notes on opposite, whorled and alternate leaves with a determination of the rank of the arrangement.

5. RELATION OF LEAVES TO LIGHT.

130. Position of leaves with reference to light.—One of the most important relations of the leaf is its relation to light, because of the work in the manufacture of sugar and starch (photosynthesis, Chapter XII). It will be seen that the various arrangements of leaves shown in the preceding paragraph are of great importance in giving them a suitable light relation. This position on the stem obviates the too great shading of adjacent leaves. A more important relation, however, is the position which leaves take in response to the stimulus of light. The position which leaves occupy on the stem is governed largely by laws of growth in the formative tissue in the bud. The position which the leaf blade takes as it expands is in response to light stimulus. This position, in general, is such as to bring the broad upper surface of the leaf so that the stronger light rays will fall perpendicularly upon it, since the work of the leaf which is carried on jointly with light may be most effective.

131. Since the stronger light rays, when we consider any considerable period of time, come from the zenith, most leaves have in general a horizontal or nearly horizontal position. But there are many conditions which bring about a different result. On the edge of a dense forest or clump of large plants, or where for other reasons there is strong shade on one side, lower plants, unless they are shade plants, have their leaves turned more or less so that they face to one side to receive the incidence of the strongest light rays.

132. Position of the leaves of "compass" plants.—There are certain plants like the prickly lettuce (*Lactuca scariola*) and the "compass" plant (*Silphium laciniatum*) whose leaves often stand so that they point north and south, no matter on which side of the stem they are attached. The leaves at the same time are turned on edge, so that the surfaces face east and west. This position is taken by the leaves in response to light and not because of any magnetic influence. The sunlight at midday is too strong for the leaves and the leaf is stimulated to turn its edge to the incidence of the strongest rays so that they glide by with no injury to the leaf. The light during the morning and afternoon hours is not so strong so that no injury comes from the exposure of the surface at this time of day. When these plants grow in the shade the leaves do not point north and south and the blade is horizontal.

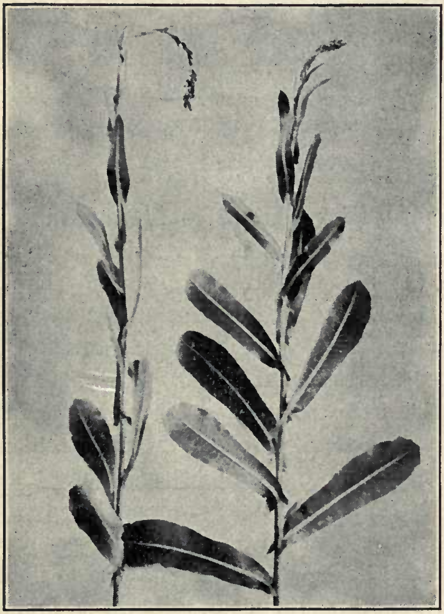


Fig. 70.
Prickly lettuce (Lactuca scariola), a compass plant, showing side and edge view.

133. Movement of leaves in response to light.—When leaves are young and their position has not become fixed, they often show marked movements in response to light stimulus. While many plants manifest this peculiarity, it is more marked in some than in others. Seedlings of many plants when placed where they receive a one-sided illumination, as near a window, or in a box open only on one side, the leaves, as well as the stems, turn so as to face the light. If the position of the seedlings is changed, the leaves will turn again. In the sunflower plant throughout its growth the younger leaves "follow the sun" all day on bright days. The leaves near the upper end of the stem are drawn somewhat together, so that they form a rosette, and turn so that their upper surfaces face toward the rising sun, the stem also turning to assist in bringing them into this position. This rosette of leaves then "follows the sun" all day and at sunset it is facing the west. After sunset the stem straightens up, and the leaves assume a horizontal position because the strongest rays of light are now from the zenith. On cloudy days the leaves remain in this horizontal position. Many other plants show this same peculiarity, the cotton plant, ragweed, sweet clover, and especially those plants belonging to the family known as sensitive plants, and to the legumes or Leguminosæ.

134. Night and day movements of leaves.—While leaves are very young, as in the bud, or plumule, growth of the cells is usually more rapid on the under side than on the upper side of the leaf. This causes the leaves to bend upward or inward toward the axis of growth of the stem. During later growth, however, growth is more rapid on the upper side, and this causes the leaves to "open" from the bud and to extend outward or even to bend downward. This upward growth tendency* of leaves in the bud is an advantage to the younger leaves and to the growing point of the stem since they are protected from drying out when in the delicate stage. When the downward growth comes into play the leaves are usually held in a horizontal position, and do not turn downward during the day, because the stimulus of light (see preceding paragraph) holds them in the most favorable light relation. But at sunset the young leaves of many plants, and all leaves of certain sensitive plants, turn downward, because the stimulus of light is removed

---

* The tendency of leaves to turn upward during early growth is called *hyponasty*, or *hyponastic* growth. The tendency later to turn downward by greater elongation of the cells on the upper surface is called *epinasty*, or *epinastic* growth.

and the tendency to downward growth, which was overcome during the day, now produces its effect. On the following day, however, the light stimulus again overcomes this downward growth and lifts the leaf again. This drooping of leaves at night is often called "sleep of plants." There is an advantage to the plant in this drooping position of the leaf at night, since radiation of heat is less than if the surface were exposed to the zenith.

135. Movement of leaves in response to touch.—Some plants are very sensitive to touch. Remarkable among these are the "sensitive" plants. A good example of sensitive plants is the *Mimosa pudica* so often grown in greenhouses. The leaves are twice compound and the pinnules (secondary leaflets) are in pairs. If one of these terminal leaflets be pinched with the fingers or with a pair of forceps, the first pair of leaflets close, or fold together above the mid-vein of the pinna. This is followed by the second pair and so on, and all the pairs of leaflets on this pinna closing in succession. When the last pair, the one at the base, has closed, all the pinnæ then move, closing in together, and the pairs of leaflets on the other pinnæ then commence to close beginning at the basal pair and extending to the terminal one. Soon also the entire leaf drops down from its point of attachment on the stem. If the plant is jarred, all the leaves droop and the leaflets close. At the base of each petiole on the underside near the point of attachment with the stem there is an enlargement, called a cushion (pulvinus) which controls the movement by the contraction or collapse of its cells. There are similar cushions at the base of the leaflets and pinnæ. At night, or when placed in darkness, the leaflets close up, and the leaves droop, opening up again with the coming of light. During the day if the sunlight is too strong, the leaves adjust themselves to the profile position, i.e., with the edge towards the source of strongest light. When the soil becomes too dry and the plant is in danger from loss of water, some or all of the leaflets close and the leaf droops, regulating itself according to the degree of dryness or drought, since in the closed position the leaves lose water less rapidly.

136. Relation of leaves to light.—This is preëminently a subject for field or outdoor study. Observations show that leaves assume the most advantageous arrangement and position to receive the best lighting. In many cases, when the leaf arrangement on the stem may be three, five or eight ranked, the leaf blades may be all arranged in a single plane, to receive the light from one direction. This often occurs in woods or groves, the petioles of the leaves twisting so as to allow the blade the most favorable position. Mosaics or patterns are formed where a number of leaves on a single shoot lie so that they are fitted in almost like pieces of mosaic and so that there is very little shading of adjacent leaves. *Fittonia* grown in greenhouses is a splendid example. *Rosettes* are formed when the leaves are crowded on the stem near the ground in the form of a rosette. *Imbricate patterns* are seen where the leaves are not so closely crowded, but overlap something like shingles on a roof so that light can reach the leaves. In the *radiate pattern* the leaves radiate in all directions from horizontal to the vertical and thus obtain a good light relation, as in the screw pine (Pandanus) often grown as an ornamental plant.

137. Irritability of tendrils and twining stems.—When a tendril or a twining stem, as it slowly swings around, comes in touch or contact with some object, this contact stimulus causes it to bend at this point bringing new points in contact so that the tendril or stem then coils around the object of support.

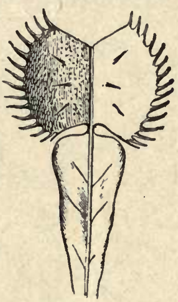


Fig. 71.

Leaf of Venus flytrap (Dionæa muscipula), showing winged petiole and toothed lobes.

Fig. 72

Leaf of Drosera rotundifolia, some of the glandular hairs folding inward as a result of a stimulus.

138. Response of insectivorous plants to touch.—Remarkable movements are shown by the leaves of some insectivorous plants. In the Venus's flytrap (fig. 71) the terminal part of the leaf is shaped like a steel trap. The blade is broad and the margin rounded and beset with numerous hairs or spines resembling the teeth of a steel trap. Upon the upper face of each side of the leaf are three prominent hairs. When these hairs are touched the second time, the leaf suddenly closes like a trap. Flies which alight on the leaf are thus caught and pressed between the folded leaf, and the leaf excretes, through special glands, juices which digest portions of the insect, which are then absorbed by the leaf and used for food. The sundew has a rounded or elliptical leaf blade covered with long glandular hairs which excrete a sticky substance. When an insect alights on the leaf the sticky substance holds it, and the hairs and leaf slowly fold inward around the insect and it is digested by the glandular juices.

CHAPTER X.

LEAVES, THEIR STRUCTURE AND MODIFICATIONS.

139. The leaf is an organ of a plant which performs several kinds of very important work. Its structure is remarkably well adapted for these kinds of work and also for its own protection, as well as for the protection of the plant against certain unfavorable conditions of the environment. A study of this structure is necessary to a clear idea of the work of the leaf.

1. STRUCTURE OF LEAVES.

140. The epidermis.—The epidermis is the outer layer of cells; the upper and lower epidermis covers the upper and lower surfaces of the leaf respectively. The epidermal cells are usually devoid of chlorophyll. The cells are usually thin, and flat in proportion to their extent. Viewed on the surface, as they can be seen by stripping off a portion of the epidermis, the cells in many plants are seen to be very irregular in outline, as in fig. 73.

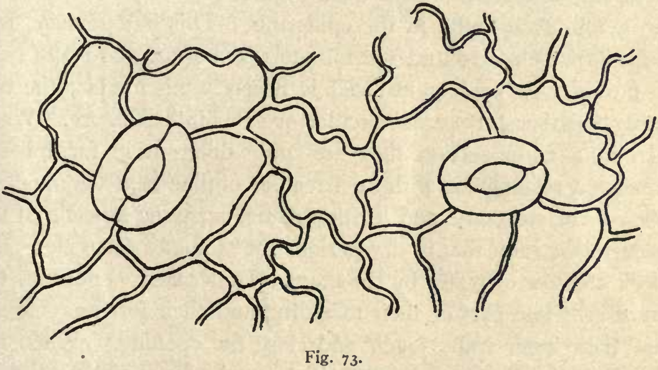


Fig. 73.
Portion of epidermis of ivy, showing irregular epidermal cells, stoma and guard cells.

When viewed from the edge, as seen in a cross section of the leaf (fig. 74), they appear quite regular and rectangular.

141. The cuticle.—Upon the outside of the epidermal layer of cells is a more or less thickened deposit of a waxy nature, the *cuticle*. This is extremely thin in some plants (shade plants, especially in moist regions), while in others it is quite thick, as in the cabbage (and in plants of dry regions). When the cuticle is highly developed, as in the cabbage plant and onion, it is difficult to wet the leaf, since the water rolls off so easily from the smooth, waxy surface.

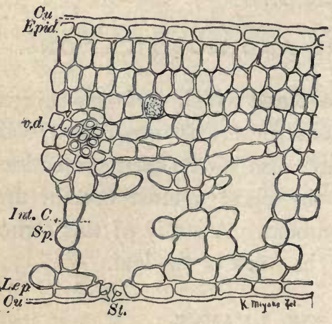


Fig. 74.

Cross section of leaf of wintergreen. *Cu.*, cuticle; *Epid.*, epidermis; *v.d.*, vascular duct; *Int. c. sp.*, intercellular space; *L. ep.*, lower epidermis; *St.*, stoma.

142. The stomates.—When the epidermis is viewed from the surface, as in fig. 73, here and there are seen peculiar and quite regular cells in pairs surrounding a minute opening in the epidermis. This is a *stomate*, and the cells which surround the minute opening are the *guard cells*. In profile view each guard cell is nearly semi-circular; the two fitting together form a subcircular or subelliptical figure. When seen in a cross section they are quite different in form, being somewhat rectangular with an irregular outline next the opening. Their form, structure, and relation to the surrounding cells of the epidermis is such that in dry periods the stomates often close and check the loss of water by the plant. Under such conditions the guard cells lose part of their turgidity, and their form so changes that their inner walls touch and close the opening. When the plant has an abundance of water the guard cells absorb enough to make them turgid, and, in swelling, their form and the thickness of the walls causes them to arch away from each other and open the stomate.

143. Epidermal outgrowths, hairs, glands, etc.—Leaves are either smooth, or hairy, or rough from other outgrowths of the epidermal cells. These outgrowths are in the form of hairs (long slender cells or rows of cells), glands (special cells for excreting various substances) and scales (as in *Shepherdia*). The hairs are simple or branched (in the mullein), some of the latter being star-shaped (as in some oaks). These hairs and scales aid the leaf in retaining moisture since evaporation of moisture from the surface is hindered.

144. Structure of the leaf in cross section.—The epidermis and guard cells as seen in a cross section of a leaf have been described above. The interior portion of the leaf consists of the *mesophyll* and the *fibro-vascular bundles*. These may be studied in cross and longitudinal section according to the way the veins run in the portion of the leaf sectioned; and the parts in general, the wood portion with its vessels and wood fibers, and the bast portion with its bast, can be made out by consulting paragraphs 94–98. The mesophyll usually consists of two kinds of parenchyma cells,—the *palisade* layer of cells and the loose, spongy tissue. The palisade layer of cells is found usually just beneath the upper epidermis. It consists of elongated cells lying closely side by side and perpendicular to the epidermis. Sometimes there are two layers of palisade cells; in the compass plants, one layer on each side of the leaf. The remaining part of the mesophyll is the loose parenchyma, so-called because the intercellular spaces are large, thus giving the cells a loose arrangement. These intercellular spaces connect throughout the leaf and also with the stomates. They thus provide for aeration of the leaf, for the entrance and escape of gases in photosynthesis and respiration, and for the escape of moisture.

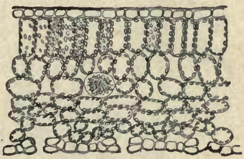


Fig. 75.

Section of ivy leaf, palisade cells above, loose parenchyma, with large intercellular spaces in center. Epidermal cells on either edge. with no chlorophyll bodies.

145. The chlorophyll bodies.—The green color of leaves (as well as of other parts of plants except in some rare cases) resides in definite bodies called *chlorophyll bodies*. These are minute, more or less oval, flattened bodies, of a soft and plasmic nature, in the protoplasm.* The chlorophyll is a green pigment in these bodies where it exists in numerous very fine grains. The chlorophyll bodies lie in the outer layer of protoplasm, next the cell wall. They are distributed throughout the cells of the loose parenchyma, the palisade cells, and the guard cells, rarely in the epidermal cells (they occur in the epidermis of ferns) and are absent from the vascular bundles.

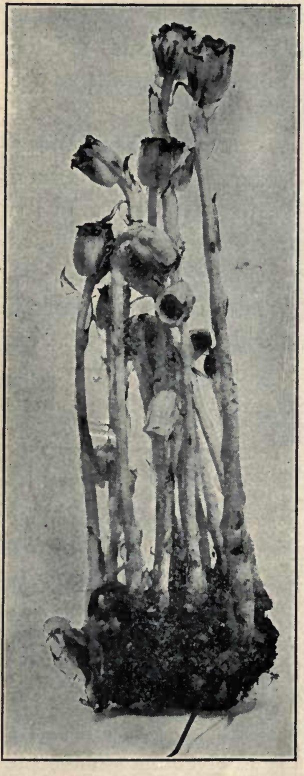


Fig. 76.

Indian pipe plant (Monotropa uniflora) with white stems and white scale leaves.

2. MODIFICATIONS OF LEAVES.

146. The normal form of the leaf, as stated in the previous chapter, is a broad, thin organ which thus exposes to the air and light a great surface in comparison with its bulk. This is because the normal work of the leaf is most advantageously and economically carried out with this form. There are, however, numerous exceptions to this form presenting what are termed modifications of leaves in different plants. These modifications are shown under a variety of conditions: first, when the leaf has entirely lost its normal function; second, where a modification is demanded to enable the

---

* *Chromatophore* is a general name for these bodies. They are capable of division, and thus grow and multiply in the plant as the cells increase. When devoid of color they are *leucoplasts*, when they have the chlorophyll green they are *chloroplasts*, when they have red or yellow pigments they are *chromoplasts*, as in the red and yellow petals of flowers, in the carrot, etc.

leaf to resist the trying arid climate of the desert, or the equally drying air of arctic or alpine regions; third, where the normal functions of the leaf are combined with some other utility; fourth, where the leaf is reduced to a very small size on certain parts of the plant devoted to other than the vegetative function (on the flower shoot for example) probably according to the law of correlation; fifth, the floral leaves, the sepals and petals of the flower, which are modified leaves with usually loss of chlorophyll, and an adaption to other ends.

147. Modifications where the normal work of the leaf is lost.—First, on underground stems like the mandrake, Solomon's seal, the wake robin, etc., the leaves are reduced to mere scales, are colorless, or at least lack the green color. The annual aerial shoot bears the green leaves. Second, in certain parasitic or saprophytic flowering plants, like beech drops (*Epiphegus*), the Indian pipe (fig. 77), etc., the leaves, though on aerial shoots, lack chlorophyll and are reduced in size to mere scales, the plant obtaining its carbohydrate food through its roots from its host, or as a saprophyte, or with the aid of a fungus mycelium in its roots. Bud scales show another modification of leaves from the normal function. Third, in the cacti the leaves are supposed to be reduced to mere spines since the stem has taken on entirely the normal function of the leaf. But in the barberry the leaves of the main shoots are largely in the form of three rayed spines. That these are leaves is seen from their position on the stem and the fact that there are bud and shoots in their axils.

Fig. 77.
Shoot of barberry showing leaves modified to spines in the axils of which a short shoot with foliage leaves is developed.

148. Modifications of leaves in arid or arctic regions.—The leaf is greatly reduced in area so that there is a small amount of surface exposed to the air in proportion to the bulk of the leaf, so that the water is conserved. These leaves often closely overlap or lie close against the stem as scales. The cassiope (*Cassiope tetragona*), which is found in sphagnum moors in some of the Northern States, and is common from Labrador to Greenland and Alaska, is an example.

149. Needle-like leaves.—These are found on many conifers, especially the pines. The leaves are long, narrow, and thick, and are called *needle* leaves. They have a thick, waxy cuticle, an epidermis with thick walls. Beneath the epidermis there are several layers of cells the walls of which are very thick and hard, and inside is the mesophyll. This form and structure of the pine leaves enables them to conserve water so that they lose it very slowly; otherwise the leaves would lose so much water that in winter the trees would be killed. The spruces have similar leaves, but they are shorter and more flattened, while some other evergreens have scale leaves, which with their structure enables them to endure the drying effect of the cold winters.

150. Modifications of leaves combining the normal functions with other utilities. — First, tendrils and tendrils on leaves, as in the pea; also where the petiole of the leaf functions as a tendril, as in the virgin's bower (*Clematis*). Second, the leaves of insectivorous plants, like the Venus's flytrap, the sundew (see paragraph 138), and the pitcher plants, of which a good example is the common pitcher plant of our sphagnum moors. Here the leaf is modified into a pitcher-shaped structure, broadened near the middle and narrowed somewhat near the free end, where there are on the inside of the pitcher numerous bristle-like hairs pointing downward.

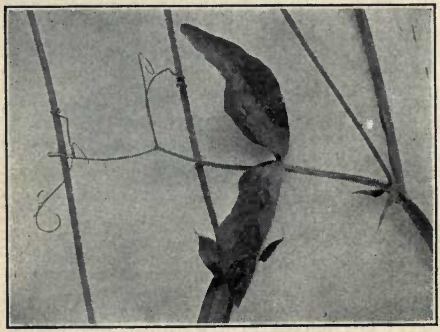


Fig. 78.
Tendrils of sweet pea coiling around supports.

Certain insects which enter the leaf are prevented from crawling out by these hairs, and after a while they fall into the water at the bottom of the pitcher and die.

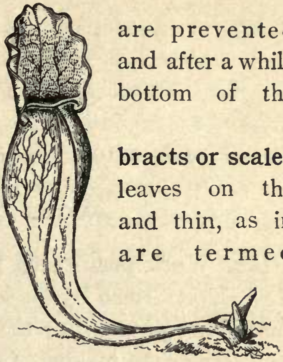


Fig. 79.
Leaf of pitcher plant (Sarracenia).

151. Reduction of leaves to bracts or scales on the flower shoot.—Reduced leaves on the flower shoot are often green, small and thin, as in the bell flower, marigold, etc. These are termed *bracts*. On some flower shoots the bracts are broad and colored like the petals of some flowers as in the flowering dogwood. Bracts of the flower shoot are sometimes termed *scales* when they are more or less rigid and thickened, as in the heads of some composites. The thickened bases of the scales on the flower head of the "artichoke" (*Cyanara Scolymus*) are edible.

CHAPTER XI.

WORK OF THE LEAVES.

152. Work performed by leaves.—There are several kinds of work performed by the leaves which we will study as follows: First, *Transpiration*, or the giving off of water; second, *Photosynthesis*, or the making of sugar and starch; third, *Respiration*, or *energesis*, the energizing of the plant, which results in waste; fourth, *Digestion*, the preparation and transformation of foods; and fifth, *Assimilation*, or the making of new living matter and the repair of waste. Several of these functions are carried on by all parts of the plant, but preëminently by the leaves, except in those plants so modified that some other plant part has taken on the work of the leaf, as in the cacti, phylloclades, etc.

I. TRANSPIRATION.

153. The loss of water by leaves.—That the loss of water by plants is chiefly through leaves can be shown by an interesting experiment as follows. A few fresh leaves are cut from a plant, and the ends of the petioles are sealed by dipping them in paraffin, These are now placed under a dry bell jar or inverted fruit jar,

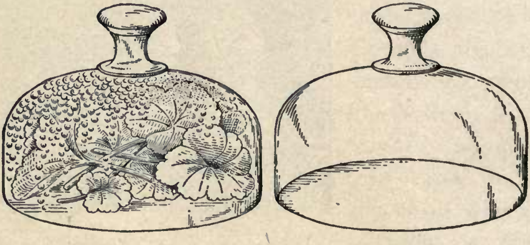


Fig. 80.

After a few hours' drops of water have accumulated on the inside of the jar covering the leaves.

and a similar vessel with no leaves under it is kept as a check. In the course of an hour or so there will be seen a film of moisture on the inside of the glass covering the leaves, while the other glass will remain dry. The moisture came from the leaves through the surface. To show this with an entire plant, the pot and soil of a plant with a goodly number of leaves are covered with rubber cloth to prevent the escape of moisture from the soil or pot. The plant is now covered with a glass bell or fruit jar so that moisture cannot escape below. The moisture which accumulates on the inside of the glass vessel indicates that the leaves in their normal position on the plant give off water.

154. Form in which the water escapes from the plant.—This can be shown by a very interesting experiment. A plant is covered with a bell jar as described above, and at the same time a piece of cobalt paper * pinned to a stake is placed under the glass vessel. At the same time another piece of cobalt paper is placed under a similar dry glass jar with no plant under as shown in fig. 82. The cobalt paper should first be dried by heat so that it is blue. In a very short time the cobalt paper under the jar with the plant will begin to redden, while the paper under the other jar is still blue. The blue cobalt paper is very sensitive to moisture and a little moisture in the air will quickly redden it before enough moisture has been given off to show on the glass jar. This demonstrates that the water escapes from the leaves in the form of water

Fig. 81.

Water vapor is given off by the leaves when attached to the living plant. It condenses into drops of water on the cool surface of the glass covering the plant.

Fig. 82.

A good way to show that the water passes off from the leaves in the form of water vapor.

---

* Make a solution of cobalt chloride in water. Saturate several pieces of filter paper with it. Allow them to dry. The water solution of cobalt chloride is red. The paper is also red when it is moist, but when it is thoroughly dry it is blue. It is very sensitive to moisture and the moisture of the air is often sufficient to redden it. Before using, dry the paper in an oven or over a flame.

vapor. When a sufficient amount of water vapor is given off by the leaves under the jar it *condenses* on the cool glass in the form of water.*

155. How the water vapor escapes from the leaf.—The living cells of the leaf contain a large percentage of water in the cell sap. The cell walls are saturated with water because they imbibe or absorb water from the cells which they bound. In the loose parenchyma of the leaf (see fig. 74) there are numerous large intercellular spaces containing air. The water on the surface of these cell walls is in contact with the air. This water evaporates † into the air spaces, or passes off into water vapor. The water vapor diffuses in the intercellular spaces, so that the air becomes very humid, more so than the air outside of the leaf on ordinarily dry days. The water vapor diffuses out of the leaf through the open stomates, and makes room for more water to evaporate from the cell wall. The cell wall in turn takes by imbibition more water from the cell, so that under conditions favorable for this process water vapor is constantly flowing out through the stomates. Some water also evaporates from the external walls of the epidermal cells, but the quantity is usually small because of the waxy cuticle over the epidermis.

156. Conditions which favor or retard transpiration.—Dry air favors transpiration, since it permits a more rapid diffusion of the water vapor out of the intercellular spaces. Currents of air also hasten transpiration, since the water vapor is quickly carried away from the surface of the leaf. This is why dry winds or high winds often cause plants to wilt, especially when the soil is dry and absorption by the roots is not equal to the transpiration by the leaves. Light also favors transpiration. Since osmotic substances are more active in the guard cells, they become turgid, curve backward and keep the stomates open. Humid air, darkness, or weak

---

* A good illustration of the condensation of water vapor on the surface of a cool object is seen in the summer when the air is very humid and drops of water accumulate on the outside of a pitcher of cold water.

† If it is desired to demonstrate the evaporation of water a shallow vessel of water can be covered with a bell jar or tumbler. The condensation of water on the inside shows some of the water has evaporated.

light retards transpiration. In darkness or weak light the stomates tend to close. For modifications of the leaf which retard the loss of water see paragraphs 148, 149.

Fig. 83.
Rhododendron maximum in freezing weather, the leaves rolled into tubes and hanging directly downward.

157. Whenever possible the student should make observations on the loss of water by plants and the effect on the plant. This can be done sometimes during excursions. Compare the conditions of plants in very dry periods in dry soil with the same plants during a moist period. Plants grown in pots * or small boxes can be set in a dry room and left without watering; some can be placed where there are dry currents of air. These can be compared with others where the air is quiet and the soil is kept moist. Plants with thick, leathery leaves, like the rubber plant or the purslane, can be set in a dry room along with plants with thin delicate leaves

---

* The pot and soil should be sealed hermetically with rubber cloth to prevent evaporation of water.

to compare the result. The purslane will sometimes grow if it is hung on the fence. It is a kind difficult to kill. Trees and shrubs with thin leaves usually shed them on the approach of winter, since water transpires from them rapidly. Evergreen trees have thick and hard leaves with a strong cuticle. They lose water slowly. Interesting observations can be made on rhododendrons, which are often grown in city parks or in private grounds. In extremely cold weather when it is freezing, the rhododendron leaves hang downward and are rolled up into a tube. In this way the leaves lose less water than if they remained flat. It will be remembered that freezing of plant tissue has a drying effect.

Fig. 84.

Rhododendron maximum during mild weather in the winter, leaves expanded and extending out laterally in normal position.

158. How drops of water exude from leaves.—If small, actively growing plants, such as the pea, corn, wheat, bean, etc., are put under a bell jar and placed in the sunlight where the temperature is suitable for growth, in a few hours, if conditions are favorable, there will be drops of water standing out on the margins of the leaves. These drops of water have exuded through the ordinary stomates, or in other cases through what are called water stomates, by the influence of root pressure. The plant being covered by the bell jar, the air soon becomes saturated with moisture and transpiration is checked. Root pressure still goes on, however, and the result is shown in the exuding drops. Root pressure is here in excess of transpiration.* This phenomenon is often to be observed during the summer season in the case of low-growing plants. During the bright warm day transpiration equals, or may be in excess of, root pressure, and the leaves are consequently limp or flaccid. As nightfall comes on the air becomes more moist, and the conditions of light are such also that transpiration is lessened. Root pressure, however, is still active because the soil is still warm. In these cases, drops of water may be seen exuding from the margins of the leaves, due to the excess of root pressure over transpiration. Were it not for this provision for the escape of the excess of water raised by root pressure, serious injury by lesions, as a result of the great pressure, might happen. The plant is thus to some extent a self-regulatory piece of apparatus so far as root pressure and transpiration are concerned.

159. Number of stomates.—It has been estimated by investigation that in general there are 40–300 stomates to the square millimeter of surface. In some plants this number is exceeded, as in the olive, where there are 625. In an entire leaf of Brassica rapa there are about 11,000,000 stomates, and in an entire leaf of the sunflower there are about 13,000,000 stomates.

160. Amount of water transpired by plants.—The amount of water transpired by plants is very great. According to careful

---

* These drops should be distinguished from those formed merely as a result of condensation of moisture on the leaves.

estimates, a sunflower 6 feet high transpires on the average about one quart per day; an acre of cabbages 2,000,000 quarts in four months; an oak tree with 700,000 leaves transpires about 180 gallons of water per day. According to von Höhnel, a beech tree 110 years old transpired about 2250 gallons of water in one summer. A hectare of such trees (about 400 on 2½ acres) would at the same rate transpire about 900,000 gallons, or about 30,000 barrels in one summer.

CHAPTER XII.

WORK OF LEAVES (Continued).

II. PHOTOSYNTHESIS.

161. The formation of sugar and starch during photosynthesis.—The work done by leaves in the formation of sugar and starch requires the air and light relations.* In the case of aquatic plants the air is mixed in the water so that fundamentally, so far as the process is concerned, the relations of land and aquatic plants to light and air are the same, though it is better to speak of the light and water relation of aquatic plants. The thin and broad form of the leaf exposes a large surface to the air and light, while the stomates and intercellular spaces of the leaf afford free communication of air into the mesophyll portion of the leaf. That sugar and starch are plant products we have learned from our study in Chapters I and II. Now we wish to learn the process by which the plant makes them.

162. Need of the light relation.—The leaves of the corn plant, the beet, onion, and most other monocotyledons which have been exposed to the light contain a certain amount of sugar. On the other hand the leaves of the bean, tropæolum, potato and most other dicotyledons which have been exposed to the light contain starch, which can be demonstrated by dissolving out the chlorophyll and treating the leaf with a tincture of iodine. A small quantity of sugar is also present. Starch disappears from leaves which have been kept in the dark during the night, and if the leaf, or a portion of it be kept in the dark the following day, or in very weak light, no starch will appear. This clearly indicates that light plays an important part in this work of the leaf and explains the need of the light relation.

---

* In the case of aquatic plants the relations are light and water, the water containing air mixed with it.

163. Need of the air relation in this work of leaves.—The air relation is also necessary in the formation of sugar and starch as well as in respiration. There is an interchange of gases in the plant during the process, and if the leaf is deprived of one of the necessary gases the formation of sugar and starch ceases. The gas which the plant absorbs during this process is carbon dioxide (one part of carbon and two parts of oxygen in the molecule of carbon dioxide = CO_2). The air consists of about twenty-one parts of oxygen, about seventy-nine parts of nitrogen and a small fraction of one part of CO_2. A small percentage of CO_2 is sufficient since during respiration of animals and plants, and by the burning of combustible material, CO_2 is constantly added to the air. More than about 4 per cent of CO_2 in the air is harmful to most plants. While CO_2 is absorbed by plants during this process oxygen is given off.

164. To show the evolution of oxygen by green plants.—For a simple demonstration of the oxygen given off by green plants, water plants are more suitable than land plants, since the gas bubbles can easily be seen as they rise in the water. Nevertheless with proper apparatus and methods of measuring and determining gases it can be demonstrated that the same gas (oxygen) is given off by green plants in the air. A few sprigs of the water weed, *Elodea* (= *Philotria*), with freshly cut stems about 10 cm. (4 inches) long, are inverted and immersed in a bottle of spring or tap water. The bottle is placed in the sunlight. Bubbles of gas will soon begin to rise quite rapidly from the cut ends of the stem. If the bottle is moved into the shade for a moment, the bubbles are given off very slowly. When moved into the sunlight again, the bubbles immediately begin to rise at a rapid rate. In the same way when pond scum (threads of the alga, *Spirogyra*, for example) are placed in a vessel of spring or tap water in the light, the bubbles of gas are given off. This is interesting as indicating, what is a fact, that this same process takes place in all green plants which have chlorophyll.

165. To determine that this gas is oxygen.—A large quantity of fresh *Elodea* is placed in a large jar of tap water. A funnel is inverted over it, leaving a few sprigs projecting under the edge of the funnel so as to hold the edge of the funnel off the bottom of the jar and permit a free circulation of water and gases. The small end of the funnel must be immersed. A very short section of rubber tubing is slipped over the end of the funnel. A test tube is filled with the water, inverted, and the open end immersed so there will be no air in the tube. It is then slipped over the end of the funnel and squeezed far enough down on the piece of rubber tubing to hold it firmly in place. The apparatus is now placed in the sunlight, where it will receive the sun during the entire day. The bubbles of gas rise into the test tube and displace the water.* When the tube is nearly full of gas the test can be made. With one hand the tube is removed, at the same time holding the thumb over the mouth to prevent the escape of the gas. The tube is now tipped so that the small amount of water will flow to the bottom. A soft wood splinter is now lighted. After it has flamed for a few seconds the flame is extinguished by blowing. The glowing splinter is inserted in the mouth of the tube. It flames again. This indicates that the gas is oxygen.

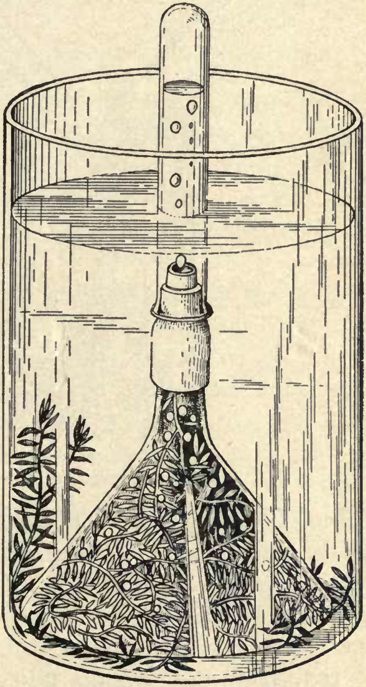


Fig. 85.
Apparatus to catch oxygen from aquatic plants.

---

* The water should be changed each morning until the tube is nearly full of gas. To do this slip the tube off the funnel into a tumbler of water. The funnel can then be removed, the water emptied and fresh water put in the jar. The tube is then placed in position again.

166. To show that CO_2 is absorbed while O is given off by plants.—Boil some spring water. This drives off the air and CO_2 which is mixed in it. When the water is cooled a few sprigs of Elodea are placed in it as described in paragraph 164. It is now placed in the sunlight. No gas is given off. If oxygen is added by thoroughly agitating the water so as to mix air with it, and it is placed in the sunlight, no gas is given off. If CO_2 is now added (by breathing into the water through a glass tube, or with a gas generator), and it is placed in the sunlight, oxygen is again given off.

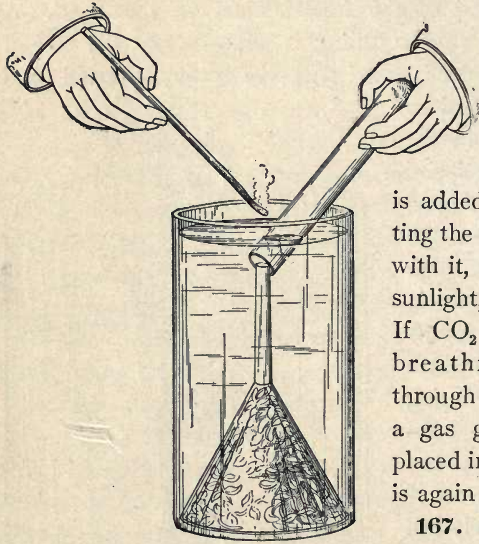


Fig. 86.
Ready to see what the gas is.

167. A chemical change takes place in the gas in the cells of the plant.—These experiments indicate that a chemical change takes place in the cells of the plant, for if a simple plant like the pond scums (Spirogyra) is used the result will be the same. Since sugar and starch are formed in the leaves during this process, they are a part of the result or product of this change.

168. How this change takes place in land plants.—The chemical change which takes place with aquatic plants, as indicated by our experiments, occurs also in the case of the green land plants. The air is a mixture of a number of gases. The principal and constant gases in the air mixture are as follows. In every 100 parts there are about 21 parts of *oxygen* (symbol for oxygen = O), about 79 parts of *nitrogen* (symbol for nitrogen = N), and a very small fraction of *carbon dioxide* (symbol for carbon dioxide = CO_2). The latter gas is a very poisonous one, or rather suffocating gas. We have already noticed that carbon dioxide is easily absorbed by water. Water is a compound of two gases, *hydrogen* two parts and *oxygen* one part, and the symbol for water is therefore H_2O. The land plants absorb* some of the carbon dioxide from the air, and it is also formed within the plant cells of all plants during respiration. But whether formed in the plant cell or absorbed from the air, **as** soon as it comes in contact with the water in the cell it is absorbed. When carbon dioxide is absorbed by water, the two together form carbonic acid ($CO_2 + H_2O = CH_2O_3$ = the symbol for carbonic acid).†

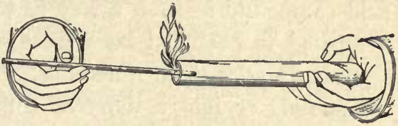


Fig. 87.

The splinter lights again in the presence of oxygen gas.

169. There are five principal requirements in the process of photosynthesis‡ during which the formation of starch and sugar in green plants takes place. First, the living plant cell; second, the presence of carbonic acid; third, the presence of chloro-

---

* The process of transpiration keeps the cell wall saturated with water. This provides the water for the solution of the CO_2 which in the dry condition (anhydride condition) could not diffuse through a dry cell wall fast enough. This is believed to be one of the important functions of transpiration. In the case of aquatic plants the CO_2 in the water is dissolved and is therefore CH_2O_3 = carbonic acid.

† In the case of aquatic plants the water in which they grow absorbs carbon dioxide from the air, thus forming the carbonic acid which they absorb from the water.

‡ It is now evident what photosynthesis means. The first part of the word comes from the Greek word φωτός = light, and the last part of the word has reference to the synthetic process, or union, or putting together. The process was formerly considered a process of *assimilation* and was called *carbon dioxide assimilation*. True assimilation, however, is brought about entirely by the living substance of the plant (see paragraph 176). In "carbon dioxide assimilation" sunlight supplies the energy for one step in the process, and it seems better to use the term photosynthesis, though if the nature of the process is kept clearly in mind there should be no very great objection to saying carbon dioxide assimilation. Some use the term *fixation* of carbon.

phyll; fourth, sunlight shining into the cell; fifth, the chemical changes. The chlorophyll absorbs some of the rays of light and this furnishes the power, we might say, to break up the carbonic acid compound in such a way as to separate its elements. But according to chemical laws these elements cannot long remain separated under these conditions. They quickly unite into other compounds or into a different compound. The different steps in the process are very complicated and some of them are not well known. But the first compound which we can definitely recognize in the plant as a result of this chemical change is the substance *sugar.** The symbol for grape sugar is $C_6H_{12}O_6$, because one *molecule* of sugar contains 6 parts of carbon, 12 parts of hydrogen and 10 parts of oxygen. In the making of one molecule of sugar, therefore, 6 molecules of the carbonic acid are necessary as will be seen by the following simple mathematical formula, $6(CH_2O_3) = C_6H_{12}O_{18}$. Now subtract the sugar symbol from this as follows, $C_6H_{12}O_{18} - C_6H_{12}O_6 = 12_0$; i.e., there are 12 molecules of pure oxygen set free in the plant cell which the plant cannot use in this process. Much of this pure oxygen escapes by way of the stomates into the open air again. It is an interesting fact that during this process by which sugar is made in plants, pure oxygen is added to the air and thus in general the proper balance or proportion of this gas is maintained; otherwise, the air would in time become so depleted in oxygen that it could not sustain animal life, since animals use oxygen of the air in respiration. It is also interesting to note that, in this process, the green plants use carbon dioxide from the air, which animals give off during respiration. Green plants, therefore, in this respect, as well as in so many others, perform a very important work in nature.

170. How starch is formed from sugar.—Sugar is changed to starch in the plant by the loss of one molecule of water. The

---

* It is interesting to note that the proportion of hydrogen and oxygen in the sugar compound is the same as that of a molecule of water, i.e., H_2O. The same is true of most sugars, and of starch. Those compounds of carbon, hydrogen and oxygen which contain the H and O in the proportion H_2O, are known as *carbohydrates.*

result can be seen from the following simple formula: Grape sugar, $C_6H_{12}O_6 - H_2O = C_6H_{10}O_5$,[*] which is the symbol for starch. In many plants the sugar formed in the leaves does not change to starch except that which is stored in the seed, as in field corn, wheat, barley, etc. Sugar is found throughout other parts of the plant, and we have seen that it is stored in quantity in the sugar beet. In some plants it is not even changed to starch in the seed, as in the sweet corn. In many plants, however, it is changed to starch in the leaf very soon after its formation in the leaf, as in most dicotyledons.

171. Where the starch grains are first formed.—The sugar is dissolved in the cell sap, but the starch is deposited in grains. These grains of starch at the time of their formation are deposited in the chlorophyll bodies. Each grain begins as a very small body and increases in size. (For translocation and storage of starch, see Chapter XIV.)

172. Photosynthesis takes place only in chlorophyll-bearing plants and in the chlorophyll-bearing parts.—Plants which have been grown in the dark lack chlorophyll.[†] When brought into the light photosynthesis does not take place until chlorophyll has been formed. So in variegated leaves, photosynthesis does not take place in the white portions because chlorophyll is absent, but it does take place in the green parts of such leaves or in such parts as have chlorophyll. Photosynthesis does not, therefore, take place in the roots, not even in the roots of green plants, nor in stems where chlorophyll is not present. Experiments with chlorophyll-less plants like beech drops (*Epiphegus*), the Indian pipe (*Monotropa*), and the fungi and bacteria[‡] show that photo-

---

[*] The symbol for starch is probably some multiple of this and is usually written $(C_6H_{10}O_5)N$.

[†] There are some few exceptions. The first leaves of pine seedlings have chlorophyll leaves even grown in the dark.

[‡] A few bacteria, however, are known to be able to form their own carbohydrates. The nitrite and nitrate bacteria which convert ammonia compounds into nitrites and nitrates in the soil obtain energy from the chemical process of making nitrites and nitrates, so that they can assimilate the CO_2 of the air. This is not photosynthesis however, since light does not supply the energy. It is *chemosynthesis*.

synthesis cannot take place in them. They are dependent for their carbohydrate food on green plants.* They obtain it either as parasites on living green plants, or by growing on their dead or disintegrated remains as saprophytes; or on other plants or animals which in their turn are dependent on the green plants primarily for their carbohydrate food.

173. Conditions favoring photosynthesis.—From the preceding experiments and discussion it is clear that light and air, the chlorophyll, and the living substance of the plant, are essential to the formation of sugar and starch. But the rapidity of their formation is influenced by the varying intensity of light, temperature, and the percentage of CO_2 in the air.†

174. Amount of carbohydrates formed.—According to some experiments by Sachs,‡ the increase in dry substance of leaves of a sunflower or squash was about 20 grams per day of twelve hours on bright, warm days, for one square meter of leaf surface. He estimates that on a warm, bright day a vigorous sunflower would make an increase in dry weight of about 36 grams, and a squash

---

* In using the term green plants here, the chlorophyll-bearing plants are understood. It should be remembered that there are green plants, especially among the fungi, which do not possess chlorophyll.

† The products of photosynthesis increase, other things being equal, with an increase of CO_2 from the normal (about .05 part in 100 of air) up to 4 per cent (4 parts to 100), but a larger increase in the CO_2 acts injuriously to the plant. With suitable temperature conditions, the products of photosynthesis increase with the increase of the intensity of light, from very weak light where photosynthesis is feeble, to the brightest sunlight where it reaches its highest intensity. Temperature also influences the rate of photosynthesis. At low temperatures it is feeble or *nil*, and increases up to 25° C.–40° C. (77° F.–104° F.) where it reaches its highest intensity, and with higher temperatures soon ceases. Photosynthesis also takes place at quite low temperatures even several degrees below freezing. Photosynthesis continues in winter mostly in evergreens at freezing or even a few degrees below, but quite low temperatures bring about inactivity of the chlorophyll bodies. The number and distribution of stomates also conditions the rate of photosynthesis since the diffusion of gases is dependent on them. When the plants are quite dry the rate is less than when the leaves are well supplied with water, other things being equal.

‡ Arb. bot. Inst. Würzburg, 3, 1884.

about 185 grams dry substance. This included other things than starch. Brown and Morris* estimate that in one day (twelve hours) one square meter of leaf surface of the sunflower will make about 8½ grams of carbohydrates of which the larger part is sugar, the smaller part starch. This would make, on the same estimates as above, about 15–20 grams of carbohydrate as the result of one day's work of a vigorous sunflower on a warm, bright day.

175. Amount of CO_2 used during photosynthesis.—Large quantities of CO_2 are used in photosynthesis. A sunflower plant uses about 50 grams CO_2 per day (= nearly 2 oz.). Supposing the earth were covered with sunflowers it has been estimated that they would consume 135,000,000,000 kilograms (= 297,000,000,000 lbs.). The amount of CO_2 in the air, if not replenished, at this rate would last the sunflowers about twenty months. This estimate is perhaps excessive. Another estimate is that a hectare (2½ acres) of forest would consume 11,000 kg. (= 24,200 lbs.) CO_2 per year. This large amount of CO_2 is being continually restored to the air by the burning of wood, coal, etc., for food, and by the respiration of animals so that the normal balance is maintained. The celebrated Krupp works for the manufacture of ordnance at Essen, Germany, alone produces about 2,500,000 kg. (= 5,500,000 lbs.) CO_2 per day. It is estimated that the human beings of the earth give back to the air about 12,000,000 kg. (26,400,000 lbs.) CO_2 each day.†

III. ASSIMILATION.

176. The term assimilation usually has a wider application by students of plants than by students of animals.—Assimilation in animals is the building up of new living matter and structures of the body, while in plants it has been customary to use the word assimilation not only for the building up of new living substance and new structures of the organism, but also for

---

* Journal Chem. Soc., 63 (Transact.), 604. See Jost, Pflanzenphysiologie, 140, 1904; p. 114, Engl. Ed., 1907.

† See "Text Book of Botany," Strasburger, Noll, etc., 196, English edition.

the formation of food products which are later used by the plant and are also used as food by animals. There is a tendency in recent years on the part of some botanists to distinguish the kinds of assimilation. Those kinds of assimilation which relate to the making of the new life substance, or the making of structures which are part of the living organism, are looked upon as true assimilation. Those processes which result in making food products are called *synthetic assimilation.* The making of sugar and starch (carbohydrates) is called *photosynthetic assimilation*, because the sun supplies the energy for the initial stages in the process. The making of carbohydrates by the nitrite and nitrate bacteria is called *chemosynthetic assimilation*, because the chemical process or *metabolism* in changing ammonia compounds to nitrites and these into nitrates by these bacteria, gives them the energy to fix the carbon from the CO_2.

177. Metabolism.—Metabolism means change, or changing around, and in the life processes of animals and plants refers to the chemical changes taking place. The building up processes, the different kinds of assimilation, are *constructive metabolism* (*anabolism*), while the breaking down processes, respiration, fermentation, decay, etc., are *destructive metabolism* (*katabolism*).

178. The building up of proteids in the plant.—The proteid substances in plants have a more complicated molecule than the carbohydrates since they contain C, H, O, N, S and sometimes P. These are largely formed in the leaf, but are formed in other parts of the plant also, and perhaps can be formed in limited extent in any living plant cell. Some plant physiologists claim that they are formed only in sunlight and in the presence of chlorophyll.*

---

* One reason for this belief is that in some plants it has been found that the nitrates (salts of nitric acid = HNO_3) which are absorbed by the roots accumulate in the leaves during the night, and disappear during the day. During the day the nitrates unite with carbohydrates (sugar) and some sulphur compounds to form proteids. Those who believe that proteids are also formed during the night concede that they are formed more actively during the day because photosynthesis is then going on, since the formation of carbohydrates is then active and in their elemental condition may more easily unite with the nitrates.

179. The leaf as the organ of assimilation.—The formation of carbohydrates, the proteids and some other substances, while taking place in all green parts of plants, is predominant in the leaf because of its adaptation to the process of photosynthesis, and the close relation of the formation of other products closely dependent on the carbohydrates. The sulphates, phosphates, nitrates, etc., absorbed by the roots meet the carbohydrates in the leaf and are here assimilated.

IV. DIGESTION.*

180. Digestion in plants includes those processes in which food products and food substances either in the plant or outside of it are changed chemically into a condition in which they can be assimilated into new life substance or plant structures, or transported to other parts of the plant, or absorbed from the outside if they are not already in a condition to be absorbed (the action of roots on insoluble solutions in soil, and the action of ferments on insects in case of carnivorous plants, paragraph 38). Several kinds of digestion are performed by leaves (digestion of insects by carnivorous plants is one example). One special kind of digestion occurring in the leaf is the digestion of starch. The starch formed in the leaf cannot be used for food by the growing leaf nor can it be transported to other parts of the plant until it is dissolved. The starch is dissolved, or digested, in the leaf by a special substance, *leaf diastase*, which is formed by the leaf for this purpose. It is active at night, so that the starch formed in the leaf during the day is changed to a sugar at night, and then flows to other parts of the plant where it is assimilated by growing organs, or is stored as reserve starch in seeds, stems, roots, tubers, etc. For a discussion of diastase, see paragraph 219.

---

* See also Chapter XVI.

CHAPTER XIII.

WORK OF LEAVES (Concluded).

V. RESPIRATION.

181. The leaves are also organs for respiration, but since respiration takes place in all growing parts of plants the subject will here be treated with reference to plants in general.

182. How seedlings breathe.—Plants breathe just as truly as animals do, though they do not have lungs. Breathing, in animals as in plants, is the taking in of a gas, *oxygen*, into the body, and giving off, or excreting another kind of gas, *carbon dioxide*. That germinating seeds give off carbon dioxide can be shown in the following way. A quart of peas which have been soaked in water for twelve or fifteen hours, are placed, without any water, in two fruit jars or two large wide-mouthed bottles, which are then closed tightly. Another jar or bottle empty but closed tightly is kept as a check. In twenty-four hours let us pour a small quantity of barium hydrate* down the inside of the jar or bottle, and close the bottle quickly again. A white precipitate † is formed. If the bottle is opened again and tipped so as to pour some of the gas into an open vessel with a little barium hydrate, the white precipitate appears in the vessel of baryta water. The gas is heavier than air and is easily poured into the baryta water. If some of the barium hydrate is poured into the empty bottle, no precipitate is formed or only a very small quantity.

Now in the other bottle the lighted end of a splinter or taper may be lowered. The flame is immediately extinguished be-

---

* To make barium hydrate. Dissolve barium oxide in water. Filter and keep in a tightly corked bottle.

† This is barium carbonate, $BaCO_3$.

cause of the presence of a suffocating gas, *carbon dioxide.* If the lighted end of a splinter or taper is placed in the empty bottle it is not extinguished soon because the suffocating gas was not present.* In time, however, it may be extinguished owing to the accumulation of the CO_2 from the burning splinter.

This experiment teaches us that the suffocating gas (carbon dioxide) is given off in quantity by the peas during germination. That it is carbon dioxide is shown by the white precipitate when the barium hydrate is poured down the inside of the bottle. Some of the element barium unites with some of the carbon dioxide by chemical change and forms *barium carbonate*, which is the white precipitate.

In this experiment care must be taken to test with the barium hydrate before holding the flame in the bottle of peas. It is much better to have a separate bottle of peas for the test with the flame. This is because carbon dioxide is formed during the burning of the splinter. To prove this pour some barium hydrate down the inside of the empty bottle after the flame has been held in it. To show that animals also exhale carbon dioxide while they breathe, take a shallow vessel of baryta water and breathe on it several times. A thin film of the white precipitate (barium carbonate) is formed on the surface of the barium hydrate.†

183. The germinating seeds take oxygen gas from the air while they breathe.—A simple experiment will show this. A handful of wheat is soaked in water, and then placed in a germinator (a moist vessel) in the folds of a wet cloth. When it has

---

* The extinguishing of the flame does not prove that CO_2 is present. That has been proven by the former experiment, and since we know by this that CO_2 is present it is fair to conclude that this is the gas in this instance which extinguishes the flame.

† Lime water may be used instead of baryta water for all the above experiments, but it is not so satisfactory as baryta water because the result is not so striking. To make lime water place a lump of lime twice as large as a hen's egg in a quart of water. Allow it to settle and in a day or two filter the liquid and keep corked tightly in a bottle.. The white substance formed when lime water is used is calcium carbonate, or carbonate of lime.

begun to sprout the bulbs of two thistle tubes are filled with the sprouted grains. A piece of sphagnum moss, or loose cotton, can be placed in the lower part of the bulb to prevent the grains from falling down the tube. The tubes may be supported as shown in fig. 88, with the small ends, one in a vessel containing a strong solution of barium hydrate, and the other in a vessel containing a strong solution of caustic potash (one stick of caustic potash in two-thirds tumbler of water). Red ink, or some red analine dye, may be added to the solution to make the liquid visible as it rises in the tube. Each bulb is closed airtight by a piece of glass cemented down with vaseline of sufficient consistency. If the experiment is properly set up, in twelve to twenty-four hours the liquid will be seen to be rising in the tubes.

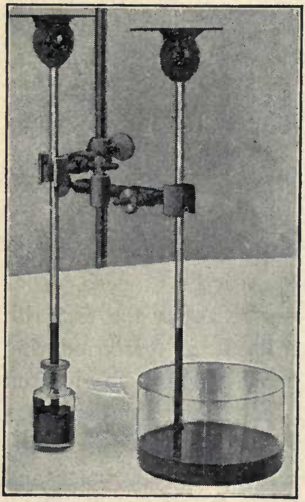


Fig. 88.
Apparatus to show respiration of germinating wheat.

184. Why the liquid rises in the tubes.—From the experiment with the germinating peas we know that barium hydrate absorbs carbon dioxide. The potash solution also absorbs carbon dioxide. The germinating wheat during respiration, i.e., while it breathes, gives off carbon dioxide just as the peas do. The carbon dioxide being heavier than the air settles down in the tube and comes in contact with the potash solution and is absorbed. Now at the beginning of the experiment the thistle tube, and the space between the wheat grains, was filled with air. If no portion of the air was taken from the tube the liquid could not rise as the carbon dioxide is absorbed. This experiment proves then that some constituent of the air is absorbed by the germinating wheat grains and undergoes a chemical change in the wheat seedlings.

185. Oxygen is absorbed by the germinating wheat.—The constituent of the air * which is removed under these conditions is one which, on undergoing a chemical change in the germinating wheat, unites with some element in the wheat to form the carbon dioxide given off. From the abundance of carbon dioxide given off it is plain that the carbon is the element in the wheat with which the constituent absorbed from the air unites. Nitrogen, it is plain, cannot unite with the carbon to form carbon dioxide. It must then be the oxygen from the air which is absorbed by the wheat, and which unites with the carbon in the wheat to form the carbon dioxide given off. The oxygen absorbed by the germinating seeds unites to form some of the substance of the seedlings, and the carbon and oxygen which unite to form the carbon dioxide come from the substance of the seedlings. The oxygen absorbed then replaces that which is given off as a waste product in the carbon dioxide. The rising of the potash or barium hydrate solution in the tube in this experiment indicates to us then that oxygen is taken from the air during the respiration of the seeds. This is exactly what takes place when we breathe, or in *animal* respiration. Oxygen is inhaled and carbon dioxide is exhaled.

186. Respiration in opening leaf buds or flower buds.—Leaf buds or flower buds are excellent objects to use in showing the excretion of carbon dioxide. If a handful of the buds is placed in a jar as described in paragraph 182 for the germinating peas, in the course of ten to twelve hours they will be ready for the test with the barium hydrate and the lighted splinter or taper. The buds can be obtained throughout the spring, summer and autumn in the open, and during the winter in greenhouses.

187. Leaves as organs of respiration.—The leaves are organs of respiration. The stomates provide the openings for the interchange of gases. The gases diffuse through the intercellular spaces and reach all parts of the leaf. The gas entering

---

* See paragraph 168, where the constituents are given as oxygen, nitrogen, and carbon dioxide.

the leaves is also diffused to other parts of the plant, the growing buds, and also parts of the stem. Some succulent stems are provided with stomates also, and the stems of shrubs and trees are provided with openings called *lenticels* through which there is an exchange of gases.

188. Conditions of respiration.—Light does not exercise any important influence on respiration, but warmth is of fundamental significance. The minimum temperature at which respiration takes place is a little below the freezing point (0° C. = 32° F.) in most plants but it has been shown to be as low as − 10° C. As temperature increases the intensity of respiration increases up to a maximum intensity, which in most plants is injurious to the other life processes, and then the intensity decreases. The optimum temperature for respiration is below the maximum, and is the highest temperature at which the other life processes are not injured. This varies for different plants. Water has no specific influence, but affects the intensity of respiration through its effect on the other life processes. Respiration ceases in completely dry plants (seeds, dry mosses, dry lichens, certain spores) and is low or altogether ceases in resting plants or parts of plants as in the autumn and winter. Oxygen is necessary for ordinary respiration, and most plants are of this nature. But an increase or decrease in oxygen content of the air has little immediate significance.

189. Respiration in fungi.—While fungi cannot form sugar, or starch, they breathe like other plants. This can be shown by placing a few half-grown mushrooms or toadstools in a fruit jar, and closing it tightly. In 10 to 12 hours the test with the barium hydrate and afterwards with the lighted splinter shows the presence of carbon dioxide.

190. Respiration necessary for growth.—This can be shown by the following experiment. Germinate some peas until the radicles are 2 to 3 cm. (about 1 inch) long. Have ready a bottle with soaked peas as described in paragraph 182 and with a small quantity of water in the bottom to keep the air in the bottle moist. Place a piece of wet filter paper on the peas. In ten or twelve hours after some of the oxygen has been used, on this paper rest three or four of the germinated peas. Close the bottle tightly. The peas in the jar will use up so much oxygen and give off so much carbon dioxide that ordinary respiration cannot take place in the seedling peas on the filter paper. Fit up a similar bottle with folds of wet paper and some free water in the bottom. Place a piece of wet filter paper on the folds of paper and on this place three or four of the seedling peas which have radicles of a length equal to those in the other bottle. Close the bottle tightly. In 24 to 48 hours compare the length of the radicles of the seedlings in the two bottles.

These experiments teach us that all plants, with very few exceptions,* breathe, or respire by absorbing oxygen and giving off carbon dioxide.

191. Respiration in the absence of oxygen.—This sometimes occurs. It can be demonstrated in germinating seeds by placing them, when the root is just emerging from the seed coats, in an inverted test tube filled with mercury, the lower end of which is immersed in mercury placed in another vessel. In the course of a day carbon dioxide is given off from the seedlings, and being lighter than the mercury displaces some of it and occupies the upper part of the inverted tube.

The carbon dioxide here comes from the living substance of the peas, just as it does in ordinary respiration. There is a loss or waste of substance by the peas which passes off as carbon dioxide. This waste is formed by a *breaking down of some of the living substance* of the peas. The same breaking down of the living substance occurs in ordinary respiration, but oxygen is absorbed from the air to replace that taken from the

---

* The exceptions are found in some of the low minute plants, for example, some of the bacteria which cannot grow in the presence of oxygen. These are called *anaerobes*, because they cannot carry on their life processes in the presence of ordinary air.

living substance, and the carbon is replaced in the ordinary* respiration of plants by the carbon which is obtained from the carbon dioxide absorbed in the making of sugar and starch.

192. Fermentation of yeast.†—Yeast as used in breadmaking to produce the "*rising*" of the bread, causing it to become spongy and light, is composed largely of microscopic plants mixed in with some food substances, etc. This microscopic plant is called the yeast plant or yeast. It is a very interesting plant, and the work it performs in bread "rising" is very instructive in connection with this subject of respiration.

The tube and the lower part of the bulb of a fermentation tube is filled with a solution of grape sugar or an infusion of potato,‡ and a small piece of yeast cake is put in the bulb. This is kept in a warm place. As the yeast plant grows, bubbles of gas will rise in the tube and displace the solution which is forced into the bulb. If some pieces of caustic potash are placed in the bulb, the potash solution absorbs the gas in the tube and the solution rises again. This shows, as we have learned above, that the gas is CO_2 which is an index of the respiration of the yeast plant, or rather of the *fermentation* of the sugar in the solution.

This fermentation has gone on largely in the absence of air, but it is somewhat at the expense of growth and reproduction of the yeast plant, for when air is present growth and multiplication of the yeast is more rapid. During the fermentation of the sugar by the yeast, alcohol is also formed. These two products of fermentation by the yeast plant are of great importance. The evolution of the gas carbon dioxide in bread making forms

---

* By ordinary respiration is meant aerobic respiration. Aerobic respiration is carried on by plants which require air. Anaerobic respiration is respiration in the absence of air. All plants can carry on anaerobic respiration for a short time, but most plants are injured and soon die or rest if air is not accessible. Some plants are active either as anaerobes or aerobes (the yeast plant), while others only as anaerobes (certain bacteria).

† Saccharomyces cerviseæ.

‡ If possible it is well to sterilize the tube after filling with the grape sugar or infusion. Also a second tube for a check is desirable.

CHAPTER XIV.

SOME SPECIAL ASPECTS OF NUTRITION OF PLANTS.

SOURCES OF PLANT FOOD.

197. The nutrition of plants includes a study of the sources of plant food, the methods of absorption and transport of the food material, the chemical processes (metabolism) in the elaboration of food materials in the plant, the building up of organic compounds used for food and storage, and the assimilation of material into new plant substance and structures which enable the plant to grow and reproduce itself. While certain plant foods may be derived under a great variety of forms, there are certain essential constituents of plant food occurring in the various compounds. There are two general classes of plant food, the *organic compounds* (example, those formed by plants, as carbohydrates, proteids, etc.) and the *inorganic compounds* * (mineral substances, etc., and those not containing carbon). The essential food constituents or *elements* in the organic compounds are *carbon*, *hydrogen*, *oxygen* and *nitrogen*. In the inorganic compounds the essential constituents or elements are *calcium*, *potassium*, *magnesium*, *phosphorus*, *sulphur* and *iron*,† though calcium is not essential to the growth of the fungi.

---

* The terms organic compounds and inorganic compounds are employed here in the older sense.

† There are a number of other elements which are not essential constituents of food, but are of use to the plant. For example, silicon (flint, most kinds of sand, sandstone, etc., are oxides of silicon) strengthens the stems of the grains and grasses, and is found in great abundance in the stems of the scouring rushes (Equisetum) which often grow where there is an abundance of sand in the soil. Many substances are found in plants which are useful perhaps in protecting the plants from certain of their enemies by rendering them distasteful or poisonous, and many other substances are found which do not appear to be of any use.

198. Sources of plant food.—The different elements, which have been found necessary constituents of plant food, are not taken up by the plant as elements, except in rare cases, and possibly also with the exception of the oxygen of respiration. Oxygen is taken into the plant as an element in the process of respiration. If this oxygen merely assisted in the combustion of plant material it would not in this instance be a food constituent, but there are reasons for believing that it is first assimilated into the living matter (see paragraph 185). Nitrogen is taken up as an element in the nutrition of a few specialized bacteria (see fixation of nitrogen, paragraphs 201–203). The mineral substances found in the ash of plants when they are burned, containing among other things calcium, magnesium, phosphorus, sulphur, iron, the plant takes up from the soil in the form of nitrates, sulphates, phosphates,* etc., which are formed during the weathering and disintegration of rocks.† The water (H_2O) of the plant is absorbed from the soil. This furnishes part of the hydrogen and oxygen. The source of the carbon for green plants is the carbon dioxide (CO_2) of the air, which the plant uses during photosynthesis. Nitrogen is obtained by absorption of nitrates from the soil and from some other compounds of nitrogen. For example, in cultivated or waste fields, the nitrogen food is mostly in the form of nitrates, while nitrates are scarce in the forest where there is an abundance of decaying leaves and humus. In the forest the nitrogen food is chiefly in the form of ammonia compounds (NH_3).

199. Most of the substances used as plant food from the soil exist there in quantities sufficient to last plants for many years.—But nitrogen compounds are rare,‡ and if

---

* Examples, potassium nitrate, calcium sulphate, magnesium sulphate, calcium phosphate, etc.

† The small particles of rock make the basis of the soil, while dead plant remains furnish the organic matter and humus which give it a darker color and make it more retentive of moisture.

‡ Phosphates are also comparatively rare in many soils, and during continued cropping when they are not returned to the soil, the soils become deficient. Phosphorus occurs in the oldest rocks and these phosphates appear in the soil from disintegration of rock. By the growth of plants they

abundant in some soils are usually soon exhausted or reduced to such a small quantity that the plants indicate the deficiency of the soil in nitrogen, by their poor and often sickly growth. Uncultivated soils, where the plant covering is left to decay, gradually become richer in plant foods. Cultivation of crops tends to impoverish the soil, if the plant foods taken out are not replenished, since mineral substances and nitrogen are removed in the harvesting of the crop. The most costly plant food is nitrogen, or nitrogenous fertilizers. Stable manure is rich in nitrogen (ammonia compounds) and is also beneficial to soil, since the plant remains in it improve the physical condition of the soil (see nitrification, paragraph 200). Among commercial fertilizers nitrogen is obtained in cotton seed meal; guäno, the excrement of birds found in rich deposits on certain islands near southern sea coasts; Chili saltpeter, a nitrate of soda found in great deposits in Chili and Peru, etc. These latter supplies of nitrogen are becoming exhausted. Indeed were it not for the fact that certain processes in nature are going on by which nitrogen, a gas constituting four-fifths of the air, is fixed, i.e., combined into nitrogenous substances, and made available for plant food, the supplies of nitrogenous food would become exhausted, since in the process of decay (especially in the absence of air) and by fire, the nitrogen fixed in compounds is set free as a gas.

NITRIFICATION.

200. Nitrification.—It has been pointed out above that in the fields the combined nitrogen absorbed by plants is usually in the form of nitrates, while in the forest where there is much

are removed from the soil and concentrated. They are farther concentrated by animals which feed on plants, as well as by carnivorous animals. On the death of the animals they are again returned to the soil, and often are deposited in considerable quantities in rocks forming extensive deposits known as phosphate rock. Large beds of this phosphate rock are very valuable, and the rock is quarried, ground and sold as a fertilizer for the soil. Extensive beds which have been of great commercial value exist in Eastern South Carolina, but are now nearly exhausted. Other beds of phosphate rock exist in Florida and recently some have been discovered in the West.

humus it is usually in the form of ammonia (NH_3). In the fields the ammonia would soon volatilize and pass off in the gaseous form in the air and be lost. Ammonia is often applied to the soil in fertilizing (in stable manure). Ammonia is also formed in the decay of plant parts and animals (especially in the absence of air which is the case in bulky parts, and in soil). The proteid substances are split into ammonia by the ferment action of certain bacteria. This process is called *denitrification*, and is the opposite of nitrification. The denitrifying bacteria can only act on the protein substances and nitrates in the absence of oxygen. They obtain oxygen from that combined in the nitrogenous substance which they denitrify. This is another example of anaerobic respiration. (See paragraph 191.) For the conservation of this ammonia it is very important that, as it is formed, it shall be converted into a more stable form which will not volatilize, and which will still be available as plant food, for while it has been shown that corn and a number of other plants can thrive as well when fed on ammonia compounds as when fed on nitrates, in practice a large part of the ammonia would be lost if it were not immediately changed to nitrates (i.e., nitrified). The process by which ammonia is nitrified is termed *nitrification*, and it is one of the most important processes in nature for the nutrition of plants. Nitrification is brought about by two different kinds of very minute bacteria, called *nitrite bacteria* (*Nitromonas*) and *nitrate bacteria* (*Nitrobacter*). These bacteria are widely distributed in the soil over the earth (though not so plentiful in the forest). The nitrite bacteria convert the ammonia into nitrous acid, and then the nitrate bacteria convert this into nitric acid which unites with another substance * and forms nitrates. This process supplies them with energy so that they are able to assimilate free oxygen from the air.

FIXATION OF NITROGEN.

201. If the free nitrogen of the air were available as such for food by all plants, one of the serious problems of the agriculturist would be satisfactorily solved, and many plant and animal foods

---

* This substance is called by chemists a *base*.

for man would be greatly reduced in price. In former years it was held by some scientific men, that the ordinary green plants could use directly the free nitrogen of the air for food. Careful experiments have demonstrated, however, that this is not the case. Still it has been known for many years that leguminous plants (clover, peas, beans, alfalfa, vetches, honey locust, soja beans, etc.) will grow, thrive, and bear a good crop in soil very poor in nitrogenous plant food provided the other conditions are favorable.

202. Root tubercle bacteria.—Careful investigations have shown that this is due to the work of microörganisms * in the roots of these plants. These bacteria are widely distributed over the earth in nearly all soils, especially in regions where leguminous plants grow. These bacteria enter at the root hairs, extend by growth in the form of a thread into the cortical region of the root where they stimulate the root cells to the formation of a gall or tubercle, which is often of different form in different species of legumes. These root tubercles are short and thick, often oval in form, or short, cylindrical and branched. They are stouter than the roots to which they are attached, so that they are easily seen when the clover, pea or other legume is dug up and the soil carefully washed from the roots (fig. 90).

Fig. 90.
Root of the common vetch, showing root tubercles.

203. Within the root tubercle the bacteria spread by means of branched threads or tubes. The cells of the tubercle are rich in protoplasm. Within the cells great numbers of free bacteria are formed which are oval or rod-like or Y or X shaped. The bacteria in this condition are filled with nitrogenous substances which they have formed by assimilating (or "*fixing*")

---

* Certain bacteria, also called microbes. The name now generally used for this particular microörganism is *Pseudomonas radicicola*. Earlier names are *Phytomyxa leguminosarum*, *Rhizobium leguminosarum*, etc.

free nitrogen which they have absorbed from the air in the soil, with carbohydrates and other organic substances which they have absorbed from the cells of the clover or other legume. The bacteria thus obtain their carbohydrate food from their "host," and to this extent they have lived as parasites at its expense. But they do very little if any injury to the clover. In fact many of these bacteria charged with this "fixed" nitrogen die within the root tubercle, and the clover or pea, or other host as the case may be, is able to absorb this nitrogenous substance and appropriate it to its own use. This is why leguminous plants thrive so well in soils poor in nitrogenous plant food. After a time some of the root tubercles die and some of the nitrogen "fat" bacteria (often called bacteroids) are set free in the soil and thus enrich the soil. Some of the living bacteria are also set free in the soil so that the soil contains numbers of them to attack succeeding legume crops. Even when the crop of clover, or peas, etc., is removed from the ground the soil becomes richer in nitrogenous substance because of the bacteroids left in the root tubercles. But more nitrogenous plant food is added to the soil in the process of "green soiling" such crops, i.e., in plowing the clover or peas under (see also *Mycorhiza*, and *Symbiosis*, paragraphs 205, 206).

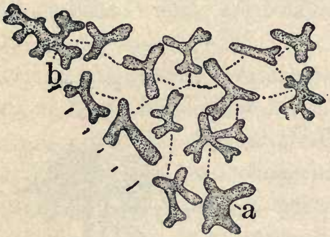


Fig. 91.

Root tubercle organism from vetch, old condition.

Fig. 92.

Root tubercle organism from Medicago denticulata.

204. Inoculation of soil with the root tubercle bacteria.— If some of the soil, where clover or peas have grown with these bacteria in their roots, be spread on soil poor in combined nitrogen where these or related crops have not been grown recently, the clover or peas will develop a greater number of root tubercles and consequently more nitrogen will be fixed to the benefit of the crop and to the enrichment of the soil in combined nitrogen. This inoculation of the soil has been put into practice in a number of different ways. One of the more recent methods is by preparing in the laboratory " pure " cultures of the bacteria on nitrogen-poor culture media in small tubes which can be sold and sent by mail to persons who wish to inoculate their soils.* The object in growing them on nitrogen-poor substances is to create in them " nitrogen hunger," for they will then more readily attack the roots of the clover, etc., in order to put them in a condition to " fix " the free nitrogen. In soil rich in combined nitrogen they do not readily attack the roots of the legumes. It is, therefore, not good policy to inoculate soils rich in combined nitrogen, for the clover, etc., will find a sufficient amount in the soil already. There have been some successes and many failures in inoculating soils with the root tubercle bacteria. Some of the failures are to be ascribed to a poor condition of the inoculating material. Other failures are probably due to the fact that the soil is already rich in combined nitrogen, and still others are probably due to the fact that there are a sufficient number of organisms already in the soil. Some of the conditions under which one might hope for good results are, first, when the soil is poor in combined nitrogen and there are few root tubercle bacteria already in the soil; second, when the soil is poor in combined nitrogen and the root tubercle bacteria may be plentiful, but of a " race " different from that which readily attacks the kind of legume it is desired to grow. For example, the race of bacteria which attack the roots of clover will not readily attack the roots of the soja bean. Those which attack peas will not readily attack the locust, etc.

---

* See Bull. No. 71 Bureau Pl. Ind. U. S. Dept. Agr., Soil Inoculation for Legumes: Bull. No. 72, Pt. IV, Inoculation of Soil with Nitrogen-Fixing Bacteria.

MYCORHIZA, SYMBIOSIS.

Fig. 93.
Beech root grown in unsterilized wood humus; *p*, strands of fungal hyphæ, at *a* associated with humus. Magnified several times. (After Frank.)

205. Mycorhiza.—The intimate union of bacteria or fungi with the roots of plants, similar to that described in the preceding paragraphs, gives rise to an interesting and complex structure the work of which is different from that of either part of this structure alone. Such a structure is called a *mycorhiza*.* There are many kinds of mycorhizæ, but they all may be arranged into two general kinds. Those where the fungus part is inside of the root are *endotrophic mycorhizæ*, while those in which the fungus part surrounds the root are called *ectotrophic mycorhizæ*. The root tubercles are endotrophic mycorhizæ. An example of an ectotrophic mycorhiza is found in trees of the oak family (oak, beech, hornbean, etc.) and some other trees where the tips of the roots are covered with a dense felt of fungus threads (fig. 93). This occurs in the forest where there is abundant humus (the decaying leaf mold), but is not always present in the same species of trees when growing in fields where humus is absent. The dense mat of fungus threads on the outside of the young roots prevents the development of root hairs, and some of the threads penetrate into the cells of the roots. The trees, under these circumstances, are dependent on the threads of the fungus for the absorption of water and food solutions from the soil, the threads thus acting as root hairs. There are great advantages to the forest trees in this association with the fungus mycelium. The fine fungus threads, extending from the mycorhiza, branch and reach out in all directions, penetrating the humus better than root hairs could. They have the power of decomposing certain insoluble nitrogen compounds and of passing them over to the tree. They also can change the ammonia compounds, so abundant in humus, into an

---

* From μύκης = mold, and ῥίζα = root.

available form for the forest trees. It is supposed that the fungus mycelium obtains some benefit from this association with the roots of trees, but this is not well understood. These mycorhizæ are shorter, stouter and also branched more than the normal roots. This difference in form, as well as their more complex structure, renders the name mycorhiza appropriate and useful. In some cases these fungus threads are the spawn of certain mushrooms and puff balls. The mycelium of the truffle, an edible fungus of great commercial value in southern France and in Italy, is supposed to have a similar relation to the roots of certain forest trees.

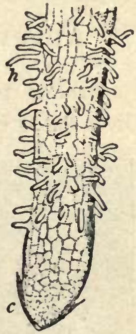


Fig. 94. Beech root in wood humus freed from fungus, root hairs *h*. (After Frank.)

206. Symbiosis.—This living together in close physiological relation of two different organisms is called *symbiosis*. In the case of the root tubercles of leguminous plants the relation is one of mutual benefit, each partner in the symbiosis (each partner is a *symbiont*) deriving some benefit from the other. The same relation is supposed to exist in the case of the mycorhiza of forest trees. This kind of symbiosis is called *mutualistic symbiosis*. Another well-known example is seen in the case of the lichens (see paragraph 432). Another kind of symbiosis occurs in the relation of a parasite to its host where the parasite living on or in the host injures or kills it but the host receives no benefit. This is *antagonistic symbiosis*. So there is *contact symbiosis* where two organisms living side by side, work together, each one supplying the other with some product of its work. An example of this is seen in the case of the bacterium (*Clostridium pasteurianum*) which lives in the soil in conjunction with two green algæ. The algæ supply the bacterium with carbohydrates and it is then able to fix free nitrogen and this combined nitrogen can be used by the algæ. Related to this but a step farther are the many cases of *metabiosis* where successive organisms digest or ferment the product of previous ones. Example, a common mold (*Aspergillus oryzæ*) growing on rice converts the starch into sugar, then yeasts ferment the sugar to alcohol, and then the acetic acid bacteria ferment the alcohol to acetic acid.

CHAPTER XV.

NUTRITION OF PARASITES AND SAPROPHYTES.

207. A parasite is an organism, plant or animal, which lives on or in another living organism at its expense, deriving all or a part of its nourishment from it. The plant or animal on which the parasite lives is called the "host." The parasite derives a part or all of its food from its host, usually inflicting more or less injury upon the host or even causing its death. Parasitic plants are represented in nearly all the great branches of the plant kingdom. There are some among the flowering plants, some among the algæ, the fungi and bacteria, but by far the greater number are found among the fungi and bacteria. One reason for this is that none of the fungi or true bacteria have chlorophyll; therefore, they cannot fix carbon, that is, cannot make their own carbohydrate foods, but are dependent on chlorophyll-bearing plants for it. The fungi and bacteria which are parasitic on green plants then obtain their carbohydrates directly from their hosts. Those which are parasitic on animals derive their carbon food from animals, but animals get their carbohydrates directly from green plants, which they eat, or in the final analysis from plants or animals which do feed on green plants either dead or alive.

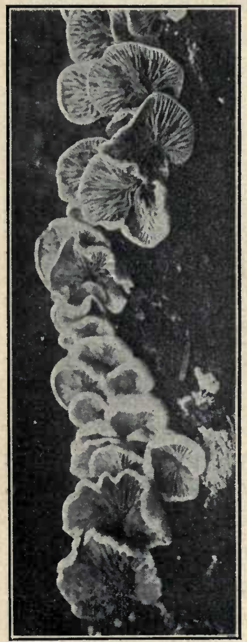


Fig. 95.

A saprophytic fungus (Crepidotus) growing on a rotten limb in the forest.

208. The fungi and bacteria which are not parasites derive their carbohydrate food by growing on dead plants or animals or on their remains, that is, on organic matter. Such plants are called *saprophytes*, a plant having the life relation of nutrition to dead or decaying organisms. The largest number of species of both bacteria and fungi are saprophytes, and many of them do very important work in the economy of nature, reducing the substance of dead plants to the condition of humus which improves the mechanical condition of the soil, removes the bulky parts of plants, and sets free many substances which can be used again for food by the green plants. Examples of these fungi are the mushrooms, toadstools, puff balls, bracket fungi, molds, etc.

NUTRITION OF PARASITES.

Although the larger number of parasites are among the fungi and bacteria there are many parasitic flowering plants. A few of these are briefly described here.

209. Nutrition of the dodder.—The dodder, or "love vine" (*Cuscuta*), is a slender twining plant which is parasitic on clover, or some other cultivated plants and on a great many weeds. There are several species. The plant has very inconspicuous flowers developed in crowded clusters. The seeds are small. When the seeds germinate on the ground a root is formed which attaches the plant to the soil. But when the slender vine twines around the living stem of its host, at the places of contact it develops wedge-shaped outgrowths which pierce the stem of the host and penetrate the fibro-vascular bundles. These outgrowths are *haustoria*, or suckers, because they attach the vine to its host and serve as absorbent organs. There are fibro-vascular bundles in the haustoria which connect with those of the vine and also form an

Fig. 96.

Dodder, showing stems twining around its host (Impatiens).

intimate connection with those of the host. Through these haustoria the dodder absorbs solutions of mineral substances, and also of carbohydrates and proteids manufactured by its host. Receiving these food substances already prepared the parasite has no need of chlorophyll nor of expanded leaves. In accordance with the general law, therefore, that when an organ ceases to function it becomes reduced or discarded, the leaves of the dodder have become reduced to mere scales on the stem, and the root dies as soon as the vine becomes attached to its host by the haustoria. The vine and its scale leaves are pale yellowish in color. The seeds of the dodder germinate in the soil developing a true root and a slender vine which lives an independent existence at the expense of the food stored in the seed. The slender vine extends out and around until it comes in contact with some plant part, when it develops the haustoria (or "sinkers" as they sometimes are called) and then the root in the soil dies.

210. Nutrition of the mistletoe (Phoradendron flavescens).—The mistletoe is a well-known plant especially in the southern half of the United States, and is often used farther north in Christmas decorations. It is a parasite on a number of trees, especially on red maple and the tupelo, but occurs on the oaks and some other trees. It is a small branched shrub often forming dense tufts on the branches of its host. It is very conspicuous in winter because it holds its leaves while its hosts are bare, and because of its green stems. Having chlorophyll it can manufacture its own carbohydrates. Its roots penetrate the branches of the trees on which it grows, and it derives its mineral foods and water from its host.

211. Other parasitic flowering plants are the beech drops (*Epiphegus*) growing attached to the roots of beech trees, the small mistletoe (*Arceuthobium*) attached to twigs and branches of the native spruce. The mistletoe of Europe (*Viscum album*) grows on a great variety of trees, but develops more freely and luxuriantly on apple trees, the black poplar and certain spruces, trees which have a soft cortex, while it is rarer on the beech, birch, etc. It becomes a great pest sometimes in apple orchards, and the farmers are said to welcome the collectors who gather it for Christmas "greens."

212. Nutrition of parasitic fungi. — Examples of the parasitic fungi are the rusts of grains, grasses and many other plants; the smut of corn, cereals, etc., the powdery mildews, the downy mildews, etc. (See Chapters XXVII and XXVIII.) Here it is only necessary to describe their mode of nutrition. In the growing stage these fungi produce slender branched thread-like structures which spread in the form of a mold over the surfaces of the leaves, or penetrate into the tissues of their hosts. The absorption of food substance takes place either directly by the threads of the fungus, or the threads develop specialized short branches, simple or branched, which penetrate the cell walls and lie in the protoplasm of the host cell. These special branches are the haustoria. They absorb food substances which flow to the threads of mycelium* where they supply material for its continued growth and later for the development of the reproductive bodies. Some of these fungus parasites often deform their host, stimulating the tissues to the

Fig. 97.
Rust of carnation stems and leaves caused by a parasitic fungus (Uromyces caryophyllinus).

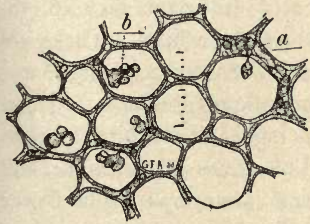


Fig. 98.
Cells from the stem of a rusted carnation, showing the intercellular mycelium and haustoria. Object magnified 30 times more than the scale.

---

* Mycelium is the special name of the fungus threads.

formation of excrescences or galls, as in corn smut, the cedar apples, azalea apples, black knot of the plum and cherry, leaf curl of peach, plum pockets of the plum, etc.

NUTRITION OF SAPROPHYTES.

213. Humus saprophytes.—Humus is composed of organic matter, largely plant remains in a state of decay. It is abundant on the forest floor and in moors where the decomposition of the plant remains is slow and incomplete. As stated in the opening paragraph of this chapter, saprophytes are plants which grow and feed on dead or decaying organic matter. Humus saprophytes are those plants which grow in and feed on humus. The humus is not easily soluble, and is rendered available as food for the higher plants by the solvent action of fungi and bacteria. Many fungi, especially the mushrooms, toadstools, puff balls, etc., are humus saprophytes. Many species grow in the forest. The threads of mycelium permeate through the humus carrying on the disintegration which was begun by other species and by bacteria, and appropriating for food some of the dissolved substances. It is by this means that the fungus part of the mycorhiza (see paragraph 205) prepares food for the forest trees with which it is associated. Some of the flowering plants which grow in humus lack chlorophyll, and some or all of their roots are mycorhizæ. These are also regarded as humus saprophytes. The Indian pipe (*Monotropa*) is one of these. This is a pretty little plant usually growing in a cluster 15 to 20 cm. (6–8 inches) high. It is white in color, sometimes with a reddish tinge. The stems are straight and fleshy, the leaves are scale-like and lack chlorophyll. The flower in one common species (*M. uniflora*) is single, and is turned on the stem like the bowl of a pipe. This plant obtains its food through the mycorhiza. This mycelium has the power of dissolving some of the carbohydrates in the humus and passing it over to the mycorhiza so that the plant can be supplied in this way with the carbohydrate food which it cannot make from the carbon dioxide of the air because of the absence of chlorophyll.

214. Saprophytic fungi.—The humus saprophytes mentioned in the preceding paragraph are of course saprophytic fungi, and the term saprophytic fungi applies not only to these humus saprophytes but to all fungi which grow on dead and decaying organic matter. But there are many saprophytic fungi which grow on plant remains which are not in the condition to which we apply the term humus.

215. The wood destroying fungi which are so common on dead logs, stumps, branches and even some species on the living trees are also saprophytic fungi. Many of those which grow on living trees are not parasites since they cannot attack a sound tree. They can only enter the tree when it has been injured so that the *living cambium layer* (see paragraph 100) is destroyed at a given point or has been broken through, i.e., at *wounds* in the tree. The wounds are produced in a variety of ways; by wind, heavy snows, the felling of timber, etc., branches are broken off, or the cambium is broken through; or by fire which kills the cambium. The heart wood which is therefore sound, but dead, is thus exposed. The germs (spores, see Chapter XXIX) carried by the wind, lodge on these wounds, germinate and form the fungus threads which grow into the heart wood and thus gain access to the heart of the tree trunk. The threads of mycelium are enabled to perforate the cell walls by the excretion of a ferment or enzyme (cytase) which dissolves an opening in the wall. Here they cause " heart rot " of the tree and render the tree unfit for timber. The fungus lives here for years, and now and then during certain seasons the mycelium develops to the outside through the wounds

Fig. 99.

A wound parasite (Polyporus borealis) causing heart rot of the hemlock spruce. The fruit bodies are shelving, white and overlap each other. The mycelium extends through the heart wood to the topmost branches and out into the roots.

and forms the well-known bracket fungi so common in the forests, or in the case of other species forms the toadstools or mushrooms often seen growing from the wounds of trees. Some of these same wood-destroying fungi grow on the dead logs, stumps and branches forming the brackets or mushrooms which are the fruiting bodies. The mycelium disintegrates the cellulose and wood.* After these have finished their work, other species come in and carry the disintegration farther, and so on until the wood is reduced to humus when still other species grow on this. The dead leaves are attacked by still other species and by a similar series of fungus forms are reduced to humus.

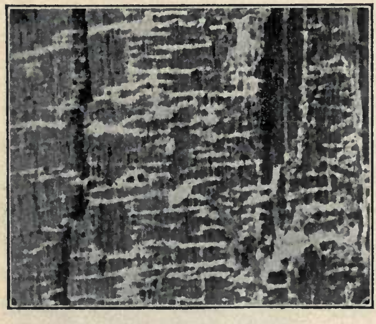


Fig. 100.

Spawn of the polyporus as it makes its way through the wood of the tree.

216. The molds which are also fungi, are, many of them, saprophytic also. They grow on fruits, preserves, old bread and isolated plant parts which are not humus (see the *bread mold* in Chapter XXVI).

217. Decay.—All decay is due to the action of living organisms, chiefly fungi and bacteria. If these organisms could be excluded from fruits, vegetables, preserves, meats, or any plant or animal part, these organic substances would be preserved indefinitely and if exposed to the air would simply dry out. Dried beef is rendered safe from decay because the percentage of moisture is insufficient for the growth of bacteria. Fruits which are first heated to kill the germs of fungi and bacteria and then sealed in "cans" to shut out the air and the entrance of germs, are pre-

---

* The mycelium of some of the bracket fungi (*Polyporus mollis*, for example) dissolves only the cellulose of the wood leaving the xylogen, while others (*Trametes pini*, for example) dissolve only the xylogen, leaving the pure cellulose intact in which the xylogen was infiltrated.

served. In some very dry climates, trees when they fall are preserved in a sound condition for a long time because the moisture is insufficient to favor a rapid growth of the mycelium of the wood-destroying fungi. The processes of disintegration of wood and leaves described in paragraph 215 are processes of decay. If it were not for such organisms as the fungi and bacteria, our forests would soon become choked up with dead trees, and nitrogenous foods in the soil would in time become used up so that all life would disappear from the earth. The fungi are chiefly concerned in the disintegration and decay of carbohydrates, as starch, sugar, cellulose and woody structures, while bacteria are chiefly concerned in the decay of nitrogenous substances. The decay of nitrogenous bodies, especially if they are in bulk, is usually called *putrefaction* because much of the process of decay is carried on in the absence of air by anaerobic bacteria, and among other products foul smelling gases are evolved. These processes of decay so often destructive of economic products, and which modern industrial development has done much to prevent as applied to food products for man, are really of the greatest importance and value viewed from the standpoint of economy in nature. All dead plants and animals left to the operation of nature's laws, by the action of a long series of organisms, are finally reduced to a condition in which they can be used as food by the higher plants again, thus perpetuating life, through the decay of the dead, and the endless circulation of food substances. Some of these processes of decay are useful in preparing certain foods. Cream is " ripened " for butter by the action of special bacteria. The great variety of cheeses with their distinct flavors and odors is made possible by the action of specific kinds of fungi. Fresh meats are made more tender and to some more palatable after a process of " ripening," which is in reality an incipient decay. Very poisonous products called ptomaines are sometimes formed in fish and other meats as a result of incipient decay by bacteria which cause serious illness and sometimes death to those who eat them.

218. Fermentation.—Fermentation is really a process of decay. Starch can be fermented into sugar by certain fungi.

Sugars are fermented into alcohol and carbon dioxide. *Alcoholic* fermentation is caused by the action of yeasts on carbohydrates, and yeasts are employed in the commercial process of brewing beer. The same yeasts are also used in bread making. When the "dough" is set aside to "rise," the yeast plant in the "yeast" which is added, ferments the sugar into alcohol and CO_2. The latter being a gas forms gas cavities in the dough which causes the bread to "rise." It is then placed in the oven, the heat expands the gas and causes the bread to "rise" still more so that it becomes "light" and the baking makes the loaf rigid in this form. *Acid* fermentation is another kind of fermentation caused by bacteria. Alcohol is fermented by the acetic acid bacteria into acetic acid. This process takes place in the making of vinegar from cider. The lactic acid bacteria (*Bacillus acidi lacti*) cause the souring of milk. Sugar and cellulose can also be fermented into butyric acid by certain bacteria.

210. Unorganized ferments.—The yeasts and bacteria which produce fermentation are called *organized* ferments, since they are living organisms. There is another kind of fermentation caused by what are termed *unorganized* ferments. These are usually known as *enzymes* or *diastases*. They are substances produced in different parts of plants and animals which act on starch and other substances in such a way as to *digest* or dissolve them. A well-known *animal diastase* (*ptyalin*) is present in the saliva of the mouth, which is necessary as one step in the digestion of starch by animals, thus the importance of thorough mastication of the food to mix the saliva with it. *Leaf diastase* is formed in the leaves of green plants to change the starch formed during the day into sugar so that it can be transported to other parts of the plant. *Malt diastase* is formed in seeds and is especially abundant in barley which is used to make "malt" in the breweries. The diastase dissolves the starch to sugar, and then the yeast (an organized ferment) ferments the sugar to alcohol. *Taka diastase* is a special diastase formed by a mold fungus (*Aspergillus oryzae*) which grows on rice grains. The fungus excretes the diastase, which acts on the starch in the rice, converting it into sugar. Taka diastase is very powerful and abundant. It is extracted from the fungus and sold for medicinal purposes. It is used by people who have weak digestion to aid in the digestion of starchy foods. Many of the plant diastases are very powerful; a small quantity can dissolve a great deal of starch without in the least diminishing its activity. Recent investigations tend to show that a diastase (called *zymase*) is produced by the yeast plant, which is the active agent in the alcoholic fermentation of sugar, and it would appear that there is not such a great difference between organized and unorganized ferments, for it may be found that the active principle in all so-called organized ferments is an unorganized ferment or enzyme. Oil products in seeds, etc., are rendered available for plant food by a ferment called *lipase*, cellulose (in some seeds) by a ferment called *cytase*, proteid bodies by ferments called *proteases*, and albuminoids by a *tryptic ferment*.

BACTERIA.

220. The bacteria are very minute plants, some of them the smallest known organisms. Like the fungi they lack chlorophyll, and derive their carbohydrate food from living or dead organisms or from organic matter, since they are not able themselves to fix carbon from the carbon dioxide of the air except in a few forms like the nitrite and nitrate bacteria (see paragraph 200). They usually consist of a single cell with cell wall enclosing the protoplasm. In form they are rod-like (*Bacillus*, *Bacterium*), thread-like and formed of many rod-like segments (*Beggiotoa*), in the form of a screw or spiral (*Spirillum*), spherical and single (*Micrococcus*), or a number of spheres in a chain (*Streptococcus*), or with the spheres in groups of four (*Sarcina*). They usually multiply by

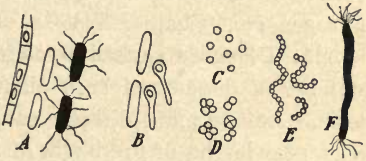


Fig. 101.

Bacteria. *A*, Bacillus subtilis. Spores in threads, unstained rods, and stained rods showing cilia; *B*, Bacillus tetani, the tetanus or lockjaw bacillus, found in garden soil and on old rusty nails. Spores in clubshaped ends. *C*, Micrococcus; *D*, Sarcina; *E*, Streptococcus; *F*, Spirillum. (After Migula.)

division, each cell dividing into two equal parts. This is called multiplication by *fission*, which means a cutting in two. For this reason they are sometimes called *fission fungi*. In reproduction many of the bacteria form *spores*, the protoplasm condensing inside the cell into a small, rounded, shining body which is much more resistant to dessication, heat, cold, and the action of poisonous substances than are the vegetative cells, some being able to resist the heat of boiling water for several minutes.

The bacteria live within, or upon the surface of, the substance upon which they feed. Their method of nutrition is similar to that of the fungi. They absorb solutions of food substances through their cell walls. The bacteria are "omnipresent," and being very minute and capable of rapid multiplication they exist in marvellous numbers. Some species multiply so rapidly as to produce new individuals in a half hour. They and their spores are easily carried about on floating particles of dust, on the clothing, the hands and other parts of the body, and by insects and other animals. They exist in the mouth, in the stomach and throughout the intestinal canal. Fortunately the larger number of bacteria are harmless and many are beneficial, as we have seen in the study of decay, nitrification, fermentation, fixation of nitrogen, etc. (Chapter XIV).

221. Diseases caused by bacteria.—There are, however, a number of diseases of both plants and animals caused by bacteria. Among plant diseases caused by bacteria are the following: pear blight, or fire blight of the pear, apple and other fruit trees (killing flowers, leaves, twigs and branches); black rots of cabbage, rots of turnip, potatoes, etc., bacteria also attack the leaves and fruit of beans, cotton; some cause the plants to wilt, as in melon and cucumber wilt; and some produce galls or tubercular swellings on the affected parts, as on the olive tree.

222. The most serious diseases caused by bacteria are those of man and other animals. Because of the small size of the bacteria they are often spoken of as *germs*, and the diseases they cause, as *germ diseases*. Some of these diseases are as follows: Typhoid fever caused by *Bacillus typhosus* in the alimentary canal, consumption or tuberculosis caused by *B. tuberculosus* in the lungs and other parts of the body, diphtheria caused by *B. diphtheriæ*, lockjaw or tetanus caused by *B. tetani*. This last organism is abundant in cultivated soil and on old rusty nails. When deep wounds in the flesh are caused by punctures with objects carrying the germs, because of the character of the wound the air is excluded. Bacillus tetanus is an anaerobe and can only grow and produce the tetanus symptoms in the absence of oxygen. Opening such a wound to admit air, and disinfecting it with a weak solution of bichloride of mercury will prevent its action. Other bacterial diseases are pneumonia, influenza or la grippe, anthrax, swine plague, etc. Many of these bacteria develop and excrete toxic substances called toxins, which are very poisonous. These act locally on the tissues, and in many cases, as in diphtheria, are carried in the blood to all parts of the system and cause the fever in the patient. The bacteria themselves are in a number of cases finally checked in their growth or killed by these same toxins which they excrete. This principle has led to an important practice in the prevention and cure of some of these diseases, i.e., by injecting what is called an *antitoxin* into the blood. In the case of smallpox the bacteria are inoculated into healthy cows and a mild form of the disease is developed. To prevent smallpox in man some " virus " of the " cow pox " is then inoculated into the system, or the person is vaccinated. The result is a very mild form of the disease and the system is able to resist it. But the distribution of the toxin in the system renders the person immune from the disease even in a virulent form for a number of years. So in the case of certain contagious diseases, as in cholera, if the patient recovers he is immune from the disease for a period of years.

In the case of diphtheria the antitoxin is obtained from the blood of healthy horses in the following way. The toxin is first obtained from pure cultures of virulent forms of the bacillus. Successive subcutaneous injections of this toxin are made in the horse every 5 to 7 or 3 to 7 days for a period of about three months when blood is drawn from the jugular vein of the horse, allowed to clot and the antitoxic serum is withdrawn. Successive injections are made up to about nine months and blood is drawn from the horse from time to time. The horse may then be given a rest for a few months and used again. In recent years it is customary to inject antitoxin into the horse along with the first doses, since a much larger dose of toxin can be administered and the process of making the desired strength of antitoxin is accelerated. The antitoxin is injected into the patient suffering from diphtheria in an early stage of the disease. This antitoxin checks the growth of the bacillus and the disease runs its course in a much milder form.

223. Public duty in the preservation of health.—With the knowledge gained in the investigations as to the cause, prevention and treatment of these germ diseases, it becomes the public duty of every person to be familiar with the principal facts as to the cause of disease, the means of infection and contagion, and to use every care not only in the preservation of his own health but in preventing the distribution of the germs which will communicate the disease to others. It is well known, for example, that the typhoid fever germs are taken into the system by drinking contaminated water or milk or by eating contaminated food. The great epidemics of typhoid fever, where they have been traced, have been found to originate from one or two isolated cases on the water shed of the public water supply. Carelessness in throwing the refuse from a patient where rains or melted snows carry the bacteria into the water supply has often resulted in an epidemic, since many of those drinking from the public supply contract the disease. All such refuse matter should be thoroughly disinfected and then covered where there will be no drainage into streams, for even if it is not drained into a water supply, flies during the warm season will carry on their legs myriads of the germs and then deposit them on food. The hands of attendants as well as other things in the sick room should be properly disinfected, since contact of these with food or fruits or with vessels used for holding milk or food leads to the contamination of these substances. Nearly every typhoid epidemic shows two sources of infection, the original one from the water supply, and then a number of secondary ones around the various primary cases due to carelessness in or lack of proper disinfection. Boiling the water or milk and thoroughly cooking the food kills the germs, but the wiser way is to prevent the primary infection. In this respect the public authorities should see to it that the water supply is kept pure both by cleanliness of the water shed, and by building proper filtration plants where a supply of pure artesian water is not available.

CHAPTER XVI.

FLOWERS, THEIR STRUCTURE AND KINDS.

In some of the preceding chapters all parts of the plant have been studied except the members of the flower shoot which will be studied now.

224. The flower is not only a very interesting, usually beautiful and conspicuous part of the plant, but it is a very important structure. The chief end towards which the plant works is the production of seed or some other structure of similar function, for the multiplication of its kind. The flower performs a very important work in the production of seed. The seed is formed in certain parts of the flower. The organs concerned in the process of pollination and fertilization, which are necessary (except in very rare cases) for the development of the seed, are formed in the flower or have a very intimate nutritive dependence on some of its parts. Many flowers have certain conspicuous, often beautifully colored members, which, it is believed, attract insects that aid in pollination. Other members are present in most flowers

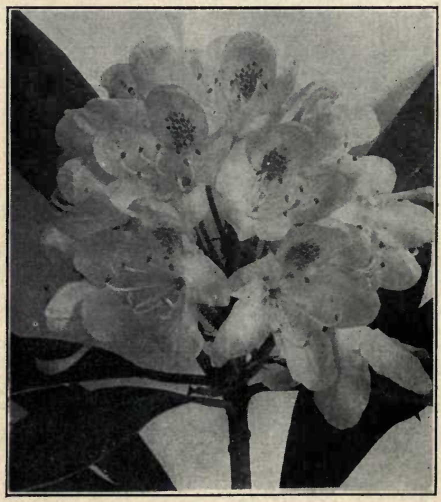


Fig. 102.
Flower cluster of Rhododendron maximum.

which serve the purpose of protecting the essential members concerned in pollination and seed production while they are in a young and tender condition, in the bud.

225. The members, or parts, of the flower are crowded together on a very short portion of the stem. This close association of a number of such important parts of a plant into one structure gives a very great importance to the flower in indicating the relationships of flowering plants. While there are other parts of flowering plants which are of importance in showing relationships, the flower is one of the most important structures in this respect. In addition to the complex structure of the flower already indicated, when we come to compare the flowers of different kinds of plants we find that the members of the flowers vary, not only in the number of the different kinds of members and their form, but in the relation of the kinds of members among themselves and to each series of members. In the simpler kinds of flowers the members are all separate and distinct, while in the more complex and highly developed ones the members are more or less united. It is important therefore in the study of flowers that we should attempt to determine not only the parts which are present, their position, and relation to each other, their function, the different mechanisms by which the different kinds of flowers perform their functions, but also the significance of the form of the flowers and their arrangements on the flower shoot.

226. The different kinds of members, or parts, of the flower appear to be arranged in whorls, because they are so closely crowded on the stem. In some flowers, the buttercup and some of its relatives, they are believed to be arranged in spirals similar to the arrangement of the leaves, though so crowded that it is difficult to determine.

Studies of a few flowers are presented here to illustrate their structure, as well as the arrangement and relation of their parts.

I. FLOWERS OF DICOTYLEDONOUS PLANTS.

The Buttercup.
(*Ranunculus.*)

227. Almost any of the species of buttercup will answer for the study of the flower. This study is made from the tall or meadow buttercup. It is common in fields and roadsides, especially in the Northern States and Canada, from May to September. The flowers are bright yellow and are borne two or three or more in loose corymbs.

Fig. 103.

Flower of buttercup (Ranunculus acris) with petals removed and arranged at left. The flower at the right has the sepals, stamens and pistils.

228. The calyx.—The outer whorl of members of the flower is the calyx. In the buttercup the calyx consists of five distinct members. Each member or part of the calyx is known as a *sepal.* In the meadow buttercup the sepals are elliptical in form and greenish. They fall away very easily and it is necessary to examine young flowers to see them. The calyx serves the purpose of protecting the other members of the flower in the bud.

229. The corolla.—Next inside of the calyx is the *corolla*. It consists of five distinct, free members or parts, of bright yellow color. Each one of these is a *petal*. The number of petals sometimes varies, six sometimes being present. Each petal is broadly obovate, wedge-shaped in outline, with a minute claw at the base on the upper side. The function of the corolla, when bright in color, is supposed to be that of attracting insects which aid in pollination. It also serves to protect the inner members of the flower in the bud.

230. The stamens.—Just inside of the corolla are a large number of small flower members known as stamens. Each stamen consists of two parts, the stalk or *filament*, and a broad terminal portion, the *anther*. The anther is slightly lobed into two parts. Each lobe is called an anther sac, or *locule*. It is a little case, containing, when ripe, the pollen grains, very small, free cells, which are produced in great numbers. In the buttercup these lobes open by splitting along the middle line on one side, and permit the scattering of the pollen which to the eye resembles a fine grained powder. The filament of the stamen is attached along the inner face of the anther, and the latter in such a case is said to be *adnate*.

231. The pistils.—The pistils are the members which occupy the center or summit of the flower. They are numerous and distinct from each other.

The pistil is recognized as consisting of three parts, the *ovary*, the *style* and the *stigma*. The ovary is the lower and larger part. It is ovate in outline and compressed. The ovary is hollow, and by cutting off one side, a small body is seen which is attached at the base. This is the *ovule* in which the embryo plant is formed after

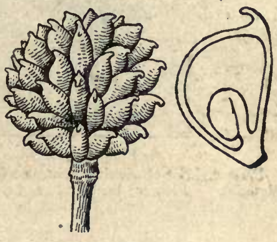


Fig. 104.
Young fruit of buttercup (R. acris) after the sepals, petals and stamens have fallen. Section of pistil at right, showing position of ovule.

fertilization, the ovule and embryo together making the seed. The style is the short, slender portion of the pistil, and bears the stigma at its apex. When the seed ripens the ovary remains closed and firmly surrounds the seed. This forms a one-seeded fruit, which is known as an *akene*.

Fig. 105.
Flower shoot of evening primrose (Œnothera biennis). Flower buds at apex, opening flowers next, and fruits forming below. Indeterminate inflorescence.

232. A flower like the buttercup, which has all four series of members, is called a *complete* flower, and because it has both stamens and pistils it is known as a *perfect* flower. Because the petals are distinct from each other it is called *polypetalous*, i.e., having many petals. Because all of the parts are free and distinct (that is, not joined to other members, or to members of the same set or whorl) it is a simple flower.

233. The part of the flower to which these different members are attached is the *receptacle*. The receptacle is a more or less broadened part of the stem. It has not elongated, and thus the members of the flower, which belong to the same series of plant parts as the leaves, are very much crowded. The pistils being in the center of the flower, therefore stand highest upon the stem, that is, at its apex. All the other members of the buttercup flower are successively below the pistil and are therefore said to be *hypogenous*, i.e., underneath the pistil.

The Evening Primrose.

(Œnothera biennis = Onagra biennis.)

234. The flowers of the evening primrose are formed in a rather loose spike, which continues to grow at the end, producing new flowers in the axils of the bracts, while the seed is ripening in the lower older fruit pods. In vigorous plants flower spikes are also formed on the branches in the axils of the upper leaves.

235. The calyx forms a long tube, the lower part of which is joined to (adnate) the outside of the ovary. This tube is prolonged far above the apex of the ovary and is about twice the length of the young ovary. The free part of the tube is easily distinguished from the part adnate with the ovary by its light green color. The calyx lobes are four in number, long, narrowly acuminate, and in the flower bud the edges fit closely, giving the bud an elongate, four-angled, pointed form. These calyx lobes are the free parts of the sepals, the edges of which are united below to form the tube. As the flower opens the calyx lobes part, and become inverted, hanging downward from the apex of the tube.

Fig. 106.

Flower of evening primrose (Œ. biennis) with corolla tube split open to show the long style.

236. The corolla is bright yellow and consists of four petals which are inserted on the edge of the calyx tube. Each petal is broadly wedge-shaped and notched in the free end, or rather it is heart-shaped. The petals are convolute in the bud, as shown in fig. 108, where they are just unfolding.

237. The stamens are eight in number, seated also on the edge of the calyx tube and partly on the base of the petals since the stamen sometimes remains attached to the base of the petal when that is removed from the calyx tube. Four of the stamens are set opposite the petals and four are alternate with them as shown in the photograph of a dissected flower in figs. 106, 107. The filaments are strongly curved at the base, all in the same general direction, with the concavity toward the axis of the spike. The anthers are *versatile*, i.e., each anther is attached by one face near the middle to the point of the filament, upon which it swings loosely. The filament is attached to the outer face of the anther, so that the anther faces inward toward the axis of the flower, and is said to be *introrse*, or *incumbent*. The anther consists of two pollen sacs (locules) which open by a long slit on the inner faces. This takes place before the flower opens and the pollen is deposited in great masses on the outer surfaces of the four lobes of the

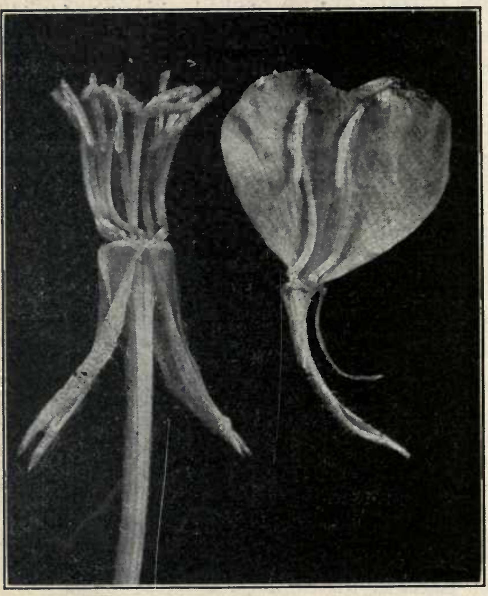


Fig. 107.

Flower of evening primrose with petals removed to show the four spreading lobes of the stigma, and anthers beneath them. Petal at right, showing two stamens attached.

stigma. The stigmatic surface is on the inner face of the stigma lobe and is not yet mature, so that the pollen from the anthers of this flower cannot usually bring about fertilization in this flower. Insects which visit this flower carry the pollen to another flower where the stigma lobes are mature, open and spreading. They are thus ready to receive the pollen brought by the insect from the former flower. This mechanism of the flower necessitates cross-pollination for the production of an abundance of seed (see chapter on Pollination).

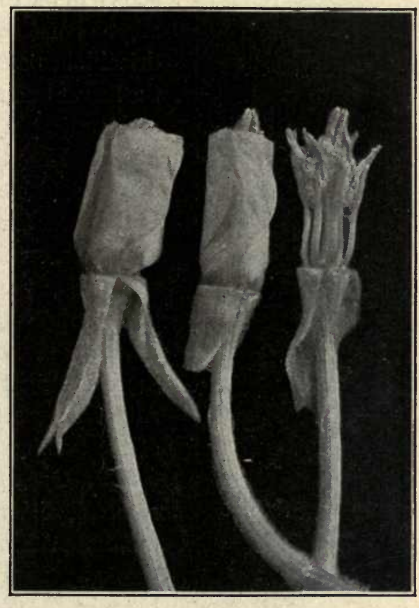


Fig. 108.
Flowers of evening primrose, the two at left showing the way the petals are folded in the bud. At the right, petals removed, showing anthers opening while the stigma lobes are still closed.

238. The pollen grains are loosely held together by delicate "cobwebby" threads, and the mass is slightly sticky, so that it adheres readily to objects which it touches. These delicate threads, shown in the photograph, fig. 109, are probably formed by the partial gelatinization and shredding of the outer layer of the walls of the pollen grains. Each pollen grain is strongly three-angled, the angles appearing as pronounced protuberances, each one nearly as large as the central body. Germination of the pollen grains takes place through these angles.

239. The pistil of the evening primrose consists of three distinct parts, the *ovary*, the *style*, and the four *stigmas*. The ovary is at first nearly cylindrical, but becomes four-angled with the ripening of the seed. The ovary consists of four locules. This indicates that it is composed of four parts which are united to form a compound ovary. The ovules are numerous and occur in two rows. The style is longer than the calyx tube and is well shown in the dissection of the flower. The stigma consists of four short, nearly cylindrical lobes at the apex of the style. In the flower bud these are erect, approximate, and project a little above the convolute petals. Here the inner faces of the anthers are pressed closely against the lower half of the outer face of the stigmas and deposit the pollen on them as described above.

Fig. 109.
Photomicrograph of pollen of evening primrose, showing threads which hold the grains in loose masses.

The four parts of the ovary and the four lobes of the stigma indicate that the pistil is made up of four parts, or *carpels*, which have become united into one compound pistil. All of the parts of the flower, therefore, of the evening primrose are in *fours.*

240. One species of the evening primrose, *Œnothera lamarkiana* (Lamark's evening primrose), has become celebrated through the experiments of the Dutch botanist, DeVries, for the sudden variations which appear in plants grown from the seed, giving rise to distinct forms. These forms are regarded as elementary species, and as indicating one method of the evolution of new species.

Butter and Eggs.

(*Linaria vulgaris = Linaria linaria.*)

241. This plant occurs by roadsides and in waste places. It is from one to nearly three feet high (3–9 decimeters), branched, with linear leaves. The leaves are mostly alternate, but are often grouped on the stem, two, three, or four arising close together on the stem and almost opposite or verticillate.

242. The flowers are in dense terminal racemes, with pedicels 3 to 5 mm., each flower arising in the axil of a slender acuminate green bract. The white or greenish-white flowers, with the orange yellow " palate " of the corolla, are very striking and gave rise to the name " butter and eggs."

243. The calyx consists of five sepals, which are green, normally acuminate and coalesced at the base by their edges. When the sepals are coalesced the calyx is said to be *gamosepalous*. Here it is deeply divided into five lobes showing clearly the five sepals.

244. The corolla is irregular, that is, the petals or their lobes are of unequal size. The petals are coalesced, and the corolla is therefore *gamopetalous*. The corolla is also two-lipped (bilabiate), as can be plainly seen from a side view. The two upper petals form the upper lip, and a short notch or incision indicates the two petals. The lower lip consists of three petals which are indicated by the lobes, two broad outer ones and a smaller middle one.

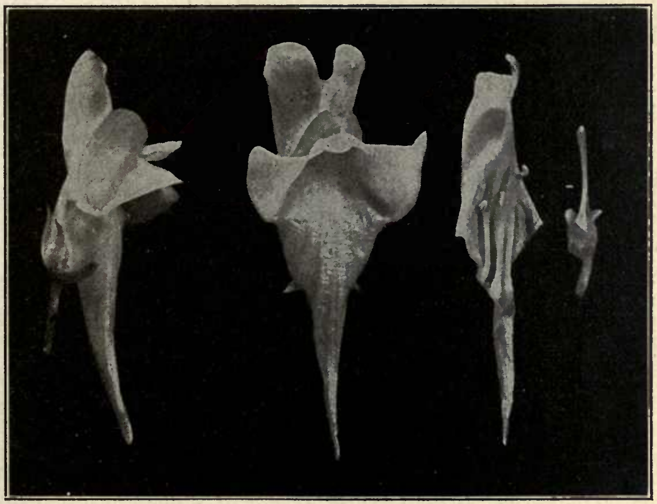


Fig. 110.
Flower detail of "butter and eggs" (Linaria vulgaris).

The lower part of this lip is prolonged into a long straight spur. The upper part of the lower lip, at the point to which the incision extends that indicates the lobes, is of a deep orange color and arched upward so that it closes the " throat " of the corolla. This is called the *palate*, and when at rest it closes the throat. By pulling apart on the two lips the throat is exposed, and at the same time it is seen that the incision which separates the two lips is much deeper than those which separate the petal lobes of each lip.

245. The stamens are four in number and are seated on the corolla near the base of the broad part of the throat around the ovary. The stamens are of two forms (*dimorphic*), the two lower ones being shorter than the upper ones. They are shown in fig. 110 attached to the base of the corolla tube, the corolla having been removed from the receptacle and the lower lip cut away. The *anther lobes* are two in number and nearly confluent at one end, where the filament is inserted between them, and diverge somewhat from this point. Each locule opens by a longitudinal slit along the inner face, the face opposite to the attachment of the filament.

246. The pistil is single and entire. The ovary is superior oval in shape and two-loculed. There is a thickened placenta on either side of the partition which is covered with numerous ovules which fill the locules. The *style* is simple, short filamentous and slightly enlarged at the end, the upper surface being the *stigma*.

The Sweet Pea.

247. The flowers of the sweet pea are produced singly or in loose clusters of two or three on long flower stems or peduncles. The *calyx* is regular, gamosepalous, green, and divided into five even or nearly even pointed lobes which represent the sepals. It is inferior.

248. The corolla is irregular and peculiar in form, said to be butterfly-shaped (*papilionaceous*). The upper petal is the broader one, nearly rounded and with a short limb. It usually stands erect, and is known as the " banner " or " standard." The two lateral petals are irregularly wedge-shaped, and are forked at the smaller end (said to have two claws). These two petals, because of their position, are known as the "wings" or *alæ*. The two front petals are partially united into one in the shape of a curved, thin, flattened body which is known as the "keel."

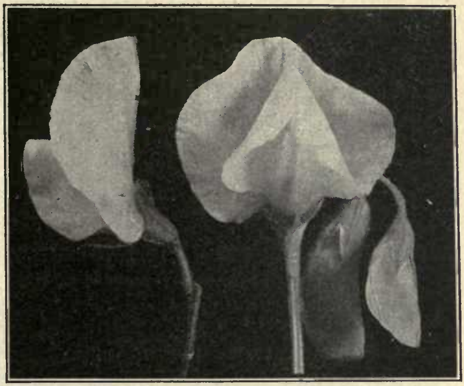


Fig. 111.
Flowers of sweet pea in front and side view.

249. The stamens are ten in number, and are in two groups. One group consists of a single stamen, the upper one. The other nine are joined into one group, the filaments being united at their base for half their length and closely wrapped about the small flattened pod, the single stamen lying at the point where the edge of the united filaments approach. When the stamens form two groups they are said to be *diadelphous* (i.e., of two brotherhoods). The anthers are adnate, two-lobed, each lobe having one locule, which opens by a longitudinal cleft on its inner face.

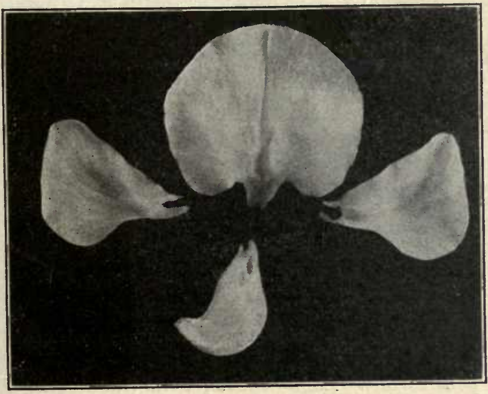


Fig. 112.
Details of petals of sweet pea flower; banner above, wings at the side, keel below.

250. The pistil is simple. The ovary is flattened, elongate, with the ovules arranged in a row at the upper edge. It forms the pod, or legume. The style is slender and curved upward, and bears the stigma, which is narrowly elliptical and somewhat broader than the style. The free part of the filaments are curved also to surround the style, bringing the anthers close around the stigma, upon which the pollen is shed before the flower opens, so that self-pollination usually takes place.

251. This type of flower, called *papilionaceous* because of its resemblance to a butterfly (*papilio*), is characteristic of a large number of plants belonging to the important family known as the pulse family or pea family (*Leguminosæ*, sometimes called *Papilionaceæ*), including the peas, beans, clovers, alfalfa, etc. Besides their importance as food for man and animals, they play a very important part in the enrichment of the soil in nitrogen through the nitrogen-fixing bacteria which grow as parasites in their roots.

Fig. 113.

Flowers of sweet pea, corolla removed. Note diadelphous stamens, one single one, the others all united.

The Sunflower.

(*Helianthus annuus.*)

252. The sunflower is widely cultivated in gardens for its showy flower head, and for the seed, which is considered a healthful food to be given occasionally to poultry and stock. It grows wild along the rich river valleys in some of the Western States.

The sunflower is an excellent example for the study of the type of flowers which form a *head.* The "flower head" is made up of a large number of flowers crowded very closely together in a rounded or flattened group on the broad receptacle.* Each one of these flowers is called a *floret.* In the sunflower head there are two kinds of flowers. The most showy flowers in the head are the long yellow strap-shaped ones on the border of the head, where they extend outward in the form of rays. These are called ray flowers. The *disk* flowers are very great in number and occupy the space inside of the circle of ray flowers. The corolla is tubular in form, and the disk flowers are often called *tubular* flowers. Each disk flower grows by the side of (really in the axil of) a slender pointed bract. On the outside of the head are a large number of overlapping green leaf-like members, each with a long, narrow, pointed end. These are bracts which together make up the *involucre,* which encloses the head in the young stage.

253. The disk flowers or tubular flowers.—The flowers should be studied in the different stages of flowering. The mode of inflorescence is *centripetal.* The flowers on the outer margin of the disk open first, while those in the center are still quite young. These form a circle, and as they pass the height of the flowering period another broad circle of flowers just inside the outer ring come into the height of flowering. The circle of

---

* Such flowers are often called compound flowers. The family to which the sunflower belongs is the *Compositæ,* and its members are often spoken of as *composites.* Besides the sunflower it includes such plants as the goldenrod, aster, daisy, yellow-eyed-susan, dandelion, chicory, lettuce, Joe-pye-weed, chrysanthemums.

flowers in the height of flowering is always very conspicuous, because the stamens and the stigmas of the flower project so far above the corolla tube at this time, and then by shortening become inconspicuous again (see figs. 114, 115). For the study of the flower several disk flowers in different stages of flowering should be separated from the disk for close examination.

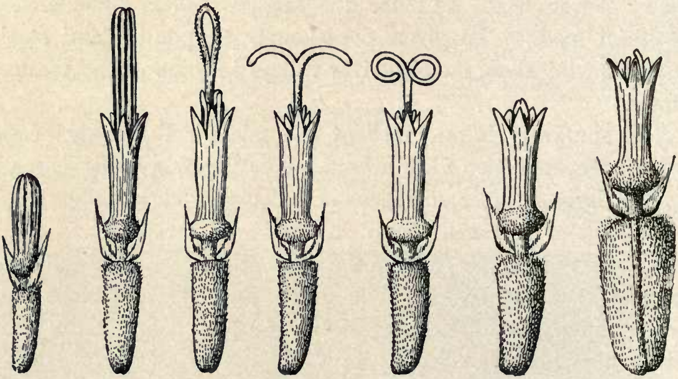


Fig. 114.
Tubular flowers of sunflower, showing details of flowering from left to right.

254. The calyx.—The calyx is very inconspicuous. The ovary is inferior since the calyx is joined to its outer surface and covers it. It is seen as a narrow wedge-shaped white body with the rest of the flower borne on its apex. The calyx is manifest here only as two small white awn-like lobes, or chaff, which are opposite (sometimes there are rudiments of smaller ones between).

255. The corolla.—The tubular corolla is abruptly broadened or inflated near the base. The apex is divided into five short acute lobes which show that it is composed of five petals. Compare this inflated portion of the corolla in tubular flowers of different ages.

256. The stamens.—The stamens are joined together by the edges of their anthers and are thus *syngenesious*. They are five in number and attached by the filaments to the lower part of the inflated portion of the corolla. The anthers thus form a tube which surrounds the upper part of the style and the stigma. They open by their inner face, shedding the pollen on the hairy outer faces of the stigma.

257. The pistil.—The ovary is narrowly wedge-shaped, four-sided by compression. The style is long and slender, and the stigma is divided longitudinally into two portions. The inner plane surfaces fit closely together, and the outer hairy surfaces are in contact with the anther locules up to and during the early stage of flowering.

258. Peculiarities in the flowering of the disk flowers.—The mode of inflorescence is *centripetal* as described above, i.e., it proceeds from the outside inward. At the time of flowering the anther tube and the stigma which it surrounds are pushed out of the corolla tube by the gradual elongation of the filaments and the style, though the anthers are often slightly in advance of the stigma (see figs. 114, 115 for details). This takes place, as I have observed it, during the night and early morning. In the course of two to four hours, the style having reached its full length, the filaments shorten and draw the anthers down into the corolla tube again. While this is going on the style remains elongated, and the upright hairs on the outer face of the cleft portion of the style catch the pollen as the open anthers are dragged downward. The great mass of pollen is thus left on the

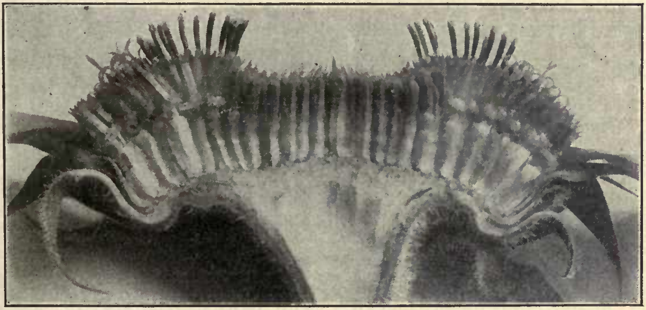


Fig. 115.
Section through head of sunflower, showing details of flowering from the outside toward the center.

outside of the exposed stigma. The two parts of the stigma now open outward and become recurved, thus exposing the stigmatic surface which is on the inner face. The pollen being caught on the hairs of the outer surface of the lobes of the style cannot come in contact with the inner stigmatic face. Now that the parts of the stigma become recurved and the stigmatic surfaces exposed, the pollen from certain flowers is brushed onto the stigmatic surfaces of others by insects which crawl in great numbers over the disk flowers, and thus cross-pollination is brought about. The style in the course of 12 to 24 hours then contracts and is drawn down again into the corolla tube. This took place in the cases which I have observed during the late afternoon and evening. In the cases observed by myself the anthers are drawn into the corolla tube at an earlier time during the previous evening and night. Some movement takes place during the day also, and some flowers lag behind, so that the process is going on continually, but the greater amount of change appears to go on during late afternoon, during the night, and in the early morning.

259. Ray flowers.—The ray flowers have a rudimentary ovary with which the calyx is consolidated, but the pistil is otherwise undeveloped and stamens are wanting. Such flowers are sterile, and are often called *neuters.* The corolla, however, is very conspicuous. The petals are united by their edges in such a way as to form a long, broad, leaf-like organ, except at the base where they form a short tube. The ray flowers of the sunflower do not show well the number of divisions of the corolla. But the ray flowers of some other composites do, as in the coreopsis, etc., where the end is five-toothed. In many composites the ray flowers are pistillate, and therefore develop seed like the disk flowers, as in the ox-eye daisy, or white weed. In the dandelion, chicory, etc., all of the flowers are strap-shaped (like the ray flowers) and are fertile. For composites of economic importance see Chapter XXXVI.

260. The composite flower shows the highest degree of specialization, by the union of parts and the massing of the flowers, of all the seed plants. They are thus believed to represent the highest stage of evolution in plants. The buttercup flower is much more simple in its structure, for all the parts are separate and distinct, and some of them formed in large numbers. There are other dicotyledons, however, in which the flowers are still more simple in structure. Some of the flowers which we have studied show different steps in the consolidation of parts of the flower. In the evening primrose the sepals are united among themselves (gamosepalous), and are adnate with the ovary, while the petals and stamens are seated on the calyx tube instead of on the receptacle of the flower. In the "butter and eggs," not only is the calyx formed by the united sepals, but the corolla is formed by the united petals (gamosepalous). In the morning glory, calyx, corolla, and pistils all show a union of their parts, i.e., the calyx is gamosepalous, the corolla is gamopetalous, and the pistil is compound. But they are all free, except the stamens, which are inserted on the inside of the corolla. In the composites the calyx tube, formed by the union of the sepals, is consolidated with the outer wall of the ovary, while the calyx *limb* or free part is reduced to mere scales or hairs, or is inconspicuous. The corolla tube, or "ray," formed by the union of the petals, is seated on the edge of the calyx tube. The stamens, united by their anthers, are joined to the inside of the corolla tube. The pistil is compound as shown by the divided style, but there is a single cavity with one ovule which develops into a seed. The walls of the ovule (seed coats) are consolidated with the ovary, thus forming a one-seed fruit known as an akene.

CHAPTER XVII.

FLOWERS, THEIR STRUCTURE AND KINDS (Concluded).

II. FLOWERS OF MONOCOTYLEDONOUS PLANTS.

The Indian Corn.

(*Zea Mays.*)

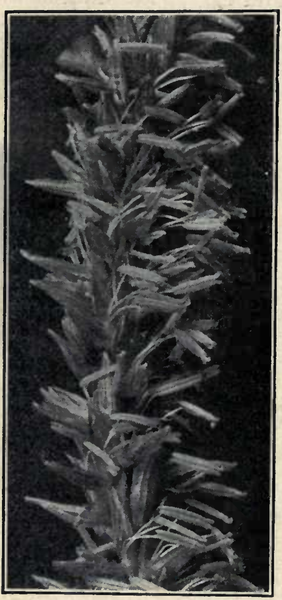


Fig. 116.
Part of staminate inflorescence of Indian corn.

261. The Indian corn (or "maize," as it is sometimes called) is a good illustration of a plant with two kinds of flowers (fig. 77), the staminate flowers, those having stamens but no pistils; and the pistillate flowers, those having pistils but no stamens. Such flowers are really of two forms (*dimorphic*). Where they both occur on a single plant, as in the case of the Indian corn, the plant is said to be *diœcious*, i.e., of two "households."

262. The staminate inflorescence of Indian corn.—This is composed of several spikes in the form of a panicle terminating the shoot, the spike which forms the axis of the panicle bearing several branches, all forming what is commonly known as the "tassel" of the corn. The spikes are made up of numerous *spikelets* which are on short and slender branches that arise from each joint of the axis of the spike. At each joint there are usually two spikelets (sometimes one or three), one nearly or quite sessile and the other on a short stalk.

263. The staminate flowers of Indian corn.—Each spikelet is made up of two flowers, one bearing perfect stamens, and another, usually sterile, bearing imperfect stamens, or none. The two flowers in the spikelet are enclosed by two small boot-shaped, ribbed and partially green bracts, known as *empty glumes*, one for each flower. If we dissect the flower by spreading these empty glumes apart, and with needles loosen from the inside the other parts of the flowers, we shall find that in the flower with perfect stamens, for example, there is another membranous bract which lies next the empty glume and often fits closely within it. This is the *flowering glume*, so called because it lies next the stamens. Upon the other side of the stamens is another membranous bract, the *palea*.

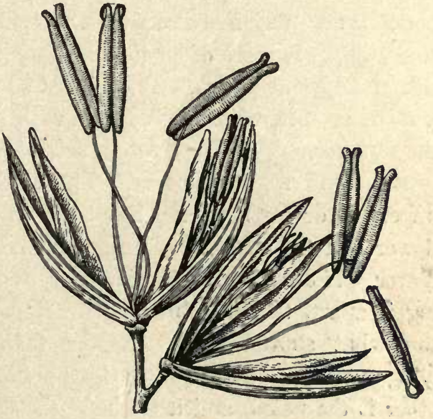


Fig. 117.
Open staminate flowers of Indian corn.

264. The stamens are three in number, which is the rule in the grasses and cereals. The filaments are long and slender. The anthers are two-loculed, being separate at each end and connected by the tissue of the "connective" for the greater part of their length. The filament is attached to the side of one end of this connective. Each locule of the anther is grooved on its outer face, so that it appears to be made up of two lobes, but there is really only one. At the time of flowering the filaments elongate and lift the anthers far out of the flower. The filaments being slender and delicate are bent over by the weight of the anther, which dangles here and is easily agitated by the wind. The anther sacs open on the outer side of the free end. A split occurs in the wall along the groove for a short distance and the walls bend backward so that a nearly circular pore is formed. The pollen grains are nearly spherical, smooth, and quite firm. As the anther dangles at the end of the filament, a slight jar, which even a slight breeze would give it, sets the pollen grains rolling out of the opening. They usually fall out in large numbers. They may fall directly on the silk of the ear of the same stalk, or, as is more often the case, the wind carries them to the silk of adjacent plants. The blades of corn, and the ground of a field, are often literally covered with pollen grains, so great is the number.

265. The sterile flower.—The sterile flower, the one with imperfect or no stamens, lies between the palea of the fertile flower and the other large empty glume which covers the sterile flower. If care is used in dissecting the sterile flower by spreading it apart, two membranous bracts will be found. They are somewhat shorter and narrower than the others. The one lying next the empty glume is the flowering glume, while the other is the palea, and it lies next the palea of the fertile flower. Between these two membranous bracts, i.e., between the palea and flowering glume of the sterile flower, may often be found remnants of the stamens, sometimes rudiments only in the form of slender threads, two or three of them. At other times filaments and anthers are both formed, but the pollen is unformed and imperfect. In many such cases the filament does not elongate and the anthers do not emerge from the closed flower. In a few cases the stamens are perfect and well formed. Such a spikelet contains two fertile flowers.

266. The pistillate inflorescence of Indian corn.—This is formed by a consolidation of several spikes into one body, known as the "ear" of corn (fig. 118). The cob is formed by the consolidation of the spikes, the flowers being borne in double rows along the outer surface, so that there is always an even number of rows of grains on an ear. The ears arise as branches at some of the middle joints of the stem in the axils of the leaves. When young they are covered by the leaf sheath, but at flowering time the end appears above the sheath and projects for some distance. The ear is surrounded and covered by a large number of leafy bracts, called "husks." They are in reality leaves; the outer ones are

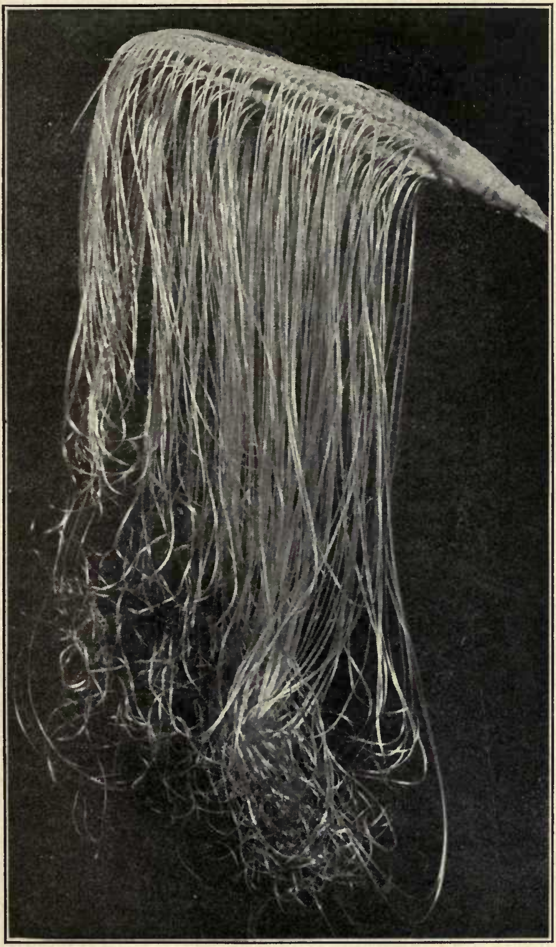


Fig. 118.
Pistillate inflorescence of Indian corn, showing long styles, the "silk."

green, and often the tip terminates in a true blade, so that the husk part may correspond to the leaf sheath. At the time of flowering the tuft of silk emerges from between the husks at the end of the ear.

267. The pistillate flowers of Indian corn.—The pistillate flowers are well seen by taking a young ear of corn soon after the silk has emerged. If the husks are carefully stripped off without breaking the silk, and this is shaken out so as to separate the threads as much as possible, it will be seen that each long thread of silk is connected with the tip of a small and young grain of corn. This is the pistil of the flower. The thread of silk is the style and the young grain of corn is the ovary. If the surface of the silky threads is examined with a hand lens for some distance over the portion which extends outside of the husks, numerous short hairs will be seen. These serve to hold the pollen grains. It is easy to see that when the pollen grain germinates the tube must travel a long distance to reach the egg cell in the ovule.

Fig. 119.
Spikelet of oat, showing two glumes.

Fig. 120.
One glume removed, showing fertile flower.

Fig. 121.
Flower opened, showing two palets, three stamens, and two lodicules at base of pistil.

Fig. 122.
Section showing ground plan of flower. *a*, axis.

268. There is a cluster of delicate white membranous scales which envelop each ovary at this stage, so that only the tip of the ovary, where the style is attached, is exposed. In the ripe ear of corn these form the chaff, which mostly remains on the cob when the corn is shelled. This cluster of chaff with the pistil corresponds to the spikelet, and in fact is a spikelet with two flowers, one fertile and one sterile, the sterile one lying below the fertile one. It is not a very easy matter to dissect out these parts to determine them, since they are soft, delicate, and some of them much plaited and folded. But in flowers where the grains are about one-fifth grown they can be teased out so that one can make out the membranous bracts. Here it will be seen that the two outermost ones are the empty glumes of the two flowers. Between one of the empty glumes and the grain of corn is the flowering glume, and the palea of this fertile flower is on the other side of the grain of corn. The two scales between this and the empty glume of the sterile flower are the palea and flowering glume of the sterile flower (compare oat flowers, figs. 119 to 123).

Fig. 123.
Flower of oat, showing the upper palet behind and the two lodicules in front.

269. The corn is a representative of the Monocotyledons making up the great family of grasses (Gramineæ), including many valuable economic plants as the grasses, cereals, sorghum, sugar cane, etc. For this study see Chapter XXXVI.

Jack-in-the-Pulpit, Indian Turnip.
(Arisæma triphyllum.)

270. The Indian turnip inhabits moist, shady woods or groves, and flowers from April to June. Its underground perennial stem is a corm (paragraph 74) which is very acrid to the taste. The annual flowering shoot is formed in the bud at the apex of the corm during autumn and winter. The plants are about 30 cm. (1 foot) high. The leaves are divided into three leaflets. The flower shoot is very odd and interesting. It is in the form of a *spadix*, a cylindrical structure, the free end sterile and with the small imperfect (either staminate or pistillate) flowers crowded around the lower part. The spadix is enclosed in a leaf-like structure, forming a broad cylindrical tube (the "pulpit") below, and above tapering into a strap-shaped part (spathe) which bends forward over the pulpit. In some plants the staminate and pistillate flowers are borne on the same spadix (plants monœcious), but usually they are all of one kind on a spadix (plants diœcious).

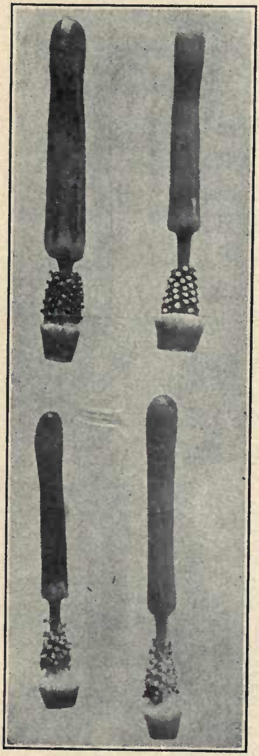


Fig. 124.
Jack-in-the-pulpit or Indian turnip (Arisæma triphyllum), spathe removed, showing spadix; the two upper figures with pistillate flowers, lower figures with staminate flowers.

271. A little observation will show that the pistillate plants are the larger and have larger corms, while the staminate plants are smaller. The larger corms have more stored food and thus produce a larger aerial shoot. But why they should produce pistillate flowers is not so clear, though it probably has some connection with the abundant food supply. It is evident, however, that this is a useful distribution of the flowers, since the pistillate flowers produce the seed, which makes a greater drain of food from the corm than the mere production of stamens and pollen would. Seed formation of the smaller pistillate plants sometimes makes such a drain of food from their smaller corm, that the ensuing year they change to staminate plants. In fact the change from pistillate to staminate plants can be demonstrated experimentally, by removing the larger part of the corm with a knife during late summer or early autumn, before the nature of the flowers for the coming year has been fixed. It follows from all these facts that seedlings, or offsets from the corm, when they flower for the first time probably bear staminate flowers. In a few years, if they are favorably situated so that the corm attains a suitable size, they then bear pistillate flowers.

272. The Jack-in-the-pulpit belongs to the arum family. A number of the species are grown in greenhouses for the ornamental foliage, while in some others the spathe is brightly colored, as in the calla lily (*Richardia*), which is not a true lily. Another very interesting member of this family is the skunk cabbage, so called because of its peculiar odor and large cabbage-like leaves. Both kinds of flowers are borne on the same spadix, which is club-shaped.

Fig. 125.
A group of jacks.

Gladiolus.

273. The showy flowers of gladiolus arise in two ranks on a long terminal shoot, but they bend to one side, giving the appearance of a long unilateral spike, which sometimes has a slight tendency to a spiral form. The base of the flower is covered by two leaf-like bracts. The showy part of the flower is the *perianth*, but, unlike the lily, the six parts of the perianth are united toward the base into a tube, which is attached to the upper part of the ovary, and the lower part of the tube is coalesced with the outer part of the ovary. The parts of the perianth are somewhat irregular, so that it has in some varieties a decidedly two-lipped appearance. The upper petal (upper lip) is usually covered by the two lateral sepals, while the two lower petals are covered by the lower sepal and the two lateral ones.

274. The stamens.—There are three stamens. These are seated on the upper part of the tube of the perianth, on the middle line of what would correspond to the sepals, or outer members of the perianth. The filaments are long and attached by a joint near one end of the anther. The anthers are long and two-loculed.

275. The pistil is compound and consists of three parts, as can be seen by the three lobes of the stigma. The style is long, slender, rises along the inner face of the upper lip, and the stigmas lie just underneath the apex of the upper member of the perianth, with the three anthers directly in front of the stigmas or slightly below them. The ovary is elongate, three-angled, and with three locules.

Fig. 126.
Flowers of Gladiolus: at right, partly dissected. The six petal-like parts form the "perianth."

276. The gladiolus belongs to the order of lilies (Liliales), which includes many plants with beautiful flowers, cultivated for ornamental purposes, as tulips, crocuses, daffodils (*Narcissus*), hyacinths, iris, lilies, etc. The cultivation of the Easter lily (*Lilium harrisii* and *L. longiflorum*) forms a large industry in Bermuda and Japan, from whence come most of the bulbs, which are forced in greenhouses by the florists. Some plants in this order are used for food, as asparagus, onion, etc.

277. The orchid family (Orchidaceæ), also belonging to the Monocotyledons, contains many plants with beautiful flowers and wonderful mechanisms for cross-pollination by the aid of insects.*

---

* See Darwin, On the fertilization of orchids by insects.

CHAPTER XVIII.

METHODS OF POLLINATION.

278. The necessity of pollination.—Pollination is the transference of the pollen from the anthers to the stigma of the pistil. This is necessary in order that the pollen grain may germinate, and that the pollen tube, by making its way down through the style, may reach and enter the ovule, to carry the sperm cell (the fertilizing element) to the egg cell. The union of the sperm cell and egg cell brings about the fertilization of the egg cell, which is necessary (except in rare cases) in order that the egg may develop into the embryo and bring about the formation of the seed. There are many different devices, or mechanisms, in the flower structure for bringing about pollination.*

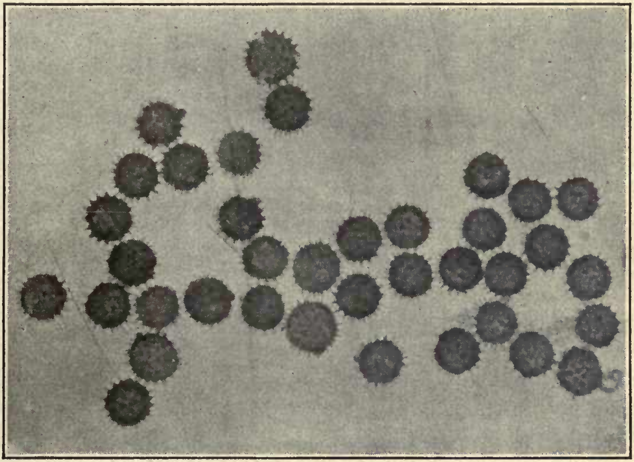


Fig. 127.
Photomicrograph of pollen grains of sunflower, highly magnified.

---

* See Darwin, Cross fertilization, etc.

279. The pollen grains and how they are shed from the anther.—The form and parts of the stamen have been described in Chapters XVI, XVII. The anthers open in different ways in different flowers. In some the anther opens by long slits, in others by a trap door, and in others by a pore at the end of the locule. The pollen grains are all free, and loose or *dusty*, or they may be held rather loosely together by a viscid or fibrous substance. In some flowers, especially the orchids, the milkweeds, etc., the pollen grains are held in one, or several, more or less compact masses called a *pollinium*.

280. Kinds of flowers as regards methods of pollination.—Most flowers can be placed in three different groups according to the general method of pollination. First. Those which are *self-pollinated*, where the anthers lie close to the stigma, or above them, and open at the same time that the stigmas are ready to receive the pollen. The pollen is usually shed directly on the stigma in the same flower. Second. Where the pollen is transported by the wind to the stigmas of a different flower. These are *wind-pollinated* flowers (*anemophilous* flowers). Though in many cases self-pollination takes place, cross-pollination is the rule because of certain peculiarities of the flower (see Darwin, Cross fertilization, etc.). The pollen in such flowers is *dusty*, so that it is easily wafted by the wind. Third. When the pollen is carried by insects from one flower to another. These are *insect-pollinated* flowers (entomophilous flowers. Self-pollination in some cases may take place here). The pollen in these flowers is usually held together loosely or firmly by a viscid substance. Humming birds also assist in the pollination of some flowers. In a state of cultivation, especially in greenhouses, it is sometimes necessary to hand-pollinate the flowers of some plants, as tomatoes, strawberries, etc.

281. A knowledge of these laws is of great importance to the horticulturist and florist. In many varieties of pears, although the flowers are perfect, it has been found that the pollen is impotent or very weak, not only on the pistil of the same flower and the flowers of the same tree, but in all the flowers of that particular variety. If an orchard of this variety is planted, without the admixture of a different variety having pollen potent for the pistils of the first variety, no fruit or but little fruit will set. But if a tree of another variety is planted here and there through the orchard, with trees of the variety from which fruit is desired, and for which the pollen of the fertilizing variety is potent, abundant and fine fruit will form.* This impotency of the pollen of one variety for all of the flowers of the same variety is not due to any deficiency in the pollen itself, but to a lack of affinity between the sperm cell in the pollen tube and the egg cell in the ovule. Varieties which are perfectly sterile (i.e., unadapted or unfitted) to pollen of their own flowers may be abundantly fertile (adapted or fitted) in cross-pollination. Rainy weather during flowering time interferes with cross-pollination, since it prevents the visits of bees.

In the case of a number of varieties of strawberries, it is necessary to plant a "fertilizing" variety among them in order to insure fertilization, since some varieties are sterile to their own pollen.

282. Close-pollination and cross-pollination.—*Close pollination* is the same as self-pollination, where the stigma is pollinated with pollen from anthers of the same flower. *Cross-pollination* occurs when the pollen is transferred from the anthers of one flower to the stigmas of another flower either near or remote. Cross-pollination takes place through the agency of the wind, insects, birds, or by the hand of man.

CLOSE POLLINATION.

283. Close pollination can take place in a great many different flowers where cross-pollination also takes place. It is remarkable that in many of these cases the pollen from a different flower or plant is often more "potent" than the pollen from the same flower. In these flowers, where close pollination alone takes

---

* See "The Pollination of Pear Flowers," U. S. Dept Agr. Bull. No. 5, Div. Veg. Path., 1894.

place, there may be little or no seed or fruit developed, but when cross-pollination takes place an abundance of seed is formed. Even when pollen from the same and from a different flower is deposited on the stigma, the pollen from the different flower prevails. Cross-pollination is important for the plant, since it insures greater vigor and greater plasticity in the offspring, which make it better fitted to survive in the struggle for existence. Still there are flowers in which the usual method of pollination is a close pollination.

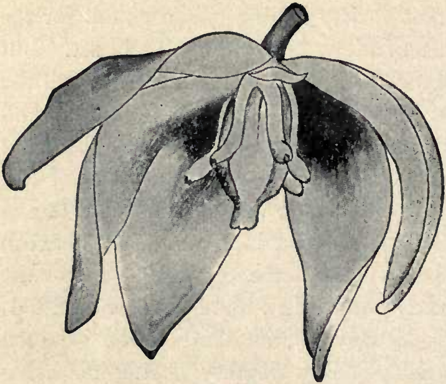


Fig. 128.
The pendent flower of *Yucca.* showing position of stamens and the ribbed ovary.— After Riley and Trelease.

284. Cleistogamous flowers.—Close pollination always takes place in cleistogamous flowers, of course if left to themselves. Cleistogamous flowers are those which remain closed during the process of pollination and fertilization. The violet is an excellent example. The showy flowers which are so conspicuous rarely develop seed. The greater quantity of seed is formed in flowers which are not showy and which are covered by the soil or leaf mold. They remain closed, and the pollen from the stamens is shed on the stigma of the same flower.

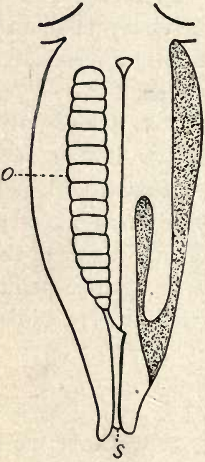


Fig. 129.
Longitudinal section of an ovary of *Yucca*, showing the funnel-shaped stigmatic opening (*s*), and the rows of ovules attached to the wall (*o*).— After Riley and Trelease.

285. Pollination of the yucca by the moth Pronuba.—This is a remarkable case of close pollination brought about by an insect. The pollen is somewhat sticky and without some aid could not be deposited in the funnel-shaped stigma. The moth resting quietly in the flower during the day, at dusk crowds down over the stamens, digs out some of the pollen mass with her foot, passes down on the ovary over one of the furrows directly over where the ovules are located, pierces the ovary with her ovipositor and plants an egg in an ovule. Then she passes on to the end of the pistil and crowds the pollen into the funnel-shaped opening of the stigma. She repeats this process several times, depositing several eggs and placing an abundance of pollen in the stigma, which insures the development of a large number of seeds, some of which can be used for food by the young larvæ.

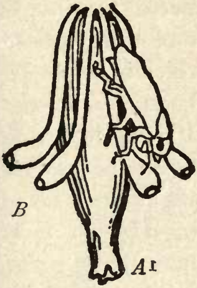


Fig. 130.
The position of *Pronuba* on the stamen of *Yucca* when collecting pollen and when thrusting it into the stigmatic funnel. — After Riley and Trelease.

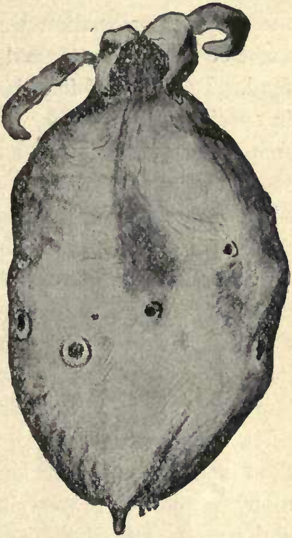


Fig. 131.
A mature capsule of *Yucca*, showing perforations made by larvæ of *Pronuba* in escaping. — After Riley and Trelease.

CROSS-POLLINATION BY THE WIND.

286. While wind pollination takes place in quite a variety of plants, it is the chief method among the grasses, cereals, Indian corn, the amentiferous trees and shrubs (those bearing catkins), and among the conifers. Whoever has been in a cornfield at the time of pollination will realize this. In the pines among the conifers, the pistillate cone stands erect and the scales flare outward during pollination. The pollen is caught on these scales and rolls down to the lower end, where it is caught in a viscid substance in the micropyle of the ovule.

CROSS-POLLINATION BY INSECTS.

287. How insects are attracted to flowers.—In order to secure cross-pollination through the aid of insects, the insects must be lured or attracted to the flowers for some highly prized food. Provision of food is made in the *nectar* which is developed in special *nectar glands*, or *nectaries*, in these flowers. *The odor from flowers* probably has more influence in attracting insects to them than anything else. This is very striking in the case of night-blooming flowers, which usually have strong fragrant odors and attract the moths which fly at night. In addition most flowers adapted for cross-pollination by insects have showy parts, which by their size and color attract the insects, and stand for them as a sign of those flowers which produce nectar. In the larger number of cases the petals are the showy parts of the flower. Sometimes it is the sepals, especially in the apetalous flowers, as in the marsh marigold, etc. In other cases the bracts of the flowers are colored and showy, as in the flowering dogwood. In many composite flowers it is the ray flowers which are showy and serve to attract the insects. In many cases these ray flowers are neutral, or do not develop seed, so that their sole function is to attract insects, while the inconspicuous disk flowers provide the nectar and produce the seeds. The neutral showy flowers in the cranberry tree or wild guelder rose (*Viburnum opulus*) are exterior to the perfect inconspicuous flowers. *This massing of flowers* into flower clusters, heads, etc., is of great advantage since the flowers are made more conspicuous, the odors are more centralized, and, as in the heads of composites, the insects crawling over the head cross-pollinate rapidly a great many flowers. According to Lubbock, flies are mostly attracted to the flowers with the duller colors, as brownish, dark purple, dull yellow, or greenish flowers. Some flowers have carrion odors which also serve to attract flies. Butterflies and bees are attracted by the bright colors, as red, blue, violet. Experiments seem to show that insects cannot see the form of objects distinctly at distances greater than four to six feet, but the colors of objects can be seen at a greater distance.

288. Landing places for insects.—Many of the flowers which attract insects are *irregular* (those with bilateral symmetry) and some portions of the flower are especially adapted to serve as a landing place. This is often the lower lip of the flower, or one or more of the lower petals (where more than one petal they are often consolidated). The keel of the papilionaceous flowers, the lower lip of bilabiate flowers, the lower petal of the canna flower, and the *labellum* of the orchids, are examples. In the violet the insect rests on the two lower petals while extracting the nectar from the nectary in the spur.

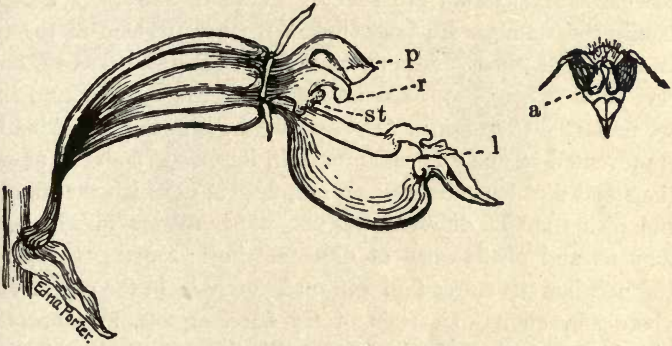


Fig. 132.

Epipactis with portion of perianth removed to show details. *l*, labellum; *st*, stigma; *r*, rostellum; *p*, pollinium. When the insect approaches the flower its head strikes the disk of the pollinium and pulls the pollinium out. At this time the pollinium stands up out of the way of the stigma. By the time the insect moves to another flower the pollinia have moved downward so that they are in position to strike the stigma and leave the pollen. At the right is the head of a bee, with two pollinia (*a*) attached.

289. Honey guides.—Some flowers have "honey guides," bright-colored lines on the petals facing the insect as it alights, which lead down to the nectary.

290. Flower structures suited to the visits of special insects.—Flowers with long spurs, which are formed from the prolongation of one or more sepals or petals into a tube, prevent most insects, except those with a long proboscis or sucking tube, from obtaining nectar. The sphinx moths and humming birds are visitors to many of these flowers. Examples are seen in the columbine, nasturtium, etc. The outer parts of some flowers are covered with a sticky substance, which probably prevents crawling insects like ants, which could not aid in cross-pollination, from reaching the nectar. This is shown in the catchflies (*Silene*), where the peduncle of the flower is sticky; in the mullein, where the hairs on the calyx are sticky; and in the rhododendrons, where the calyx and corolla are sticky. In many flowers of the pea family the stamens are protected in the keel formed of the two lower petals. Many flowers, as the dandelion, hawkweed, chicory, pond lily, crocus, close on cloudy and rainy days and thus are protected from rain. As stated above, self or close pollination is prevented in many flowers: first, in imperfect flowers (monœcious and diœcious flowers); second, flowers in which the stamens and pistils are of different lengths; third, flowers in which the stamens and pistils open at different times; fourth, the special and peculiar structures found in many orchids, in the canna, etc., where movements of certain of the floral organs, in connection with insect visits, assist in cross-pollination, or the insect is led into one part of the flower and out at the other in such a way as to bring about cross-pollination.

291. Imperfect flowers.—In those flowers where the stamens and pistils are in different flowers, often in different flower clusters or on different plants, cross-pollination is necessitated. Many of these are wind-pollinated as stated above in many of the trees with catkins. Others of this group are insect-pollinated, as in the willow and chestnut. Here the stamens and pistils are the showy parts, and the nectar also attracts the insects.

292. Flowers with stamens and pistils of unequal length.—In flowers where the stamens and pistils are of unequal length, so that when the insect visits one flower one part of its body comes in contact with the pistil and another part comes in contact with the anthers, this part brushes off and carries some of the pollen. In the next flower, or one of the succeeding ones which the insect visits, the length and position of the stamens and pistils will be reversed, so that the pollen from one of the previously visited flowers will be brought in contact with the stigma and its viscid surface will pull off some of the pollen. The common bluet (*Houstonia*) and the bellflower (*Campanula*) are examples, as well as the primrose so commonly grown in greenhouses. This plant can be used for study and demonstration. Not only do the length and position of the stamens and pistils in such flowers favor cross-pollination by insects, but Darwin has shown that in some of them the pollen of the long stamens is impotent or weak on the short pistil of the same flower, but is prepotent on the long pistil of another flower, and so the pollen of the short stamens is prepotent on the short pistil of a different flower.

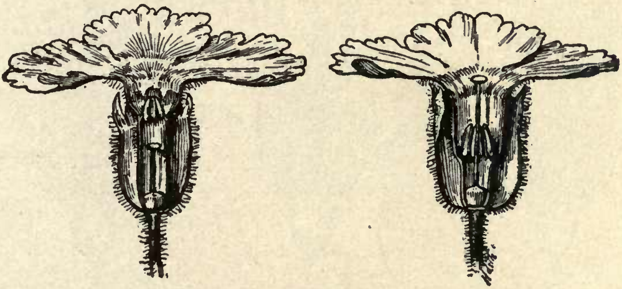


Fig. 133.
Dichogamous flowers of Primula.

293. Flowers in which the stamens mature first.—This is shown in the great willow herb or fire weed (*Epilobium*). When the stamens are mature the four stigmas are closed and the style is bent backward. Later when the anthers have shed their pollen, the style straightens out, and the stigmas open and become receptive. In the evening primrose (*Œnothera biennis = Onagra biennis*) the stamens also mature first (see paragraph 237). The same is true of the high mallow with purple flowers. The stamens are erect, shed their pollen, then wither and become recurved, while the styles then elongate and the stigmas become receptive. In most of the composite flowers the stamens mature first (see the study of the sunflower, paragraphs 254–258). In the bellflower (*Campanula*) the stamens are joined by their anthers into a tube, and mature their pollen before the stigma, which is inside the tube, is receptive and open. The stigma now elongates, and the brush on the outside of the closed stigma sweeps out the pollen. The stigma now opens, the lobes curving outward so that the pollen does not fall on its upper receptive surface, but the visiting insect brings pollen from another flower.

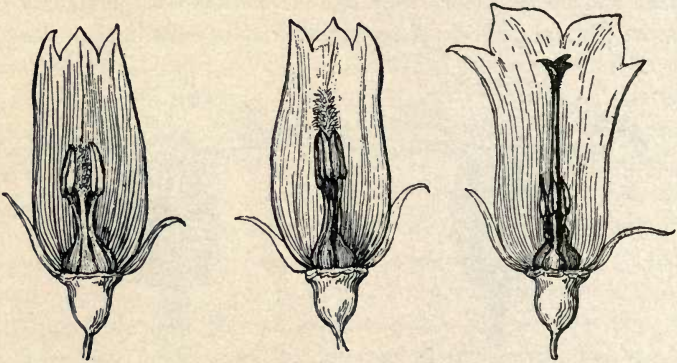


Fig. 134.

Proterandry in the bellflower (Campanula). Left figure shows the syngenœcious stamens surrounding the immature style and stigma. Middle figure shows the immature stigma being pushed through the tube and brushing out the pollen; while in the right-hand figure, after the pollen has disappeared, the lobes of the stigma open out to receive pollen from another flower.

294. Flowers in which the pistils mature first.—In the figwort the flower is urn-like, and the mature stigma is thrust outside of the flower by the long style, while the stamens are curved backward in the flower. When the stigma of this flower is past the receptive stage, the stamens straighten out and bring the anthers to the outside of the flower, where they shed their pollen so that a visiting insect can carry it to another flower in which the stigma is receptive. In the skunk cabbage the stamens in the flowers of some plants mature first, while in other plants the pistils mature first.

295. Movements executed by stamens or pistils to aid in cross-pollination.—The movements of the pistils and stamens described in the study of the sunflower (paragraph 258) and of the bellflower in the preceding paragraphs are illustrations. A remarkable case is seen in the mountain laurel (*Kalmia*). The stamens are bent outward and the anthers are held in little pockets near the base of the petals. When the insect is crawling over the flower and touches the stamens, the anthers are released suddenly, fly up and throw the pollen on the body of the insect. The action of the stamens can be seen by touching the filaments with a pencil or other object. The common garden sage (*Salvia*) presents a very peculiar structure and movement of the stamens (fig. 136). As the insect enters the flower it pushes against the lower sterile anther lobe, which causes the connective to swing on its hinge in such a way as to bring the upper lobes ready to discharge the pollen down on the back of the insect. On visiting another flower where the pistil is older the insect on entering brushes some of the pollen off on to the stigma. The orchids show some of the most remarkable movements of any flowers during cross-pollination. In some the pollen mass (pollinium) is attached to a slender curved stalk which is held in tension like a spring, and on the other end is a viscid

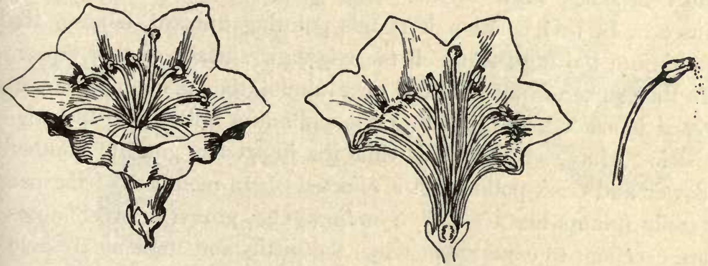


Fig. 135.

Kalmia latifolia, showing position of anthers before insect visits, and at the right the scattering of the pollen when disturbed by insects. Middle figure section of flower.

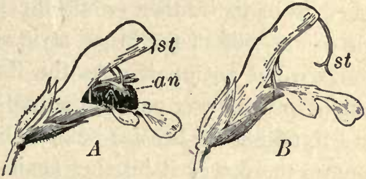


Fig. 136.

Two flowers of common sage, one of them visited by a bee. After Lubbock.

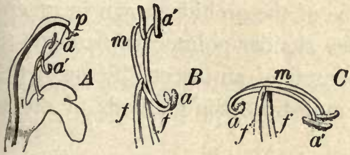


Fig. 137.

Flower and stamens of common sage.

disk. When the insect alights on the labellum and touches a sensitive structure, the pollinium is set free, the tension of the curved stalk causes it to fly out like a spring, and the viscid disk attaches itself to the head or to the proboscis of the insect. In this position it stands pointing upward, holding the pollinium too high to touch the stigmatic surface of that flower. In the course of half a minute or a minute, the stalk curves downward in such a position that the pollinium will strike the stigmatic surface. But by this time the insect has gone to another flower and cross-pollination is effected.* In members of the pea family (plants like *Cytisus*, *Spartium*, etc., grown in greenhouses are excellent to experiment with) the pistils and stamens are held in the keel. When an insect alights on the keel the style suddenly flies upward and the brush of hairs throws out the pollen on to the body of the insect. When it visits another flower in which the stigma shows above the keel and is receptive, some of the pollen is brushed on to the stigma. In the canna flower the pollen is shed from the anther (while the flower is still closed) and glued on to one side of the broad style right by the side of the stigmatic surface but not on it. As the flower partly opens, bumblebees alight on the lower petal (labellum), which suddenly curves downward, taking the bee far below the stigmatic surface. As the bee enters the flower it brushes against the pollen mass and removes some of it, but as it was immediately lowered it could not rub this pollen onto the stigma while it was taking the nectar. But as it visits the next flower, when it first enters some of the pollen from the previous flower is brushed off on the stigma. Interesting experiments can be made on some of the orchids grown in greenhouses with a lead pencil or other slender-pointed instrument to imitate the movement of the proboscis of an insect. Some of the native orchids can be used to demonstrate the methods of cross-pollination.

296. Flowers constructed to lead the insect in at one point and out at another.—Some of our native species illustrate

---

* Darwin's work "On the Fertilization of Orchids by Insects" should be consulted. Full descriptions and illustrations are given.

this. One species of the lady-slipper (*Cypripedium*) is shown in fig. 138. The insect enters about the middle of the boat-shaped labellum. In going out it passes up and out at the end near the flower stalk. In doing this it passes the stigma first and the anther last, rubbing against both. The pollen caught on the head of the insect will not touch the stigma of the same flower, but will be in position to come in contact with the stigma of the next flower visited.

Fig. 138.
Cypripedium.

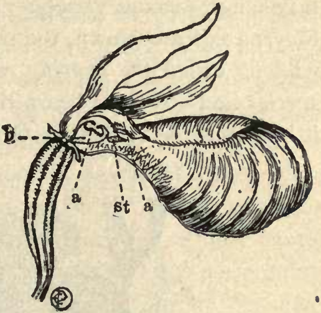


Fig. 139.
Section of flower of Cypripedium. *st*, stigma; *a*, at the left stamen. The insect enters the labellum at the center, passes under and against the stigma, and out through the opening *b*, where it rubs against the pollen. In passing through another flower this pollen is rubbed off on the stigma.

297. Pollination of the Smyrna fig.—Figs have been cultivated in parts of the United States for many years, in the Gulf and Atlantic States and in California. But the variety which has been in successful cultivation during most of this period is inferior to the imported figs. Consequently they could not come into successful competition with the superior imported variety, the Smyrna or Turkey figs. Nevertheless they have been grown in considerable numbers for home use by the cultivators.* Because of the inferior quality of the figs in cultivation here, a number of attempts have been made during the last forty years to introduce the Smyrna fig into cultivation in California. Trees were successfully grown, but they failed to mature fruit, the young figs falling early from the trees.

---

* This variety of the fig belongs to the same species as the Smyrna fig (Ficus carica), but the flowers are modified and sterile (often called popularly "mule" flowers), and the fruit has taken on the habit of forming without fertilization. This variety is also grown to some extent in Southern Europe.

The cause of this lay in the fact that the Smyrna fig produces only pistillate flowers. To set fruit they must be pollinated from a pollen-producing variety. In the Mediterranean region where Smyrna figs are grown, the pollen for this purpose comes from a wild fig called the *caprifig*, which is the staminate form of this species and of course bears the pollen. From very ancient times it has been the custom in Oriental regions to gather branches of the caprifig and hang them in the trees of the edible fig during the season when the latter is in flower. From these caprifigs a small insect issues, called the fig-fertilizing insect (*Blastophaga*). In coming out of the caprifig it drags out with it quantities of pollen. It then visits the pistillate flowers of the Smyrna fig, in which the branches are hung, and those near by, for the purpose of depositing its eggs. In doing this it crawls over the pistillate flowers and brushes off pollen of the caprifig in them.

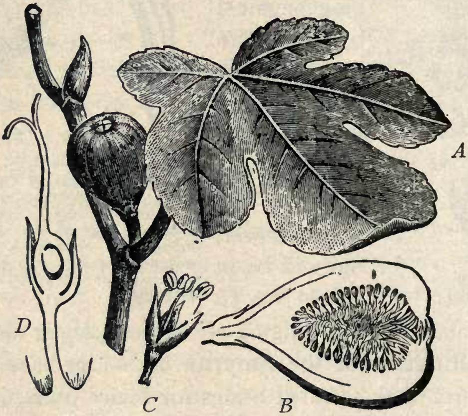


Fig. 140.
The fig. *A*, branch bearing a fig; *B*, section of fig showing flowers within; *C*, staminate flower; *D*, pistillate flower.—After Wossidlo.

In the home of the Smyrna fig there are said to be three generations of fruit on the caprifig, the spring and early summer crop, known as the *profichi*, the midsummer crop, the *mammoni*, and the autumn crop, *mamme*, the latter remaining on the trees all winter. The insect hibernates in the *mamme*. In the spring it comes out and deposits its eggs in the *profichi*. By the time this generation is ready to come out the flowers of the Smyrna fig are ready for pollination. Many of the insects of the *profichi* generation, which are in the fruits left on the caprifigs, lay their eggs in the second crop, the *mammoni*, and those issuing from these deposit their eggs in the *mamme*. In this way the insects continue their existence from year to year in great numbers in the caprifig. About 1882 a large number of Smyrna fig trees were started in California. But they bore no fruit. A few years later another attempt was made and the caprifig as well as the Smyrna fig was introduced by cuttings. But as the insect was not present, failure again resulted. For a few years some Smyrna figs were produced by artificial pollination with pollen from the caprifig. Attempts were then made to introduce the fig-fertilizing insect. In 1898 to 1900 this was successful and Smyrna figs were produced through the agency of this insect which were equal in quality to the imported figs.* Their culture, therefore, promises to become a valuable industry in California and some of the Southwestern States if proper attention is given to it. The process of hanging the branches of fruit of the caprifig in the Smyrna fig trees is called *caprification*.

298. The fruit of the fig is peculiar. It is the enlarged fleshy, somewhat pear-shaped receptacle, the end of a shoot, which is hollow, and the numerous flowers are borne over the surface of this hollow. The "seeds" are small, hard nutlets, and each one is in reality a small fruit, the seed being united with the wall of the ovary. It is said that the "seed" gives the flavor to the Smyrna fig.

---

* L. O. Howard, Smyrna Fig Culture in the United States, Year Book of the United States Department of Agriculture, 79–106, pls. 1–8, and text figs. 1900.

CHAPTER XIX.

FERTILIZATION AND DEVELOPMENT OF THE SEED.*

299. Fertilization consists in the union of two cells, or of the nuclei of two cells of a different nature, a sperm or male nucleus with an egg or female nucleus. The result is a stimulus or impulse given to the fertilized egg to develop and form an embryo plant which later can develop into a plant like the parent. The male, nucleus, or *sperm* nucleus, is derived from the pollen grain which is formed in the anther of the stamen. The egg is developed in the embryo sac within the ovule, which is in turn formed in the ovary, a part of the pistil.

Fig. 141. Nearly mature pollen grain of trillium. The smaller cell is the generative cell.

300. The formation of the pollen, the sperm cells, and pollen tube.—The pollen is formed, as we have seen, in the anther. When the pollen grain is very young it consists of a free cell in the pollen sac. The cell wall encloses the protoplasm, the living substance, and within this is a very important organ of the cell, the *nucleus*, which is a more or less rounded body, finely granular and usually appearing denser than the protoplasm. As the pollen grain ripens a change takes place in its contents as follows. The nucleus divides into two nuclei, and very often a curved thin cell wall is formed separating a small mass of the protoplasm with one nucleus from the larger mass containing the other nucleus, as shown

---

* The study of the processes of fertilization and the development of the seed requires special preparation of material and the use of technical methods which could not be employed by students in the first-year course. It is desirable, however, that students should have a general knowledge of these processes. This chapter is presented for this purpose. It can be supplemented, if desirable, by demonstrations of microscopic material prepared by the teacher or purchased for the purpose.

in fig. 141. Very soon this smaller cell becomes free and its protoplasm floats in the protoplasm of the larger cell. This is the condition in which most ripe pollen grains are; there are two cells, one floating within the protoplasm of the larger one. The larger cell is sometimes called the *tube* cell because later it grows out into the *pollen tube.* The smaller one floating within the larger one is called the *generative* or *body cell.** After a pollen grain falls on the stigma it *germinates* and forms a long tube which grows down through the style into the ovary, where it enters the ovule. The two nuclei move into the pollen tube. The nucleus of the body cells divide into two nuclei either in the tube or before entering it. These two nuclei are the *sperm nuclei,* or *male nuclei,* and they are brought into the ovule by the pollen tube.

Fig. 142.
Germinating pollen grains of Peltandra; generative nucleus in one undivided, in other divided to form the two sperm nuclei; vegetative nucleus in each near the pollen grain.

301. Structure of the ovule.—The ovule is nearly oval in form. There are usually two coats on the ovule, but sometimes only one. Except at the stalk end where the tissues are more or less blended, the coats of the ovule can be seen in a lengthwise section as two distinct layers of tissue, but there is a circular

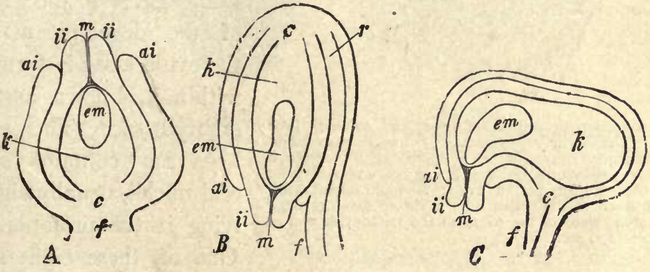


Fig. 143.
A represents a straight (orthotropus) ovule of Polygonum; *B*, the inverted (anatropus) ovule of the lily; and *C*, the right-angled (campylotropus) ovule of the bean; *f*, funicle; *c*, chalaza; *k*, nucellus; *ai*, outer integument; *ii*, inner integument; *m*, micropyle; *em*, embryo sac.

---

* Or central cell of the antheridium. See Chapter XXXV.

opening at the apex of the ovule, so that there is a communication from the outside. This opening is the *micropyle.* The stalk of the ovule attaches it to the wall of the ovary. In a straight ovule the ovule stands out straight in line with its stalk. In a right-angled ovule the stalk is bent over at the upper end, so that the ovule stands about at right angles. In the inverted ovule the upper end of the stalk is bent so strongly that the ovule is inverted and the stalk is then fused with the side of the ovule. This part of the stalk is called the *raphe* (see fig. 143 for details).

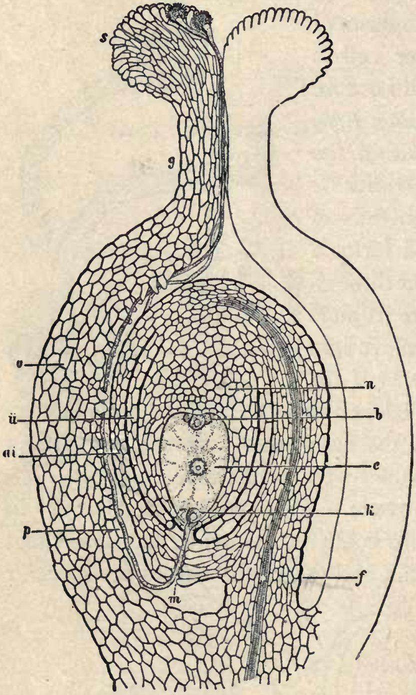


Fig. 144.

Diagrammatic section of ovary and ovule at time of fertilization in angiosperm. *f*, funicle of ovule; *n*, nucellus; *m*, micropyle; *b*, antipodal cells of embryo sac; *e*, endosperm nucleus; *k*, egg cell and synergids; *ai*, outer integument of ovule; *ii*, inner integument. The track of the pollen tube is shown down through the style, walls of the ovary to the micropylar end of the embryo sac.

302. The embryo sac and egg.—At the close of the development of the ovule a sac is formed within it, known as the embryo sac. This embryo sac contains several nuclei, usually eight, lying in the protoplasm. One of these eight nuclei in the embryo sac, with the protoplasm around it, is the *egg cell.*

303. Fertilization.—When the pollen tube grows into the ovule at the micropyle it enters the embryo sac, into which it empties the two sperm nuclei. One of these sperm nuclei fuses with the egg nucleus. This is *fertilization.*

304. Development of the embryo.—The fertilized egg now grows and divides into two cells, and these into more cells, forming the young embryo which lies in the sac within the ovule. This is why the term *embryo sac* is employed for this structure. At the time of fertilization the endosperm begins to form, and develops the tissue, some of which is used in the growth of the embryo, and the rest is stored as food, either by the side of or around the embryo, or in the cotyledons, according to the kind of seed, for use by the young seedling.

305. Formation of the seed.—We are now ready to learn how the seed is formed. In the bean, pea, squash, and many other seeds, the embryo uses up all of the endosperm which is formed, storing up in the cotyledons what is not used in making the tissues of the different parts of the embryo. During this process nearly or quite all of the inside portion of the ovule has been used as food for the developing endosperm. There remain then the walls of the ovule (the integuments), which make the walls of the seed. Inside lies the embryo, with sometimes a papery remnant of the interior of the ovule, as in the squash, pumpkin, etc. In the forming grain of corn, wheat, castor bean, etc., the embryo uses up only a portion of the endosperm, so that in the seed there are embryo and endosperm, surrounded by the walls of the ovule; the embryo and endosperm with the enveloping ovule

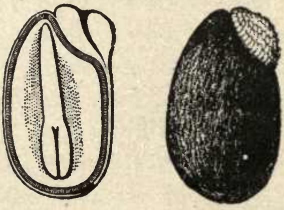


Fig. 145.

Seed of violet, external view, and section. The section shows the embryo lying in the endosperm.

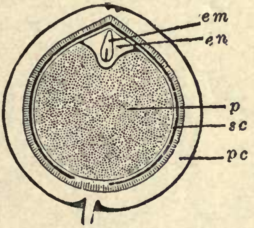


Fig. 146.

Section of fruit of pepper (Piper nigrum), showing small embryo lying in a small quantity of whitish endosperm at one end, the perisperm occupying the larger part of the interior, surrounded by pericarp.

walls make the seed; but in the grain of wheat, corn, etc., the wall of the ovary is fused with the walls of the ovule, making the ripe grain. In the water lily, the pepper, and some other plants, a part of the interior of the ovule is left in the seed. This is called *perisperm* when it is present in the seed, so that in such a seed there are *embryo*, *endosperm*, and *perisperm* surrounded by the integuments or ovule walls.

306. Albuminous and exalbuminous seeds.—In the study of the substances stored in the grain of corn and wheat it was found that there is a large quantity of starch in the endosperm. This is an albuminous substance. Seeds containing endosperm at ripeness are called *albuminous seeds*, while those like the bean, pea, etc., with no endosperm are called *exalbuminous*.

CHAPTER XX.

THE FRUIT.

I. PARTS OF THE FRUIT.

307. The fruit of the plant is the final result of the work of the flower. The seed is formed in connection with the fruit, usually within the fruit. It is the *end* or *aim* for which the plant throughout its life has been working, in order that through the seed the plant may be multiplied, distributed,* and invigorated. The word *seed* is often used to denote any reproductive body which may be planted or "sown" to reproduce that plant again. In a strict sense, however, seeds are only formed by the true seed plants.† The seed in this sense consists of the ripened ovule containing the embryo plant. The ovule has one or two coats (*integuments*) (fig. 143) which become in the ripe seed the seed coats. The ovule is formed within the ovary. In many plants the walls of the ovule are free from the wall of the ovary, as in the pea, bean, etc., so that the seed when ripe becomes free from the wall of the ovary and separates by the splitting of the fruit.

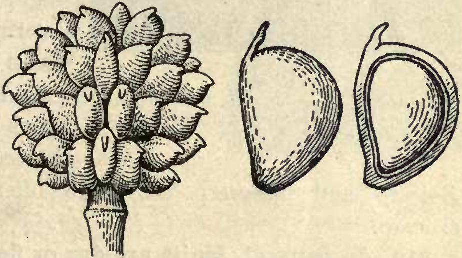


Fig. 147.

Aggregate fruit of buttercup (R. acris), with separate akene at right, one in section showing the seed inside the old ovary wall.

308. The fruit consists of the ripened ovary including the seed, and in many cases other accessory parts of the flower as

---

* It must be remembered that many plants multiply and become distributed in other ways also.

† The Spermatophyta, including the gymnosperms and angiosperms.

calyx, receptacle, etc., combined with it. The fruit may be formed of a single simple pistil or it may be formed of several simple pistils crowded together (*aggregate*, or *collective* fruits), or there may be accessory parts of the flower which *reinforce* the fruit (*accessory* or *reinforced* fruits).

309. The pericarp.—The wall of the ripened ovary is called the *pericarp*. It is the part of the fruit which envelops the seed, and may consist of the carpels alone, or of the carpels and the adherent part of the receptacle, or calyx. In many fruits the pericarp shows a differentiation into layers, or zones of tissue, as in the cherry, peach, plum, etc. The outer, which is here soft and fleshy, is *exocarp*, while the inner, which is hard, is the *endocarp*. An intermediate layer is sometimes recognized and is called *mesocarp*. In such cases the skin of the fruit is recognized as the *epicarp*. Epicarp and mesocarp are more often taken together as exocarp.

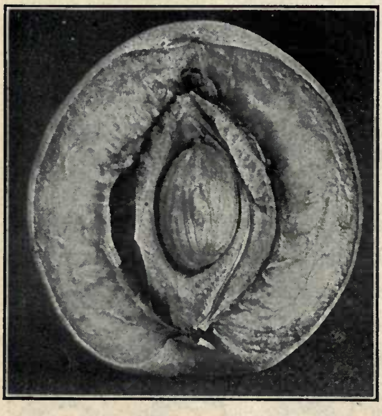


Fig. 148.
Section of drupe, or stone fruit of peach, showing the fleshy exocarp, stony endocarp, and the "meat" or embryo within.

310. In general, fruits are dry or fleshy. Dry fruits may be grouped under two heads. Those which open at maturity and scatter the seed are *dehiscent*. Those which do not open are *indehiscent*.

II. INDEHISCENT FRUITS.

311. The akene.—The thin, dry wall of the ovary encloses the single seed. It usually does not open and free the seed within. Such a fruit is an akene. An akene is a small, dry, one-seeded, indehiscent fruit. All of the crowded but separate pistils in the buttercup flower when ripe make a head of akenes, which form the fruit of the buttercup (fig. 147). Other examples of akenes are found in other members of the buttercup family, also in the composites, etc. The sunflower seed is a good example of an akene. It should be borne in mind that the sunflower "seed" (and "seed" of other composite flowers) is a fruit containing the seed.

312. The samara.—The samara is a dry fruit, with a thin membranous expansion extending more or less around the edge, somewhat resembling wings, which serve to float the seed and aid in distribution by the wind. The "winged" fruits of the maple, box elder (fig. 149), elm, etc., are examples. They are sometimes called "key" fruits.

313. The caryopsis is a dry fruit in which the seed is united with the pericarp (wall of the ovary), as in the wheat, corn, and other grasses. It is perfectly proper to say "seed wheat," "seed corn," "grass seed," etc., if it is understood that these grains are fruits including the seed. It would be absurd to insist that in all such cases one must avoid the use of the term *seed* when speaking of the grains and of akenes, and use instead sunflower fruit, wheat fruit, corn fruit, grass fruit, etc., or oat fruit and barley fruit. In the latter "seeds" not only are the seed coats united with the pericarp, but this is firmly enclosed within the palæ of the flower.

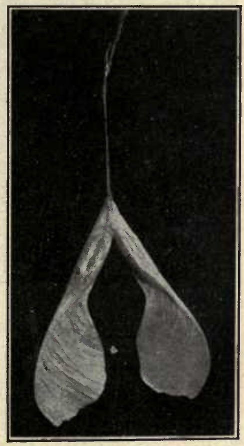


Fig. 149.
A winged fruit, a samara, fruit of the box elder.

314. The schizocarp is a dry fruit consisting of several united carpels (compound pistil) which splits at maturity in such a way that the carpels separate from each other but do not themselves dehisce and free the seed, as in the carrot family, mallow family.

315. The acorn.—The acorn fruit consists of the acorn and the "cup" at the base in which the acorn sits. The cup is a curious structure, and is supposed to be composed of a crown of numerous small leaves (involucre) at the base of the pistillate flower, which become united into a hard cup-shaped body. When the acorn is ripe it easily separates from the cup, but the hard pericarp forming the "shell" of the acorn remains closed. Frost may cause it to crack, but very often the pericarp is split open at the smaller end by the wedge-like pressure exerted by the emerging root during germination.

Fig. 150.
Fruit of corn, husks spread to show ear.

316. The hazelnut, chestnut, and beechnut.—In these fruits a crown of leaves (involucre) at the base of the flower grows around the nut and completely envelops it, forming the husk or burr. When the fruit is ripe the nut is easily shelled out from the husk. In the beechnut and chestnut the burr dehisces as it dries and allows the nut to drop out. But the fruit is not dehiscent, since the pericarp is still intact and encloses the seed.

317. The hickory nut, walnut, and butternut.—In these fruits the "shuck" of the hickory nut and the "hull" of the walnut and butternut are different from the involucre of the acorn or hazelnut, etc. In the hickory nut the "shuck" probably consists partly of calyx and partly of involucral bracts consolidated, probably the calyx part predominating. This part of the fruit splits open as it dries and frees the "nut," the pericarp being very hard and indehiscent. In the walnut and butternut the "hull" is probably of like origin as the "shuck" of the hickory nut, but it does not split open as it ripens. It remains fleshy. The walnut and butternut are often called drupes or stone-fruits, but the fleshy part of the fruit is not of the same origin as the fleshy part of the true drupes, like the cherry, peach, plum, etc.

III. DEHISCENT FRUITS.

Of the dehiscent fruits several prominent types are recognized.

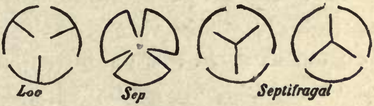


Fig. 151.
Diagrams illustrating three types (in cross section) of the dehiscence of dry fruits. *Loc*, loculicidal; *Sep*, Septicidal, Septifragal.

318. The capsule. When the capsule is syncarpous (compound pistil) it may dehisce in three different ways: 1st. The carpels split along the line of their union with each other longitudinally, as in the azalea or rhododendron. 2d. The carpels split down the middle line, as in the fruit of the iris, lily, etc. 3d. The carpels open by pores, as in the poppy. Some syncarpous capsules have but one locule, the partitions between the different locules when young having disappeared. The "bouncing-bet" is an example, and the seeds are attached to a central column in four rows corresponding to the four locules present in the young stage.

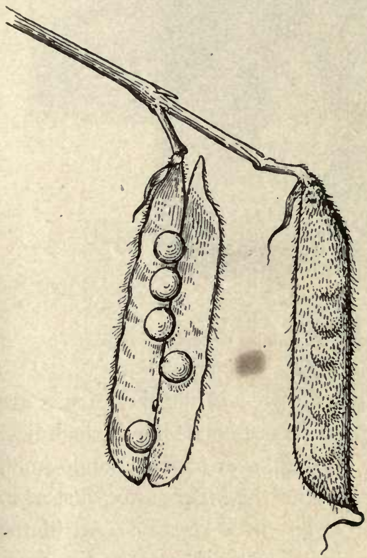


Fig. 152.
Pods of Sweet Pea.

319. A follicle is a capsule with a single carpel which splits open along the ventral or upper suture, as in the larkspur, peony.

320. The legume, or true pod, is a capsule with a single carpel which splits along both sutures, as the pea, bean, vetch, etc. As the pod ripens and dries, a strong twisting tension is often produced, which splits the pod suddenly, scattering the seeds.

321. The silique. In the toothwort, shepherd's-purse, and nearly all of the plants in the mustard family, the fruit consists of two united carpels, which separate at maturity, leaving the partition wall persistent. Such a fruit is a silique; when short it is a silicle, or pouch.

322. A pyxidium, or pyxis, is a capsule which opens with a lid, as in the plantain.

IV. FLESHY AND JUICY FRUITS.

323. The drupe, or stone-fruit.—In the plum, cherry, peach, apricot, etc., the outer portion (exocarp) of the pericarp (ovary) becomes fleshy, while the inner portion (endocarp) becomes hard and stony and encloses the seed, or "pit" (figs. 148, 153). Such a fruit is known as a drupe, or as a stone-fruit. In the almond the fleshy part of the fruit is removed.

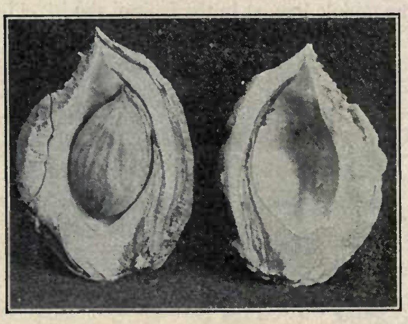


Fig. 153.
Peach pit, the hard endocarp split open, showing the embryo within.

324. The raspberry and blackberry.—While these fruits are known popularly as "berries," they are not berries in the technical sense. Each ovary, or pericarp, in the flower forms a single small fruit, the outer portion being fleshy and the inner stony, just as in the cherry or plum. It is a drupelet (little drupe). All of the drupelets together make the "berry," and as they ripen the separate drupelets cohere more or less. It is a collection, or aggregation, of fruits, and consequently they are sometimes called *collective fruits*, *multiple* or *aggregate fruits*. In the raspberry the fruit separates from the receptacle, leaving the latter on the stem, while

Olivers – gen
Be

Fig. 154.
Cluster of blackberry fruits, aggregate fruits.

Fig. 155.
Blackberry fruit, aggregate fruit; at left, the fleshy part of receptacle bearing the drupelets is removed, showing the dead and withered, persistent stamens; at the center, the fruit is cut to show the fleshy receptacle.

the drupelets of the blackberry and dewberry adhere to the receptacle and the latter separates from the stem.

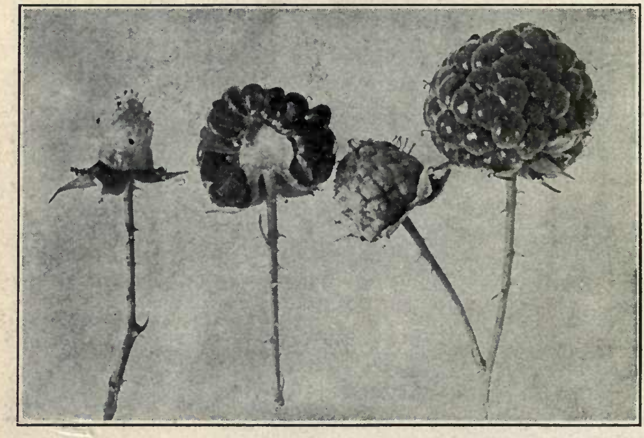


Fig. 156.
Aggregate fruit of raspberry; at left, the drupelets removed, showing the persistent receptacle.

325. The berry.—In the true berry both exocarp (including mesocarp) and endocarp are fleshy or juicy. Good examples are found in cranberries, huckleberries, currants, snowberries, tomatoes, etc. The calyx and wall of the pistil are adnate, and in fruit become fleshy so that the seeds are imbedded in the pulpy juice. The seeds themselves are more or less stony. In the case of berries, as well as in strawberries, raspberries, and blackberries, the fruits are eagerly sought by birds and other animals for food. The seeds being hard are not digested, but are passed with the other animal excrement and thus gain dispersal.

Fig. 157.
Fruit of tomato, a berry.

V. REINFORCED, OR ACCESSORY, FRUITS.

326. When the receptacle is grown to the pericarp in fruit, the fruit is said to be reinforced. The receptacle may enclose the pericarp, or the latter may be seated upon the receptacle.

Fig. 158.
Section of tomato fruit.

327. In the strawberry the receptacle of the flower becomes large and fleshy, while the "seeds," which are akenes, are sunk in the surface and are hard and dry. The strawberry thus differs from the raspberry and blackberry, but like them it is not a true berry.

328. The apple, pear, quince, etc.—In the flower the calyx, corolla, and stamens are perigynous, i.e., they are seated on the margin of the receptacle, which is elevated around the pistils. In fruit the receptacle becomes consolidated with the wall of the ovary (with the pericarp). The receptacle thus reinforces the pericarp. The receptacle and outer portion of the pericarp become fleshy, while the inner portion of the pericarp becomes papery and forms the "core." The calyx persists on the free end of the fruit. Such a fruit is called a *pome.* The receptacle of the rose-flower, closely related to the

Fig. 159.
Fruit of squash, a pepo.

apple, is instructive when used in comparison. The rose-fruit is called a " hip."

329. The pepo.—The fruit of the squash, pumpkin, cucumber, etc., is called a pepo. The outer part of the fruit is the receptacle, which is consolidated with the outer part of the three-loculed ovary. The calyx, which, with the corolla and stamens, is attached to the upper part of the ovary, falls off from the young fruit.

Fig. 160.
Section of squash fruit.

VI. FRUITS OF GYMNOSPERMS.

330. The fruits of the gymnosperms differ from nearly all of the angiosperms in that the seed formed from the ripened ovule is naked from the first, i.e., the ovary, or carpel, does not enclose the seed.

331. The cone-fruit is the most prominent fruit of the gymnosperms, as can be seen in the cones of various species of pine, spruce, balsam, etc.

332. Fleshy fruits of the gymnosperms.—Some of the fleshy fruits resemble the stone-fruits and berries of the angiosperms. The cedar " berries," for example, are fleshy and contain several seeds. But the fleshy part of the fruit is formed, not from pericarp, since there is no pericarp, but from the outer portion of the ovule, while the inner portion of the ovule forms the hard stone surrounding the endosperm and embryo. An examination of the pistillate flower of the cedar (juniper) shows usually three flask-shaped ovules on the end of a fertile shoot subtended by as many bracts. The young ovules are free, but as they grow they coalesce, and the outer walls become fleshy, forming a berry-like fruit with a three-rayed crevice at the apex marking the number of ovules. The red fleshy fruit of the yew (Taxus) resembles a drupe which is open at the apex. The stony seed is formed from the single ovule on the fertile shoot, while the red cup-shaped fleshy part is formed from the outer integument of the ovule. The so-called "aril" of the young ovule is a rudimentary outer integument.

333. The fruit of the maidenhair tree (Ginkgo) is about the size of a plum and resembles very closely a stone-fruit. But it is merely a ripened ovule, the outer layer becoming fleshy while the inner layer becomes stony and forms the pit which encloses the embryo and endosperm. The so-called "aril," or "collar," at the base of the fruit is the rudimentary carpel, which sometimes is more or less completely expanded into a true leaf. The fruit of Cycas is similar to that of Ginkgo, but there is no collar at the base. In Zamia the fruit is more like a cone, the seeds being formed, however, on the under sides of the scales.

VII. THE "FRUIT" OF FERNS, MOSSES, ETC.

334. The term "fruit" is often applied in a general or popular sense to the groups of spore-producing bodies of ferns (fruit-dots, or sori), to the spore capsules of mosses and liverworts, and also to the fruit-bodies, or spore-bearing parts, of the fungi and algæ.

CHAPTER XXI.

SEED DISPERSAL.

335. Necessity for distribution of seed.—While the formation of seed is the end towards which the energy of the plant is directed, this energy would be almost wholly misspent were there no means for the distribution of the seed over the surface of the earth. Were there no means for the natural distribution of seed, the seed would fall to the ground from the plant where it was produced. Extension of the plant over new territory would only progress so far as the branches reached. This would be tedious and very slow and would not enable the plant to multiply itself rapidly enough to maintain its hold. The present wide distribution and great variety of plant life on the globe would have been impossible.

336. To succeed in filling their place in nature plants must be in a position to throw vast quantities of seed into any territory which becomes unoccupied, or into new territory each year. Since they do not possess the intelligence of man whereby they might discover unoccupied territory and bend their energies to placing their seed there, it is necessary that vast quantities of seed be produced each year, and left to the natural means of distribution. In this way plants are sending out seed every year in all directions, so that it may be ready to produce new plants whenever opportunity offers.

337. Natural means for distribution of plants.—The natural means for the distribution of plants over the earth is a subject of great interest and importance, and should have due consideration in the study of plants. While studying seeds and fruits in the laboratory especial attention should be given to those structures and peculiarities which assist in the distribution of the seed. In excursions to the fields, forests, or parks, instructive examples are often met with. Most plants are distributed according to natural ways by means of seeds, or the seedless plants by spores (see Chapters XXIII–XXIX). Some seedless plants, however, are distributed also by buds (*Lycopodium lucidulum*, paragraph 514, certain ferns as *Cystopteris bulbifera*, paragraph 496), and some by plant parts, and some seed plants are distributed by other means than by seed. The best means, however, for natural distribution of the seed plants is by the seed. There are several natural means by which the seeds are dispersed, the most important of which are as follows: first, by the wind; second, by animals; third, by water; fourth, by mechanisms of the fruits for the forcible expulsion of seeds.

338. Dispersal of seeds by the wind.—Many seeds which are small and light are often blown by the winds for considerable distances without having any special provision in the nature of floats or wings. The seeds of many grasses and other herbs are very light and in strong gales are driven far, and when they fall on rather hard loose ground may from time to time be driven along just as particles of soil are. There are many seeds or fruits, however, which are provided with special appendages which serve as floats, or as surfaces, which " catch " the wind and enable them to be borne along. Of the winged seeds notable examples are seen in the samaras of the elm, where a thin membranous outgrowth attached to the seed renders the seeds buoyant, or the wing is firmer as in the blades of the maple or pine. In the milkweed the flattened brown seeds are packed in great numbers and very regularly in the large pods, and each seed has a large tuft of long, white, delicate, hair-like outgrowths. These hairs are packed very closely together in the pod. As the pods split open the hairs become dry, and in curling take up much more room, thus crowding the seeds out of the capsule, when they are caught by the wind and floated away. To show how buoyant they are, such seeds may be set free in the quiet air of a room, and they will float slowly to the floor. In the Virginia creeper, or virgin's bower, the long curved style remains attached to the akene and is covered with numerous delicate bristles. The style when dry is more or less spiral, and the seeds whirl in a peculiar fashion as they fly through the air. The akene which contains the seed is heavier than the feathery style, and as it falls to the ground the end which contains the radicle is brought next the ground, so that the chance of germination and the establishment of the seedling in the ground is favored. Striking examples are seen in the "seeds" or akenes of many of the composite flowers like the dandelion, thistle, prickly lettuce, etc. Here the hairy pappus on the end of a long beak provides for the floating of the fruit, its action being much like that of a parachute as the akene slowly comes to

Fig. 161.
Dandelion seeds.

the ground "right side up," i.e., with the radicle of the embryo downward. In the dandelion the flower stem elongates just as the seed is ripening, so that the head is lifted up where the currents of air readily reach it. The bristles of the pappus in many composites, at first straight, turn out at nearly right angles, like the spokes of a tiny wheel, so that it is more effective as a float. The so-called "tumble weeds" are rolled on the ground by the wind to great distances, and the seeds are scattered by the way. Some of these are the light, much branched grasses, which when ripe and dry are broken off by the wind and swept along on the ground. The "resurrection" plant (*Lycopodium*) is another example of a plant which is distributed by the wind. As it dries up during droughts it curls into a rounded mass, the roots are torn from the ground, it rolls along in the wind, and with the advent of rains takes root and grows again.

Fig. 162.
Lactuca scariola.

339. Dispersal of seeds by animals.—In general there are two ways in which animals distribute seeds: first, by eating the fruits; second, by seeds which cling to their bodies. *Edible seeds and fruits.* In the case of small seeds or grains which are eaten by animals not all the seeds are crushed and some pass through the alimentary canal unharmed. In the case of fruits eaten by animals many have small seeds with hard seed coats, and very few of these seeds are crushed. The hard seed coats further protect the embryo from the solvent action of gastric juices, while in the case of some seeds it is believed that they germinate better after being subjected to the action of various substances while passing through the alimentary canal of birds, etc. Fruits like the raspberries, blackberries, grapes, cedars, are eaten by birds and other animals and the seeds deposited often far away from the place where they were grown. Many such fruits have bright colors and attractive flavors at the time of ripening. *Grapplers on seeds and fruits.* These are well known to nearly all persons who tramp the fields or forest, and may also be "picked up" along the highways and in gardens. Hooks or barbs are produced on parts of the fruit which cling tenaciously to rough soft objects coming in contact with them. Common among these are the "beggar ticks," the akenes of one of the composites (*Bidens*), which have barbs on the two lateral prongs at one end of the flattened fruit. In some sections these are called "devil's bootjack." Slender

Fig. 163.
Fruit of burdock (Arctium lappa).

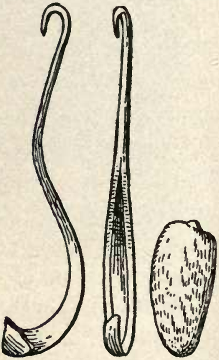


Fig. 164.
Hooks and akene of burdock.

akenes of the same genus are called "Spanish needles." The oval fruit of the "cockle-bur" is covered with long hooks. In the "burdock" the numerous bracts, surrounding the head containing the numerous akenes, are extended into a long slender process terminating in a hook. The "sticktights," or "tick trefoil," are sections of the pod of a leguminous plant (*Desmodium* = *Meibomia*) which are covered with numerous hooks. In the various species of avens (*Geum*) the long style of the akene is jointed near the end and curved into a hook. It separates at the joint, leaving the hook on the long beak (fig. 167). Besides the seeds provided with grapplers many seeds adhere with mud to the feet of animals, and in the case of birds are often transported to great distances, especially by wading birds and waterfowl.

340. Dispersal of seeds by water.—Streams have long been recognized as lines for the transport and centers of distribution of seeds. Some seeds because of their light weight and slightly impervious coats float for long distances on the water. Others which may sink are swept along in the strong current. Even on high ground, many seeds are carried to considerable distances by the "run-off" water during heavy rains. Seeds are distributed also along the shores of ponds and lakes as they float on the water which is moved by winds. Also along the shores of the ocean the

Fig. 165.
Fruits of tick trefoil (Desmodium).

seeds of many coastal plants are distributed to great distances by the ocean currents. It has been found that many seeds will retain their vitality after immersion in the salt water of the ocean for three or four weeks, and some will germinate after prolonged immersion. Darwin has shown by experiment that about fourteen per cent of the seeds of British plants will bear immersion in sea water for four weeks and still germinate. The distribution of certain plants on near-by islands, or in some cases on islands quite remote, is sometimes explained by the ability of the seeds to bear the prolonged soaking of an ocean voyage from one shore to another.

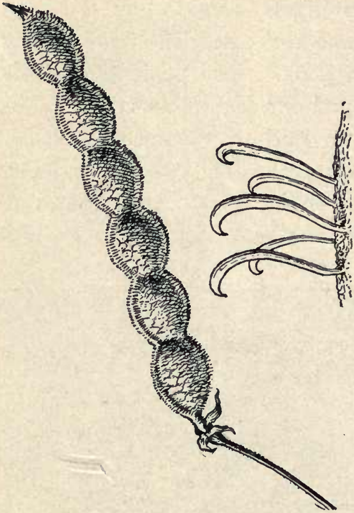


Fig. 166.
Seed pod of tick trefoil (Desmodium); at the right some of the hooks greatly magnified.

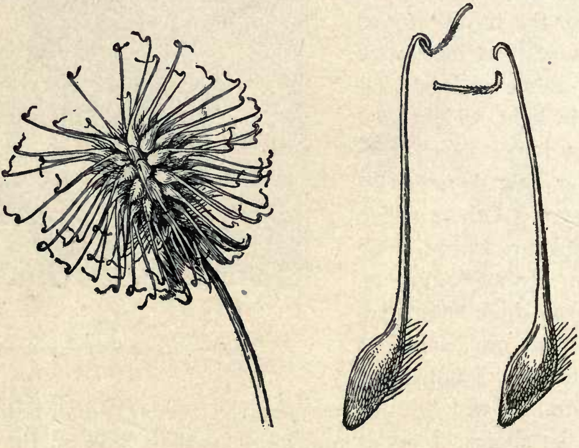


Fig. 167.
Seeds of Geum showing the hooklets where the end of the style is kneed.

341. Dispersal of seeds by expulsion.—The seeds of many plants are thrown for short distances by the sudden explosion of the capsules, or by pressure which squeezes them out in such a way that they are suddenly released. The valves of the pods in the common vetch (one of the wild peas), as they dry, are brought into a spiral tension so that they suddenly split apart and curl, thus throwing out the peas. In the "touch-me-not" (Impatiens) the valves of the pod are also in tension, and when touched or jarred they split and curl with sudden force, scattering the seeds. In others, as in the witch hazel and violet, the pod splits open and the valves squeeze from behind in such a way as to force the seeds out in much the same manner that many a child shoots watermelon or apple seeds by squeezing them from between the thumb and finger. The "squirting cucumber" is so called because by the absorption of water a pressure is produced which squirts out the seeds.

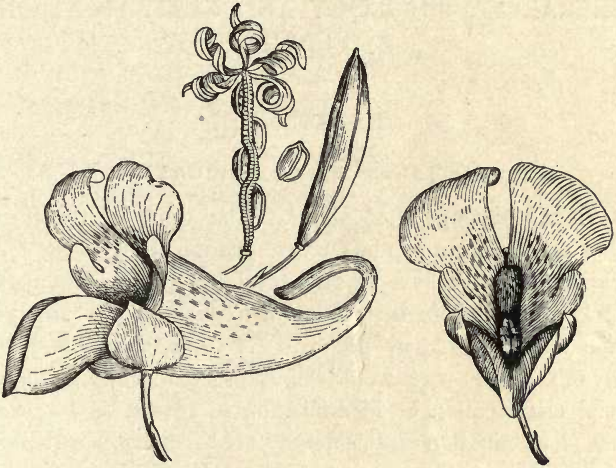


Fig. 168.

Touch-me-not (Impatiens fulva); side and front view of flower below; above unopened pod, and opening to scatter the seed.

PART II.

GENERAL MORPHOLOGY AND CLASSIFICATION OF PLANTS.

CHAPTER XXII.

OUTLINE OF CLASSIFICATION.

342. Morphology * of plants is the study of the forms of plants and the form of plant parts. In the study of the life and work of plants we have studied the form of the plant parts (of the higher plants) in their relation to function, i.e., in relation to the work which they perform. A more critical and minute study of the plant parts would be necessary in connection with the special classification or identification of plants, as for example in the determination of the flowers. In general morphology we study the more general types of form under which the plant parts appear. In *comparative* morphology we study the form of the same organ or plant part in different plants, even in those of very remote relationship, in order to recognize organs of the same kind under different guises, and to trace the evolution of plant organs in order to acquire a clearer knowledge of the broader relationships existing among all plants.

343. Classification.—Classification is the arrangement or classifying of objects or ideas in an orderly and intelligible manner, in such a way that those of one special kind or general kind are grouped together. The classification of plants, then, is the arrangement of plants according to the kinds, or according to the relationships, into larger or smaller groups according to the grade of relationship and the number of plants of any one kind. For

---

* *μορφή*= form, *λόγος*= discourse.

work will permit the discussion of but a few. It may be convenient to precede this study with a brief outline of a general classification including the divisions of a higher grade, since it is only the more general features of morphology and relationship which come within the scope of this work.

PLANT KINGDOM.

SUBKINGDOM I. **Thallophyta.**

THE ALGÆ.

Class I. Chlorophyceæ.
  Subclass Protococcoideæ.
  Subclass Conjugatæ.
  Subclass Confervoideæ.
  Subclass Siphoneæ.
Class II. Charophyceæ.
Class III. Cyanophyceæ.
Class IV. Diatomeæ; or Bacillariales.
Class V. Phæophyceæ.
Class VI. Rhodophyceæ.

THE SLIME MOLDS.

Class VII. Myxomycetes.

THE BACTERIA.

Class VIII. Schizomycetes.

THE FUNGI.

Class IX. Phycomycetes.
Class X. Ascomycetes.
Class XI. Basidiomycetes.

SUBKINGDOM II. **Bryophyta.**

THE LIVERWORTS.

Class XII. Hepaticæ.

THE HORNED LIVERWORTS.

Class XIII. Anthocerotes.

THE MOSSES.

Class XIV. Muscineæ.

SUBKINGDOM III. **Pteridophyta.**

THE FERNS.

Class XV. Filicineæ.

THE HORSETAILS.

Class XVI. Equisetineæ.

THE CLUB MOSSES.

Class XVII. Lycopodineæ.

THE QUILLWORTS.

Class XVIII. Isoetineæ.

SUBKINGDOM IV. **Spermatophyta.**

THE NAKED SEED PLANTS.

Class XIX. Gymnospermæ.

THE ENCLOSED SEED PLANTS.

Class XX. Angiospermæ.

CHAPTER XXIII.

ALGÆ.

347. The algæ are plants of a low grade of organization. They live in the water, or a few of them in moist situations. Those growing in the sea are popularly called "sea mosses," while those growing in fresh water are called "pond scums," "water nets," etc. It should be understood that the algæ are not true mosses. They are all simpler in structure and lower in the scale of classification than the mosses. The simplest algæ are single-celled plants. From this simple condition single individuals or cells are easily associated into colonies, or firmly united into filaments, or cell plates, which reach massive size in the rockweeds and kelps.

348. The plant body of the algæ thus varies greatly in size as it does in form. The plant body of the algæ is not divided into true stems, roots, and leaves. There are, it is true, algæ which possess root-like, stem-like, and leaf-like organs, but they do not belong to the same part in the plant's life cycle that the true roots, stems, and leaves of the ferns and seed plants do. For this reason they are not regarded as true roots, stems, or leaves from the standpoint of comparative morphology, although from the standpoint of physiology or *function* such algæ possess stems and leaves. Such a plant body, which is not differentiated into true roots, shoots, and leaves, is called a *thallus*. The plant body of the algæ as well as of the fungi is a thallus. They are characteristically the thallus plants or *Thallophytes*.

The algæ possess chlorophyll * and are thus able to live inde-

---

* There are a few parasitic algæ which lack chlorophyll, and their method of nutrition is similar to that of the fungi, although some of them store starch which they obtain from their green host. Example, *Rhodochytrium*, parasitic on the ragweed in North Carolina, and probably other Southern and Atlantic States, and on one of the milkweeds in Kansas.

pendently of other plants. They obtain their mineral and nitrogenous foods from the water, while they fix the carbon from the carbonic acid absorbed from the water, in the presence of the chlorophyll and sunlight.

The characters of structure and reproduction should be studied in connection with the individual plants.

GREEN ALGÆ * (CHLOROPHYCEÆ).

The Conjugating Green Algæ (Conjugatæ).

349. Spirogyra.—The plant spirogyra lives in fresh water in ponds, the borders of lakes, or in pools. Sometimes it is found in very slow-running water. It is in the form of simple threads or filaments which may be quite long and are unbranched. Large numbers of these threads are tangled together into a mat which floats in the water. Much gas which is given off during photosynthesis is caught in the meshes of the tangle, buoys the mat of the alga up to the surface of the water where the light is more efficient, and gives the plant a frothy appearance, which suggested such names as "pond scum," "frog spittle," etc. The threads are made up of cells which are cylindrical in form and

Fig. 169. Spirogyra before placing in salt solution.

Fig. 170. Spirogyra in 5 per cent salt solution.

---

* To the Teacher. The number of green algæ studied must be determined by the teacher, and will depend to some extent on the time, the facilities, and material at hand. If only one is studied carefully it preferably should be Spirogyra. If two, then Vaucheria or Œdogonium should be included because of the differentiation of the sex organs. In more advanced classes the shield Coleochæte might be included. In addition to laboratory work, such portion of the text should be studied as the teacher finds time and adaptability of the pupils will permit. The general features of the plant body, the progression from single cells to threads and cell plates, the general features of sex organs and their differentiation into two kinds, as well as the life cycle, should always be kept foremost.

joined end to end. These threads are delicate and silky in appearance and somewhat slimy to the touch when lifted by the hand.

350. The spirogyra cell.*—The thread of spirogyra is composed of similar cells, and a study of one cell is sufficient to show the structure of all in the vegetative or growing stage. The most prominent part of the cell is the chlorophyll body, which is in the form of a spiral band and lies next the inside of the cell wall coiled around in the cell. The band is more or less irregular along the edges. The number of these chlorophyll bands in a cell varies in the different species from one to five or six, while in a given species the number may vary from one to two, in another from two to three, and so on. At quite regular intervals in the chlorophyll band there is a round shining nodule-like body called a *pyrenoid*. The pyrenoid is peculiar to the algæ, being found in many of them. Outside of the algæ it is found only in a few species of liverworts. The pyrenoids are probably reserve food products of a proteid nature. The pyrenoid in spirogyra is often surrounded by a layer of fine starch grains. Near the center of the cell is a large body of a more or less granular nature and colorless. This is the *nucleus* of the cell. It is elliptical to convex in form or in outline as seen in profile in some species, and angular in others. Within each nucleus is a *nucleolus* (sometimes two or three nucleoli). In the living cell these usually appear more dense than the substance of the nucleus and highly refringent. The protoplasm of the cell is a viscid granular substance forming a thin layer next the wall which is connected by strands of the same substance which radiate out from a granular layer surrounding the nucleus. These strands can be distinctly seen, as they radiate out from the angles of the nucleus, and divide into more slender strands which terminate in the wall layer of protoplasm at a point where the pyrenoid is located in the band. The spaces between the strands, which here are quite large, are filled with a watery fluid, the cell sap. The term protoplasm was earlier used to include the nucleus, which was supposed to be only a denser

---

* This paragraph is chiefly for reference, but advanced classes may be able to include it.

portion of it. Now the nucleus is known to be a distinct organ of the cell, while the protoplasm proper is called the *cytoplasm*, i.e., the *cell plasm*. Strictly speaking the cytoplasm shows two different conditions or kinds, a very thin outer layer next the wall, which is homogeneous, the *ectoplasm*, and the inner portion, of a granular nature, the *endoplasm*. The structure of the cell of spirogyra might be recapitulated as follows:

- Cell
  - Cell wall
  - Chlorophyll band or Chloroplast
    - Sphere of starch grains
    - Pyrenoid
  - Protoplasm in old sense
    - Cytoplasm
      - ectoplasm
      - endoplasm
      - Wall layer
      - Nuclear layer
      - Strands
    - Nucleus and nucleolus
    - Vacuoles containing cell sap

351. The structure of the spirogyra cell represents fundamentally the structure of all living cells in the resting condition, i.e., when the cell is not dividing. The chlorophyll is absent in many cells, and so are the pyrenoid and starch grains. But the cytoplasm, the vacuoles, the nucleus and nucleolus are present in all living cells. The cytoplasm, nucleus and nucleolus constitute the *living substance* of the cell. By reference to fig. 171 of the amœba, a single-celled animal, these important parts of the cell are seen to be present.

352. Plasmolysis of the cell.* —The plant spirogyra is an excellent one in which to study certain work of the cell. In the

---

* This subject might well be introduced in connection with the study of methods for strengthening the stem and leaves or in the study of absorption by roots. It is introduced here for the reason that spirogyra is much easier to use than the tissues of the higher plants because no sections are necessary. Also it is convenient in connection with the study of spirogyra as a plant. The paragraph is chiefly for reference.

normal condition of working cells they are in a condition of *turgor*, that is, they are in a state of tension produced by inside pressure. This makes the cell *plump*, as one might say, or *firm*. When cells are united together in masses as in vegetables, in leaves, or in succulent stems, all of the cells being in a state of turgor, these parts of the plant are firm and held in position. If the cells lose their turgor the tissues become limp or wilted. The inside pressure (or endosmotic pressure) is due to the presence of certain salts, sugars, etc., in the cell sap which are separated from the water outside of the cell by the cell wall and the wall layer or membrane of protoplasm (or more strictly speaking by the ectoplasm). Since the water outside has no salts in it, or if present they are in a less concentrated form than those in the cell sap, the water moves more readily through the plasma membrane into the cell sap than it can move outward. The inside pressure presses the plasma membrane firmly against the cell walls. The cell wall being elastic, yields slightly and thus is pressing in the opposite direction against the plasma membrane. This produces the state of turgor in the cell. The opposite condition of turgor in the cell is *plasmolysis*, or shrinking of the plasm. This can be produced artificially by mounting some threads of spirogyra in a five per cent solution of common table salt, or in a strong sugar solution. This solution being of a greater concentration than that of the cell sap, the flow of the water is now in the outward direction through the plasma membrane, and this is pressed inward from

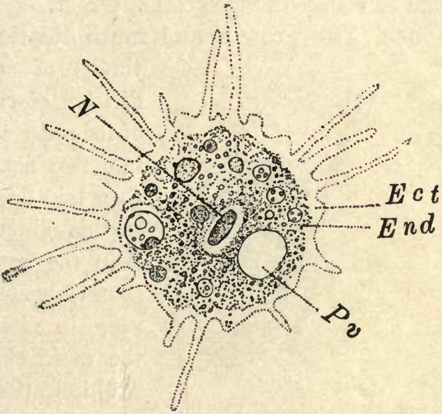


Fig. 171.

Amœba, showing pseudopodia. — *Ect.* ectoplasm, *End.* endoplasm, *N.* nucleus, *Pv.* pulsating vacuole. (After Claus.)

the cell wall, as shown in fig. 170. It often takes place so regularly that the contents of the cell are collected into a well-defined sphere or elliptical body inside the cell. Now if the salt solution be removed and fresh water added, the movement of water will be inward again, the cell will recover from the state of plasmolysis and be restored to the state of turgor.

353. The growth and multiplication of spirogyra.—The thread of spirogyra grows by the division of cells and then elongation of the cells. The nucleus divides first into two nuclei and a cross wall is then laid down between them. The two daughter cells are at first shorter than the parent cell, but each one soon elongates. This process taking place in all of the cells brings about the rapid elongation of the thread. Multiplication of the threads takes place by the separation of a single thread into several shorter ones, the thread breaking at a cross wall, by the splitting of the cross wall, so that the cell is not injured. Strong inside pressure, which sometimes results by a change in the water, often causes this separation of the threads.

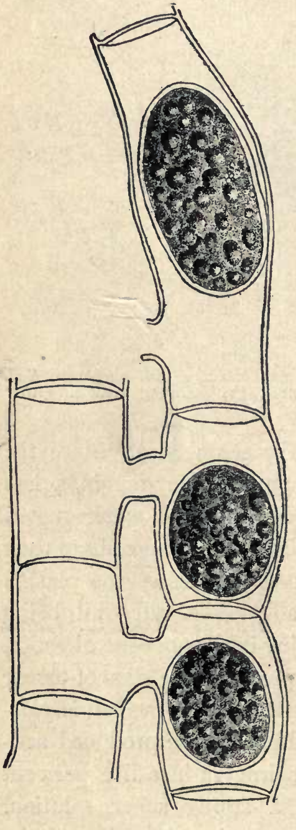


Fig. 172.
Zygospores of spirogyra.

354. Reproduction by conjugation.—Sexual reproduction in spirogyra takes place by a process known as *conjugation*. When the conditions are favorable two threads lying near each other conjugate by tubes developed from opposite cells. The tubes meet and the walls at the point of contact dissolve, making an open communication between the two cells. This is the conjugation tube, and where two conjugating threads lie side by side for some distance the conjugation of the opposite cells presents a ladder-like figure. The protoplasm from one of the cells flows over through the tube into the cell opposite, carrying with it the chlorophyll band and all of the cell contents, but some of the water is lost. The merged contents of the two cells now contract into a rounded or elliptical body called the *zygospore*, or *zygote*, as shown in fig. 172. A thick and firm wall is formed and much of the protoplasm is changed into an oily substance, in which condition it is more resistant to unfavorable conditions of dryness or cold. The two nuclei fuse into one nucleus. The fusion of the cell contents and fusion of the nucleus of the two gametes into one is known as *fertilization*. The zygospore is a resting spore and serves to carry the plant over unfavorable conditions or periods of weather.

355. The gametes and gametangia.—The cell in which the zygospore is formed is the *receiving* cell, while the other one is the *supplying* cell. Each conjugating cell is a *gametangium* (i.e., a gamete case), and the portion of its content which takes part in the formation of the zygospore is a *gamete*. When one cell of a thread in ladder-like conjugation is a receiving gamete, all the others of the same thread are also receiving gametes. All the cells of a single thread are likewise supplying gametes. Usually there is no difference in the size of the supplying and receiving cells, and it is impossible to say what the nature of the gamete is until movement of the protoplasm from the supplying gamete is taking place. While the sex of the threads appears in these cases to be distinct, there is no differentiation in the size and form of the egg

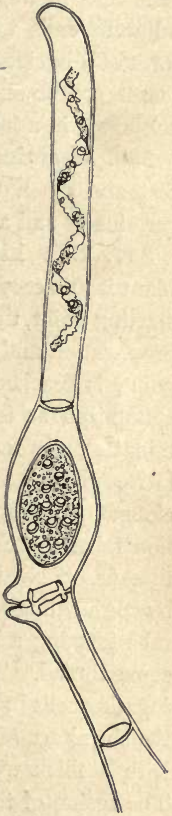


Fig. 173.

Spirogyra, showing conjugation by a buckle joint between two adjacent cells of the same thread.

and sperm, the receiving gamete corresponding to the egg or female cell, while the supplying gamete corresponds to the sperm or male cell. There are some species, however, in which adjacent cells in the same thread conjugate by lateral tubes at the adjacent ends which bend toward each other and fuse in the form of a buckle joint (fig. 173). Evidently here the two sex elements are present in a single thread. These species may also conjugate in a ladder-like manner.

356. Germination of the zygospore.—After a period of rest and when the conditions become favorable the zygospore germinates and a new thread is developed from the fertilized egg.

357. Life history of spirogyra.—The life history of a plant is an account of its development from the egg, or from some starting point, through its different forms, including the means for propagation and reproduction, until the egg, or the same starting point, is reached again. The life history of spirogyra may be epitomized as follows. The zygospore (the fertilized egg) germinates and produces the plant in its filamentous form, the vegetative phase. Growth and increase take place by division and elongation of any or all of the cells. Propagation or multiplication takes place by the breaking up of the threads into separate threads. Sexual reproduction takes place by conjugation, either by conjugating tubes between cells of two distinct threads, or by a tube forming a buckle joint connecting two adjacent cells of the same thread. The zygospore is formed in one of the two conjugating cells by the fusion of the contents of the two cells into one, the shrinkage of this mass from the wall forming a rounded body with a thick wall within the female gamete case, or egg case. The fusion of the two nuclei in the zygospore completes the process of fertilization of the egg which passes through a resting stage. The life history is sometimes spoken of as a *life cycle*. It may be represented by the diagram or by the following formula: *

$$\text{Plant, veg.} \begin{array}{l} \nearrow \text{male gamete} \searrow \\ \searrow \text{female gamete} \nearrow \end{array} \text{zygospore} = \text{fertilized egg} \rightarrow \text{Plant, etc.}$$

---

* This formula, and those which follow other groups of plants, are not to be memorized by the pupil. It is simply presented to serve as a graphic representation of the life cycle.

This formula may be abbreviated by the use of signs as follows: $P - P - P - \left\langle\begin{matrix}g\\g\end{matrix}\right\rangle E \rightarrow P$, etc., in which P stands for plant and its repetition indicates multiplication of the plant from similar parts, not by means of special reproductive or propagative bodies; g = gamete, E = the fertilized egg, zygospore or oöspore, as it is called in special cases.

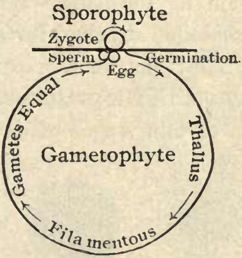


Diagram No. I. Illustrating the life cycle in the development of Spirogyra. Course of development follows the direction indicated by arrows. Zygote equals fertilized egg, which in this case is the zygospore.

358. Zygnema.—*Zygnema* is another genus of filamentous algæ closely related to *Spirogyra*. It differs chiefly in the form of the chlorophyll bodies. These are star-shaped and two in a single cell. The nucleus in the cell is not so conspicuous. Growth, multiplication and conjugation take place as in *Spirogyra*. The life history follows the same course and the plant is found under similar conditions.

359. The desmids.—The desmids form another family of conjugating algæ. They are mostly single-celled plants of very beautiful form and markings, while a few of them unite into filaments. They occur in fresh water, often mingled with spirogyra and other green algæ. The single-celled forms are bisymmetrical, each half being exactly like the other. They multiply by dividing so as to separate these two halves, and each half then reproduces a new one in place of the lost half. They conjugate by the protoplasts (the cell content) from two cells separating from the cell wall and uniting to form a zygospore which is thick-walled and often beautifully sculptured.

SINGLE-CELLED GREEN ALGÆ (PROTOCOCCOIDEÆ).

360. Pleurococcus.*—This plant is a representative of the single-celled green algæ. It is often found growing on the north or shaded side of trees, rocks, walls, etc., forming a thin green layer. The green mass is made up of numerous green cells, single or in groups of two, three, or four. These groups are formed by the division of the single cells, the new cells, or "daughter" cells, remaining attached for a time before separating. Sexual reproduction is not known.

361. The red snow plant, Hæmatococcus.—This is a single-celled plant which, in certain stages of development, contains a red pigment which disguises the color of the chloroplast. It is often found covering large tracts of snow in arctic regions. A very closely related species, if not the same, inhabits the shores of lakes, ponds, and streams in rocky areas of the North Temperate region. It is often found in shallow depressions of rock along the shore, where in dry weather it resembles a coat of dull red paint on the rocks. The plant is now in the resting stage. When rains come the plants revive, come out of the resting state, are provided with two long lashes or whips (cilia or flagella)

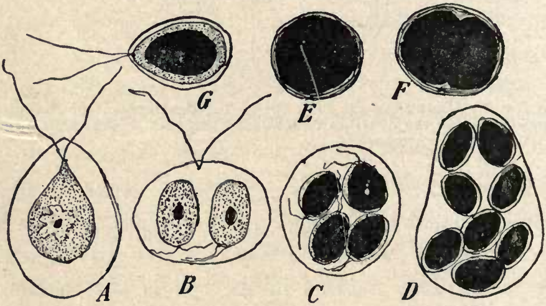


Fig. 174.

Sphærella lacustris (Girod.) Wittrock. *A*, mature free-swimming individual with central red spot. *B*, division of mother individual to form two. *C*, division of a red one to form four. *D*, division into eight. *E*, a typical resting cell, red. *F*, same beginning to divide. *G*, one of four daughter zoöspores after swimming around for a time losing its red color and becoming green. (After Hazen.)

---

* Pleurococcus vulgaris = Protococcus vulgaris.

which lash about and cause the plant to swim rapidly around in the water. In the swimming stage the plant is green, the chlorophyll usually not being obscured by the red pigment. As the small pools dry out the swimming plant passes again into the resting stage and acquires the red pigment.

362. Single-celled green algæ in colonies.—The single-celled algæ just described lead an independent or individual existence. There are others in which the individuals are associated in definite colonies. Some of these are motile during their vegetative existence as in *Pandorina morum.* This is a colony of sixteen like individuals arranged in the form of a sphere enclosed in a thin gelatinous sheath, each oval individual with a pair of cilia projecting beyond the sheath. The vibration of the cilia causes a rapid rotary motion of the sphere. The colony multiplies by each individual dividing into sixteen small individuals. The small colonies separate from the parent and grow to the normal size. Sexual reproduction takes place when these small individuals separate and conjugate in pairs, usually a small one with a large one, producing a zygospore. Some of the colony algæ are non-motile as in the water-net (*Hydrodictyon*).

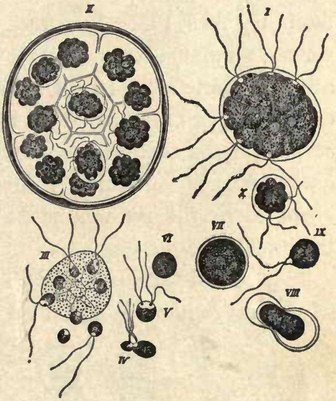


Fig. 175.

Pandorina morum (Müll.) Bory. I, motile colony; II, colony divided into 16 daughter colonies; III, sexual colony, gametes escaping; IV, V, conjugating gametes; VI, VII, young and old zygospore; VIII, zygospore forming a large swarm spore, which is free in IX; X, same large swarm spore divided to form young colony. (After Pringsheim.)

FILAMENTOUS GREEN ALGÆ.

The Confervas (Confervoideæ).

363. General characters.—The larger number of these algæ are thread-like, either simple or branched. Some of the marine forms are leaf-like, as the "sea lettuce." The chlorophyll is in small, oval, flattened chloroplasts. They multiply by the formation of special bodies from the protoplasm of individual cells. These bodies are called spores, and are provided with cilia so that they swim about in the water after escaping from the parent cell. They are thus called "*swimming spores*," "*zoöspores*," or "*zoögonidia*." These spores are not formed as the result of a sexual process. The process is an *asexual* one, hence they are often termed *asexual* swimming spores. Sexual reproduction takes place in some by the fusion of two swimming spores, similar to the asexual spores, forming a zygospore. In others definite sexual organs are formed, a large one, the female organ, an egg case (called an *oögonium*), which contains the *egg* or *oöspore;* and a smaller one, the male organ, a sperm case (called an *antheridium*), containing a number of small motile male cells, the *sperms*. Fertilization in these results from a fusion of a sperm with the nucleus of the egg.

364. Ulothrix.—*Ulothrix* is an example of the first kind of sexual reproduction described above. The plant forms simple threads. In asexual reproduction a number of small, oval, 4-ciliated swimming spores are formed from the protoplasm of a single cell. These escape, and after the swimming period come to rest, germinate and produce the *Ulothrix* thread again. In sexual reproduction similar biciliate swimming spores are formed which unite in pairs to form zygospores (fig. 176). *Cladophora*, *Chætophora*, *Drapernaudia*, etc., are branched forms with a similar method of reproduction.

Fig. 176.

Ulothrix zonata. *A*, base of thread. *B*, cells with zoöspores, *C*, one cell with zoöspores escaping another cell with small biciliate gametes escaping and some fusing to form zygospores; *E*, zoöspores germinating and forming threads; *F*, *G*, zygospore growing and forming zoöspores. (After Caldwell and Dodel.)

365. Œdogonium.—*Œdogonium* is an example of the second kind of sexual reproduction. The thread-like plant is simple. It grows in length by the repeated division of certain cells, the marks of the successive divisions remaining on the cell wall near one end, giving a peculiar appearance as in fig. 177. In asexual reproduction the content of a cell forms a single large zoöspore or swimming spore, with a crown of cilia near one end. After escaping from the parent cell and swimming around it comes to

Fig. 177.

Portion of thread of œdogonium, showing chlorophyll grains, and peculiar cap cell walls.

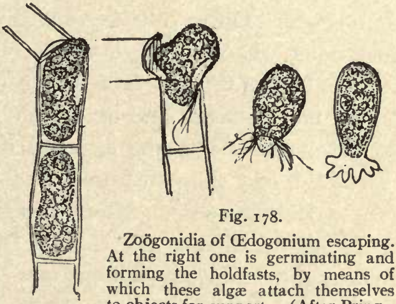


Fig. 178.

Zoögonidia of Œdogonium escaping. At the right one is germinating and forming the holdfasts, by means of which these algæ attach themselves to objects for support. (After Pringsheim.)

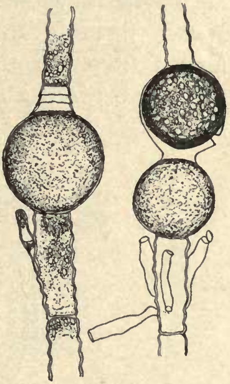


Fig. 179.

Œdogonium undulatum, with oögonia and dwarf males; the upper oögonium at the right has a mature oöspore.

rest, attaches itself to a place of support by a disk-like grappler, and grows into another *Œdogonium* thread. In sexual reproduction certain cells become transformed into female organs by becoming enlarged and rounded. This enlarged cell is the egg case (*oögonium*, or egg producer), and contains a single large egg or oöspore. Other cells become divided into smaller cells by cross walls. Each of these small cells is a male organ, the sperm case (*antheridium*). The sperms are like the swimming spores, but much smaller and devoid of chlorophyll. One enters an egg case, passes into the egg and unites with the nucleus. The fertilized egg (oöspore) then acquires a thick wall and becomes a resting spore. After a period of rest the protoplasm of the fertilized egg forms four zoöspores, each of which can grow into an *Œdogonium* plant, thus completing the life cycle. In some species both the sperm case and egg case are on the same thread, while in other species they are on separate threads. In still others small male plants are first formed from a special swimming spore intermediate in size and color between a zoöspore and sperm.

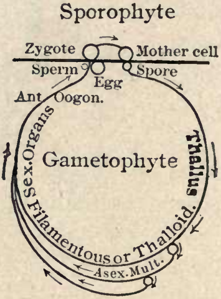


Diagram No. II. Illustrating the life cycle in the development of Œdogonium. Course of development follows the direction indicated by arrows. Zygote equals fertilized egg. Asexual multiplication by asexual spores.

366. Coleochæte.—*Coleochæte* represents the highest stage of development of the filamentous green algæ. The plants occur in fresh water attached to larger aquatic plants. They are mostly filamentous and branched, but a few form small,

Fig. 180.
Stem of aquatic plant, showing Coleochæte, natural size.

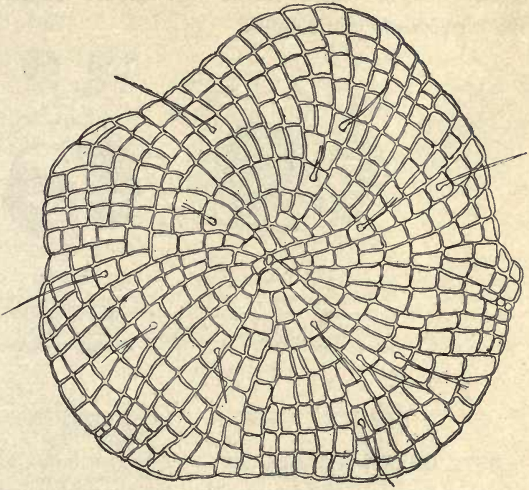


Fig. 181.
Thallus of Coleochæte scutata.

flattened, more or less circular cell plates. Asexual reproduction is by biciliate zoöspores, one each from a parent cell. In sexual reproduction sperm cases are formed in groups of four, each one producing a small biciliate sperm. The egg cases (oögonia) are large and possess a long slender beak called a *trichogyne.* The sperm becomes attached to the trichogyne; its nucleus moves down the tube, enters the egg and fuses with the nucleus of the egg. The egg after fertilization becomes surrounded by an envelope of branches growing from cells adjacent to the egg case, and then passes through a resting stage. When it germinates it produces a small mass of

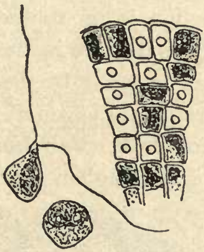


Fig. 182.
Portion of thallus of Coleochæte scutata, showing empty cells from which zoöspores have escaped, one from each cell; zoöspores at the left. (After Pringsheim.)

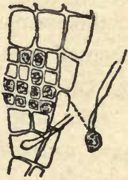


Fig. 183.
Portion of thallus of Coleochæte scutata, showing four antheridia formed from one thallus cell; a single sperm at the right. (After Pringsheim.)

cells, each of which forms a zoöspore capable of producing the *Coleochæte* plant again.

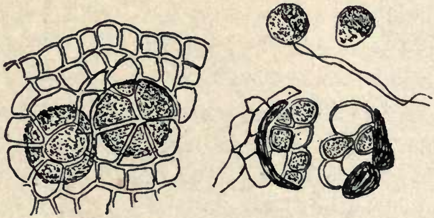


Fig. 184.
Two sporocarps still surrounded by thallus. Thallus finally decays and sets sporocarp free.

Fig. 185.
Sporocarp ruptured by growth of egg to form cell mass. Cells of this sporophyte forming zoöspores.

Figs. 184, 185. C. scutata.

SIPHON GREEN ALGÆ (SIPHONEÆ).

367. General characters.—The siphon algæ are mostly filamentous and branched, but are characterized by the absence of cross walls in the vegetative threads, or by few such walls. The threads are thus like a *siphon* or tube. There are many nuclei in the protoplasm of a single thread or compartment. The chlorophyll bodies are numerous, small, oval, flattened bodies. Asexual reproduction is by zoöspores, or in some cases by non-motile spores. Sexual reproduction is either by the conjugation of small motile gametes, or by the special organs, the sperm and egg cases (antheridia and oögonia).

368. The green felts (Vaucheria).—The "green felts" are good examples of the siphon algæ. They occur in fresh-water

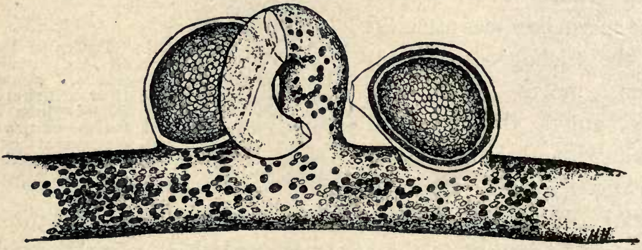


Fig. 186.
Vaucheria sessilis, one antheridium between two oögonia.

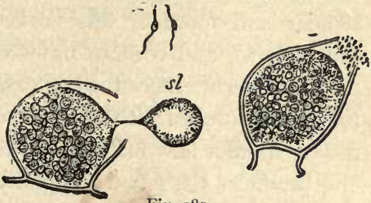


Fig. 187.
Vaucheria sessilis; oögonium opening and emitting a bit of protoplasm; sperms; sperms entering oögonium. (After Pringsheim and Goebel.)

ponds, lakes, streams, or on damp soil. The threads are long, branched, and continuous, that is without cross walls except where reproductive organs or cells are formed. The plants usually form dense mats of a coarse consistency and are known as "green felts," because of the felted consistency of the mats. Asexual reproduction is by large spores formed from the protoplasm in the ends of the threads separated by a cross wall. Some of these spores are motile, with numerous pairs of cilia over the surface, while others are non-motile. These spores escape from the enclosing cell wall. In sexual reproduction specialized short branches are formed, which are separated from the parent wall

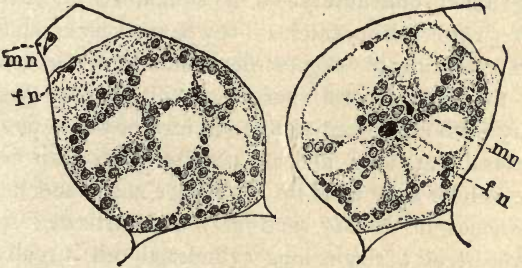


Fig. 188.
Fertilization in Vaucheria. *mn*, male nucleus; *fn*, female nucleus. Male nucleus entering the egg and approaching the female nucleus. (After Oltmanns.)

Fig. 189.
Fertilization of Vaucheria. *fn*, female nucleus; *mn*, male nucleus. The different figures show various stages in the fusion of the nuclei.

by cross walls. Some of these become broadly oval and form the egg cases (oögonia), each with a single egg. Others are slender and more or less curved. These are the sperm cases (antheridia), and contain numerous biciliate sperms. In fertilization a sperm enters the egg case at the opened end, passes into the egg and unites with one nucleus at the center. A thick-walled resting spore is now formed, the oöspore, which in turn germinates and produces the green-felt plant again.

STONEWORTS, OR BASS WEEDS (CHAROPHYCEÆ).

369. General characters.—The stoneworts or bass weeds occur in fresh or brackish water. They have a very complex organization, representing the highest development of the green algæ, and only the most general characters will be given here. The plants vary from a few centimeters (an inch or so) to more than a meter (several feet) long, and are usually much branched. The stems are slender and made up of distinct nodes and internodes. The internodes in *Nitella*, and in the decorticated species of *Chara*, consist of a single long cylindrical cell, usually several centimeters long, but in *Nitella* sometimes 30 centimeters (1 foot) long. At the nodes are whorls of short cylindrical outgrowths resembling branches. They are called "leaves" but are not true leaves. The true branches arise in the axils of these "leaf" whorls. The internodes in most species of *Chara* are covered with a cortex of cells. The sexual organs are sperm and egg cases (antheridia and oögonia). The stoneworts are remarkable for the striking movement of the protoplasm in the cells. The protoplasm flows down one side of the cell and back on the other, turning at the ends.

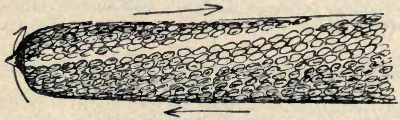


Fig. 190.
Cyclosis in Nitella.

REVIEW OF THE GREEN ALGÆ.

370. Importance of studying the green algæ.—There are several important reasons for studying even a few members of the green algæ. First. They are generally of simple structure, either single-celled or filamentous, and serve as excellent objects, easily prepared, for microscopic study of the cell and its contents, the processes of absorption, plasmolysis, etc. Second. The sexual organs and methods of reproduction are simple and easily studied. Third. It is believed that some members of the green algæ, existing perhaps ages ago, were the ancestors of the higher green plants. It is therefore of interest to study a few types to see how the green algæ themselves are organized, and show among themselves different stages in this process of evolution from simple organisms consisting of a single cell to the more complex ones where cells are united into threads, cell plates and cell masses.

371. Increase in the complexity of the plant body.—The simplest condition of the plant body is found in such plants as the red snow plant (*Hæmatococcus*). The plant is a single cell. It multiplies by division into two plants which are associated in the parent envelope but a short while, when they escape and become independent. In such a plant as *Pleurococcus* the cells are united for a longer period during multiplication, while in the colony algæ like *Pandorina*, and the water-net, the individuals are permanently united in a loose association. Most of the desmids are single-celled plants, but other members of the conjugating algæ are filamentous. They are, however, really colony algæ, since each cell of the thread is identical in structure, and potentially identical in function; each cell is capable of division and growth, growth not yet being localized at any definite growing point, or area. In the filamentous algæ (Confervoideæ), however, while the cells are nearly all alike, growth is localized, either at the tips of the threads and branches, as in *Cladophora* and *Chætophora*, or in definite cells at any point in the thread, as in *Œdogonium*. Many of the filamentous forms are branched. This produces a more complex plant body. In some forms the branching is so close and compact as to approach tissue masses in the cushion-like mats or spheres of some species of *Coleochæte* and *Chætophora*, or to form definite leaf-like cell plates, as in the sea lettuce and the shield *coleochæte.*

372. Differentiation of sexual organs.—In the lower green algæ, the one-celled forms (Protococcoideæ) and the conjugating algæ (Conjugatæ), the gametes are usually equal in size, though in some forms there is a distinct difference, the male, or sperm cell, being smaller than the female, or egg cell. This is true in many of the filamentous algæ (Confervoideæ) where both gametes are motile cells. In forms like *Œdogonium*, and *Vaucheria* among the siphon algæ (Siphonales), definite and distinct organs are developed the sex of which can be recognized. The female organ, the egg case (oögonium), is large and contains a single large egg with an abundance of cytoplasm to furnish nutriment to the germinating egg. The male organ, the sperm case (antheridium), is smaller in size, but develops usually a very large number of small sperm cells. These escape at some little distance from the egg case. Of the large number of sperms formed only a very few ever reach the egg to fertilize it. The production of the large number of sperms is a provision of nature to make sure that some by chance will reach the egg. Since the sperm case is some distance from the egg case it is necessary that some means shall be provided to bring the sperm to the egg. The sperms have two, or several, cilia and are free swimming.

CHAPTER XXIV.

ALGÆ (Continued).

THE BLUE-GREEN ALGÆ* (CYANOPHYCEÆ).

373. General characters.—The blue-green algæ include some of the simplest forms of plant life. In some respects the cell is less specialized than in any of the lowest green algæ. The chlorophyll is not in definite chlorophyll bodies, but is diffused throughout the protoplast and is more or less guised or obscured by a blue pigment, *cyanin*, hence the name blue-green algæ or *Cyanophyceæ* (bluish algæ). A few of them have brownish or red pigments. The red shimmer of the red sea is caused by the presence of myriads of one of these algæ, *Trichodesmium erythræum*, which has a red pigment. The nucleus is not so distinctly organized as in most plants. According to some the deeply stained nuclear matter (chromatin) is distributed throughout the cell in granules, while some recent investigations seem to show that there is a definitely organized nucleus but less specialized than in the other algæ. The plants exist as single spherical cells, spiral cells, as colonies, and as filaments composed of numerous

---

* TO THE TEACHER. In first-year courses it may not be possible to study any of the members of these groups with the aid of the microscope. Where possible, however, some of the members of each group should be at hand for examination, either in the fresh condition, dried and mounted, or preserved in formalin or alcohol. A variety of species mounted on cards make interesting objects for observation of color, and for general plant form. The rockweed is an excellent type for the browns. In schools located in cities near the seacoast more can probably be done in the study of the browns and reds than in the interior. For this reason several types of these are included. In more advanced classes it may be found convenient to include some microscopic study where facilities for this work are provided. The Cambridge Botanical Supply Company, Cambridge, Mass., makes regular collections and shipments for schools during the autumn.

cells. They occur in fresh, brackish, or salt water, and on damp rocks, soil, etc. A number of species have a preference for foul water or waters which contain organic matter. Some of these on decaying produce very foul odors, and sometimes occur in reservoirs for public water supply. Here they may become a great nuisance and a menace to health. They can be destroyed by adding small quantities of copper sulphate to the water in the reservoirs without injury to the water for drinking purposes.* Some of the blue-green algæ are remarkable for growing in warm, or hot, water, at a temperature which would prevent the growth of other forms of plant life except certain bacteria. In the hot water flowing from the geysers at Yellowstone Park some of these algæ live in water at a temperature of 58°–68° C., or scantily at 75°–77° C. The blue-green algæ multiply by division of the cells and by breaking up of the colonies or threads. In the filamentous forms this division takes place much as in spirogyra, by simple splitting or fission of the cells. For this reason they are sometimes called fission algæ. See also Bacteria, Chapter XXV. Other characters are brought out in a study of the examples.

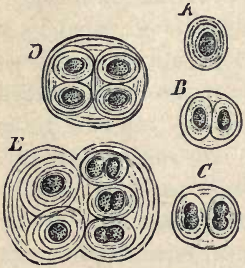


Fig. 191.
Glœocapsa.

374. Glœocapsa.—This is a one-celled alga which forms thin bluish-green patches on the ground or on rocks, logs, etc. Each cell is roundish, and is surrounded by a thick capsule of a gelatinous nature which is stratified in distinct concentric layers. The cells look as if they were enclosed in gelatinous capsules, hence the name *Glœocapsa*. In multiplication the cells divide into two daughter cells and these again divide in like manner. The divisions take place in different directions, each cell having a distinct stratified gelatinous envelope, and several of these enclosed for a time in the envelope of the parent cell, which becomes larger with the increase in the number of the cells.

---

* See Bull. No. 64 Bureau of Plant Industry, U. S. Dept. Agr., 1904, and Bull. No. 76, 1905.

375. Oscillatoria.—*Oscillatoria* is one of the filamentous forms, and some of the species are very common. They grow in small pools or in large bodies of rather shallow water. They often grow on the soil at the bottom, forming distinct films or sheets which are lifted by the bubbles of oxygen, as a result of photosynthesis, which are entangled in the meshes of the film, and then float as a scum on the surface of the water. The threads are made up of thin disk-like cells which are broader than long. Near the cross walls are seen distinct but small granules which are supposed to be reserve food products. The threads of *Oscillatoria* exhibit a peculiar motion; they sway or oscillate back and forth slowly, something like a pendulum. This peculiar motion of the threads suggested the name *Oscillatoria*. They also glide slowly in the direction of the axis of the thread. The division of the cells is a transverse fission. The threads multiply by breaking up into shorter threads. The threads are surrounded by a thin gelatinous layer, in nature similar to that of the cell wall. In some related genera the threads are enclosed in a thick gelatinous layer.

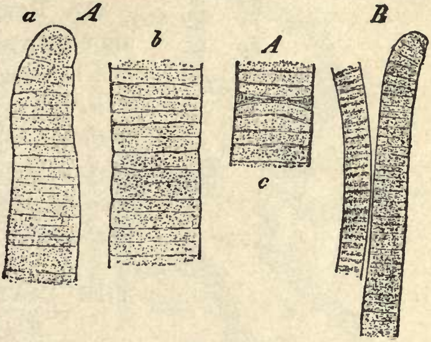


Fig. 192.

A, Oscillatoria princeps: *a*, terminal cell; *b*, *c*, portions from the middle of a filament. In *c*, a dead cell is shown between the living cells. *B*, Oscillatoria froelichii: *b*, with granules along the partition walls.

376. Nostoc.—The *Nostoc* plants occur on damp soil or wet rocks in thick gelatinous masses or nodules, sometimes quite firm. The cells are rounded and connected like a string of beads. Numbers of these bead-like chains are scattered through the jelly-like mass. Here and there in the chain are larger colorless cells.* Division of the cells and multiplication of the threads takes place much as in *Oscillatoria*. A related plant is *Anabæna*, which is

---

* Called *heterocysts*, which means other cells, or other kind of cells.

often found floating on the water. Some of the cells in *Anabæna* become much longer than the others and larger. These function as spores and multiply the plant.

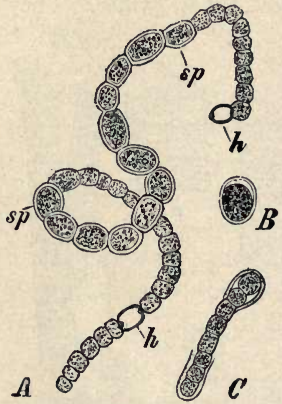


Fig. 193.
Nostoc linckii. *A*, filament with two heterocysts (*h*), and a large number of spores (*sp*); *B*, isolated spore beginning to germinate; *C*, young filament developed from spore. (After Bornet.)

377. Review of the blue-green algæ.—In addition to the characters and habits given under *general characters* it is to be noted that they differ from the other algæ by the absence of sexual reproduction, or at least that sexuality has not yet been discovered in the group.

THE DIATOMS (DIATOMEÆ: BACILLARIALES).

378. General characters.—The diatoms are single-celled plants, a few remaining loosely joined into filaments. They are remarkable for the possession of a silicious skeleton, called a *frustule*, which encloses the protoplast. This skeleton is in two parts (valves) resembling a box with its cover, some of the forms resembling an old-fashioned pill box (fig. 194). Some of the frustules are remarkable for the fine and beautiful sculpturing, and are used for test objects in determining the resolving power of high-grade microscopic lenses. The diatoms occur in fresh and salt water. They exist in vast numbers. The diatoms together with other microscopic plants and animals form what is called the *plankton* (wandering life of the sea) of fresh and salt waters, especially of the deep waters. Extensive deposits of diatomaceous earth several feet in depth, made up almost entirely of the skeletons of diatoms, exist, for example, in southern England, in places in the Adirondack Mountains, at Richmond, Va., in Nevada, California, etc. This is sometimes used as a polishing powder. The frustules also occur in guano.

379. The frustules of the diatoms are of various forms, elliptical, oblong, wedge-shaped, circular, etc. Many are free, while others are attached to objects by gelatinous stalks, the stalks becoming branched as the diatoms multiply by fission. They possess chlorophyll, which, however, is often more or less obscured by brownish or yellowish pigments. In multiplication the protoplast divides in line with the plane between the two valves, and the two daughter cells separate each with one valve. The naked part of the protoplast now deposits a new valve on that side. This new valve must necessarily fit inside of the old one. It is evident, therefore, that some of the new plants become smaller and smaller with each successive division. If these divisions continued, the cells would in time become infinitely small. But they finally cast off both valves and grow to the normal size. Such a cell is called an *auxospore* (an increasing spore). A process of conjugation also takes place in some species when the protoplasts from two cells unite to form an auxospore.

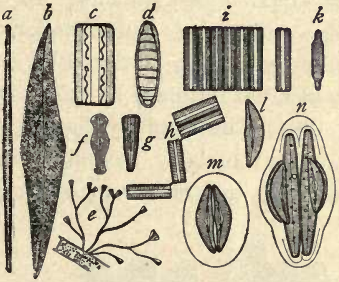


Fig. 194.

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*, *n* forming auxo-spores. (After Kerner.)

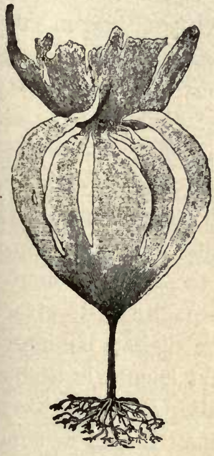


Fig. 195.

Laminaria digitata, forma cloustoni, North Sea. (Reduced.)

THE BROWN ALGÆ (PHÆOPHYCEÆ).

380. General characters.—The brown algæ chiefly inhabit salt water and they are widely distributed along the shores of oceans and seas from arctic to tropic regions. While there are many small filamentous forms, the class is remarkable for the number of large forms exceeding in size any of the other algæ. In many of these the plant body is differentiated into stem and leaf-like structures, and the stems are attached to rocks by disks or root-like holdfasts. The cells contain chromatophores with chlorophyll, and in addition a brown pigment (*phycophæin* = algal brown). Asexual reproduction takes place in some forms by zoöspores (*Ectocarpus*), and sexual reproduction by the union of equal motile gametes. In other forms asexual reproduction is wanting, but multiplication is provided for by the immense number of eggs produced by a single plant (rockweed = *Fucus*), which are fertilized by much smaller sperms.

381. The kelps.—The kelps include the largest plants found among the algæ. A stalk, either short or long, is present, which expands into one or many leaf-like expansions, the blades, which are often very stout and large. The stalks are attached to the rocks by haustoria, or grapplers, which are disk-like, or in many species resemble a dense tuft of short stout roots. The giant kelp (*Macrocystis*), which grows in the Pacific, is 200 to 300 meters (700–1000 feet) long. The genus *Laminaria* is widely distributed and occurs on both the Atlantic and Pacific coasts. Some of these have simple strap-shaped stout blades 10 meters (30 feet) or more long. The digitate laminaria (*L. digitata*) has a broad blade which is split lengthwise into a number of finger-like processes. The sea palm (*Postelsia*) has a stout erect cylindrical stem with numerous stout blades hanging from the top. The kelps are flexible and tough and are able to resist the pounding of the surf on the rocky shore. Asexual repro-

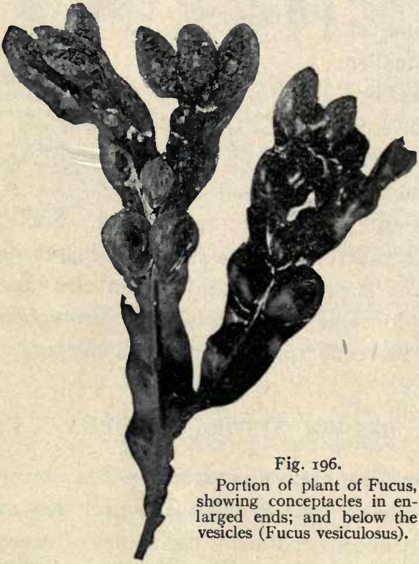


Fig. 196.
Portion of plant of Fucus, showing conceptacles in enlarged ends; and below the vesicles (Fucus vesiculosus).

duction takes place by zoöspores formed in single-celled spore cases (sporangia) in large groups upon the blades. Sexual reproduction is not known.

382. The rockweeds, Fucus.—The species of *Fucus* are very numerous and widely distributed in the temperate and arctic seas. They can be seen often in vast quantities attached to the rocks at low tide when they are often uncovered. The short stalk is attached to the rock by a disk-like holdfast. The blade is branched in a forked manner, and the middle line is thickened in the form of a midrib. Growth takes place in a small depression at the apex of each leaf. Some species are provided with large bladder-like vesicles in the leaves (*Fucus vesiculosus*). The sexual organs are developed in small cavities called *conceptacles.* In some species the male and female organs are on different plants (diœcious), in others they are in different conceptacles of the same plant (monœcious), while in some both are formed in the same conceptacle (hermaphrodite). These conceptacles are grouped in definite patches, their conical mouths, slightly elevated, giving a punctate appearance, which is easily observed. The conceptacles are oval or flask-shaped, and numerous slender filaments arise from the bottom and sides and project through the opening. The egg cases are large rounded bodies attached by a stalk to the

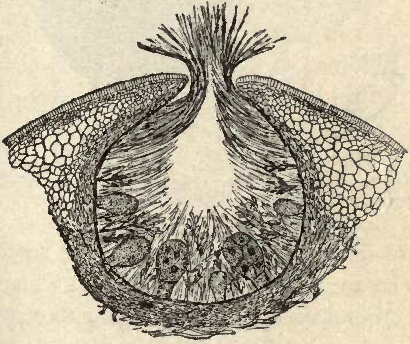


Fig. 197.
Section of conceptacle of Fucus, showing oögonia and tufts of antheridia.

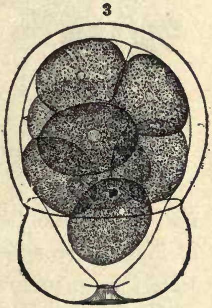


Fig. 198.
Oögonium of Fucus with ripe eggs.

wall of the conceptacle, each of which contains eight eggs. The eggs are set free by the rupture of the wall, and escape to the outside. The sperm cases are small elliptical bodies borne as branches on very much branched filamentous outgrowths from the wall. Each sperm case develops a large number of small biciliate sperms, which also escape to the outside in the sea water. Here they swim among and around the eggs, often causing them to revolve. One sperm finally enters and fuses with the egg nucleus. The fertilized eggs which reach favorable localities start to grow within a day and develop new rockweed plants.

Fig. 199.

Antheridia of Fucus on branched threads.

Fig. 200.

Antheridia of Fucus with escaping sperms.

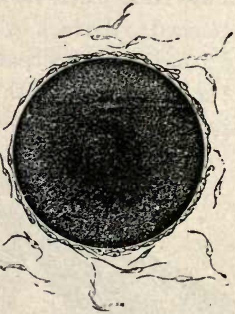


Fig. 201.

Eggs of Fucus surrounded by sperms.

383. Sargassum.—This is another rockweed which is interesting because of the large number of small bladder-like floats developed as lateral outgrowths, in addition to the thin blades and the reproductive branches. *Sargassum* is sometimes spoken of as gulf weed. Large numbers of them are broken away by the waves, from the rocks on the shores of the West Indies, and are carried by the gulf streams to the open sea between the 20th and 40th parallels of latitude, where they often accumulate in vast numbers, forming what are called "Sargasso seas," and sometimes interfere with navigation. Here they grow vegetatively, but are not known to fruit under these conditions.

384. Uses of the brown algæ.— Some of the kelps (*Laminaria japonica* and *L. angustata*) are used as food by the Japanese and Chinese. Some species of kelps are used as food for cattle, and are spread upon the land for fertilizers by farmers and peasants along the north Atlantic coast and in some European countries. *L. digitata* is said sometimes to be employed in surgery. Iodine is extracted from some kelps and rockweeds.

THE RED ALGÆ (RHODOPHYCEÆ).

385. General characters.—The larger number of the red algæ grow in the sea, but a few grow in fresh water. They possess chromatophores with chlorophyll, but in most forms this is obscured by a reddish * or purplish pigment. The various colors are red, purple, brownish red, and green. Some forms are filamentous, others are more bulky and cord-like or strap-shaped, while others are leaf-like. Nearly all forms have a greater or lesser amount of a gelatinous or slimy substance surrounding the parts of the plant. In the method of reproduction, and in the life cycle of some forms, they have reached the highest stage of development of any of the algæ. Asexual reproduction, where it occurs, takes place by the formation of groups of spores, four in each group (tetraspores), while in sexual reproduction the fertilized egg develops a large number of spores.† While these methods of reproduction are characteristic of the red algæ,

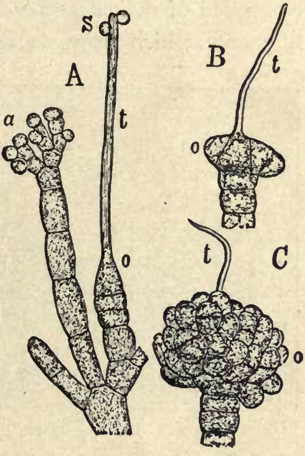


Fig. 202.

A red alga (Nemalion). *A*, sexual branches, showing antheridia (*a*); carpogonium or procarp (*o*) with its trichogyne (*t*), to which are attached two sperms (*s*); *B*, beginning of a cystocarp (*o*), the trichogyne (*t*) still showing; *C*, an almost mature cystocarp (*o*), with the disorganizing trichogyne (*t*). (After Vines.)

---

* Phycoerythrin.

† Called *carpospores*, i.e., fruit spores, because the mass of spores is the fruit.

the members of the class can usually be recognized by their reddish or reddish purple color. The red algæ are usually found in deeper water than the brown or green algæ, occupying the lower zone of the alga-inhabited region below ebb tide, where the waters are more dimly lighted. The red algæ are more sensitive to bright light than the brown and green and suffer discoloration in the brighter light region. In the shade they grow nearer the surface. Some species are bright red when growing in the shade, or dull red when they grow in brighter light.

386. Nemalion.—The plant body of nemalion is a slender, cylindrical, branched shoot. The central strand is firm and composed of delicate threads. It is covered by a cortex of loose filaments which arise as lateral branches and extend outward. It represents the simplest type of sexual reproduction in the red algæ, though there are filamentous forms with a much more simple structure of the thallus, i.e., the plant body. *The sexual organs.* The male organs, or sperm cases (antheridia), are small rounded cells borne in crowded clusters, on short branches, at the end of a branch. Each sperm case contains one or two non-motile sperms. *The female organ.* This is borne on a special branch of four or five cells, called a *procarp.* The terminal cell is the egg, but is called a carpogonium in the red algæ, because it gives rise to a fruit body, the *cystocarp.* It is extended into a long slender process called the *trichogyne*, or egg hair. The egg with its hair thus resembles very closely the egg case of Coleochæte. *Fertilization.* In fertilization a sperm comes in contact

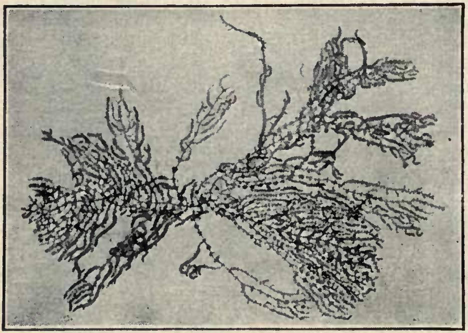


Fig. 203.

Batrachospermum cœrulescens. Natural size. It grows during the summer season in slow running water.

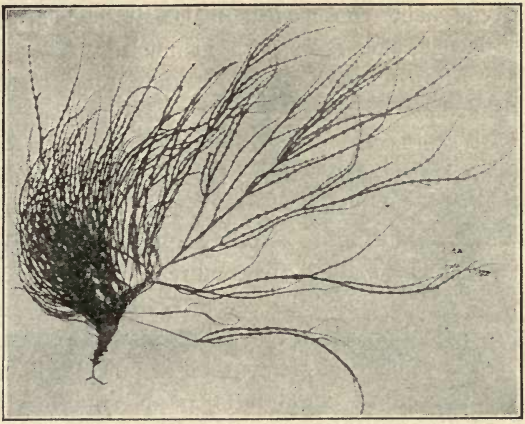


Fig. 204.

Lemanea fucina which grows only in the winter in turbulent water of streams. Natural size.

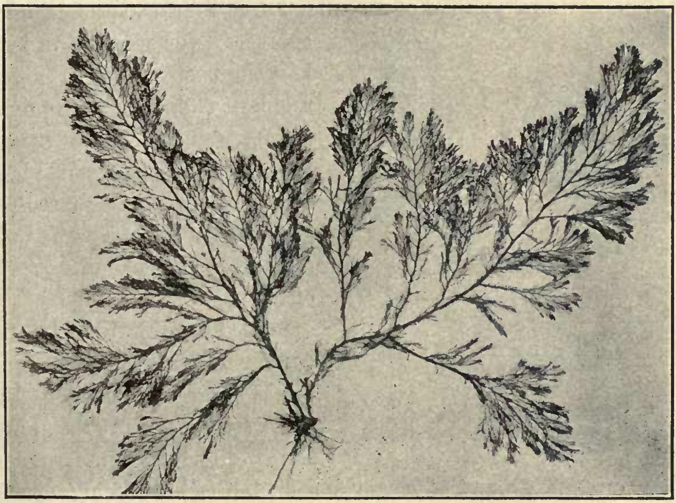


Fig. 205.

Polysiphonia nigrescens from rock at Hellgate.

with the egg hair. Its nucleus makes its way inside, travels down to the egg and fuses with its nucleus. *The fruit case, cystocarp.* After fertilization, the fertilized egg buds out in various directions and produces a mass of closely branched threads with short cells. The terminal cells are the spores (*carpospores*), and together the mass is called the *cystocarp.* Each spore is capable of developing a new nemalion plant.

387. Batrachospermum and Lemanea are fresh-water forms with a similar method of sexual reproduction. The former multiplies also by non-motile spores (often called gonidia), a single spore being formed in a small globose spore case. *Batrachospermum* is a beautiful plant, green or purplish in color, very profusely branched in dense tufts around a central axis. It occurs in shallow streams and pools. *Lemanea* is remarkable for the fact that it grows only during the winter in the coldest part of the year, often underneath the ice, and in very turbulent water.

388. Tetraspores in the red algæ.—Many of the red algæ have an asexual method of reproduction in the formation of tetraspores. Four spores are borne in a single spore case in a very regular fashion. In many species, and perhaps in all, they are borne on special plants which do not bear sexual organs, as in *Polysiphonia violacea*, *Gracillaria*, *Rhabdonia*, etc.

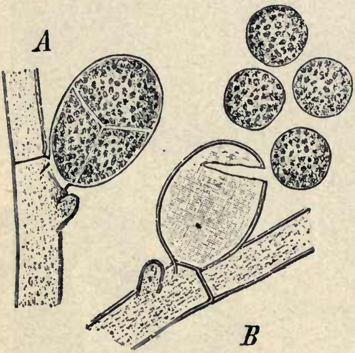


Fig. 206.

A red alga (Callithamnion), showing spore-case *A*, and the tetraspores discharged, *B*. (After Thuret.)

389. Fertilization in the higher red algæ.—The process is more complicated than in *Nemalion* and the lower forms. The sperm cases are developed in groups, a single non-motile sperm being formed in each sperm case. After fertilization the fertilized egg does not directly form the spores. It conjugates directly, or by the growth of long filaments, with one or more neighboring cells on other branches. This is probably for the purpose of obtaining a greater amount of nutriment for the development of the fruit spores, which are formed by the growth and branching of this neighboring (auxiliary) cell.

390. Uses of the red algæ.—Many of the red algæ develop quantities of a gelatinous substance in their tissues. Several of these are used for the manufacture of gelatines and agar-agar. *Gracillaria lichenoides* and *wrightii* are used for this purpose, the former species occurring along the coasts of China and India. Some are also used for food. The "Irish" moss, *Chondrus crispus*, widely distributed in the northern Atlantic ocean, is used for food and for medicinal purposes. Another plant used for similar purposes is *Gigartina mamillosa*, in the Atlantic and Arctic oceans.

Fig. 207.
Irish moss (Chondrus crispus).

CHAPTER XXV.

BACTERIA.

391. General characters.—The bacteria are very minute plants, some of them being the smallest organisms known. An idea of the size of very small ones can be obtained from the fact that if placed side by side it would take 5000 to make a line 1 mm. long, or 125,000 to make a line one inch long. Like the fungi they are devoid of chlorophyll, not being able to make their own carbohydrate food. A few can fix carbon from the air (see paragraph 200). They are dependent on green plants for carbohydrate food, and obtain this from the sugar or starch, etc., in other plants upon which they grow as saprophytes or parasites (see Chapter XV), or from organic matter either of plant or animal origin which was primarily obtained from green plants. They are in the form of rods, or spheres, or screws. The outer layer of the wall is slightly gelatinous, and this peculiarity is made use of in fixing them to glass slips in mounting them for study, by the use of heat. Some of the bacteria are non-motile, while others are motile. The motion is usually a jerky irregular rotary motion, but the spiral forms dart rapidly along like a forward-moving screw. The motile ones are provided with delicate cilia (fig. 101), which cannot be made visible except by special treatment with mordants and stains. They multiply by simple fission as in the blue-green algæ. Resting spores are formed in many species by the condensation of the protoplasm into a small shining body within the cell which is able to resist greater extremes of heat, cold, dryness, etc.

392. The principal forms of bacteria and their methods of multiplication.—Many of the rod-like bacteria belong to the genus *Bacillus*. In multiplication this rod divides into two short rods which increase in length to the size of the parent rod. In some species these daughter rods separate very readily, while in others they hold together for some time, making a long and fine thread which later separates into the separate rods. *Beggiatoa* forms long filaments of short cells similar to those of *Oscillatoria* but lacking the blue-green color. The screw or spiral forms are found in the genera *Spirillium*, *Vibrio*, etc. They also multiply by cross division of the cells. The round, or spherical, forms are found in a number of different genera according to the method of association of the individuals. In *Micrococcus* (minute berry) the rounded cells divide into two which quickly separate. In *Streptococcus* with rounded cells, the cells after dividing remain in chains similar to the bead-like chains of *Nostoc*. In *Sarcina* the rounded cells divide in two or three directions, the cells remaining held together in small cubical groups for a time.

393. The work of bacteria in decay, fermentation, and disease.—For a discussion of this see paragraphs 220–223, which should be studied in connection with this chapter.

394. Comparative review of the bacteria.—The bacteria resemble the fungi in that chlorophyll is absent. Because of their method of multiplication by simple division, or cutting in two of the cells, which is sometimes called *fission*, they are called *fission fungi* or *Schizomycetes*, and by some are classed with the fungi. But this method of fission is like that of the blue-green algæ, which they also resemble in the variety of forms and association of cells, as well as in the simple condition of the protoplast, and the slimy covering of the cell walls. For these reasons some consider them more closely related to the blue-green algæ, and place them in a class called *Schizophyceæ*, with two sub-classes, the Cyanophyceæ (blue-green algæ) and the Schizomycetes (Bacteria). Still others place them in a class (Schizomycetes) distinct from either the fungi or blue-green algæ. This seems to be the better arrangement.

CHAPTER XXVI.

FUNGI.

GENERAL CHARACTERS; MOLDS; MILDEWS.

395. General characters.—The fungi are plants of a low grade of organization, in this respect resembling the algæ. In fact they stand as a parallel group. The plant body, or thallus, of the lower and higher forms in structure is very much like that of many of the algæ, and some of the methods of reproduction are very similar to methods of reproduction in some of the algæ. There are, however, some features of structure and methods of nutrition in which they differ strikingly from the algæ. First. The fungi are entirely devoid of chlorophyll as well as the bodies (plastids) which are the basis of the chlorophyll bodies. Second. Not having chlorophyll, photosynthesis does not take place, and they cannot make their own carbohydrate food, i.e., the sugar and starch. They are dependent on chlorophyll-bearing plants for this food, just as animals are. Third. They live chiefly on organic matter, either dead or living plants or animals, or their remains. The fungi according to their method of nutrition can be grouped in two categories: first, *Saprophytes*, which live on dead or decaying organic matter (plants and animals); second, *Parasites*, which live upon, or in, living plants and animals (see Chapter XV). In defining the structural elements of the fungi it is convenient to speak of two parts: first, the vegetative or growing part, and second, the fruiting or reproductive part.

TO THE TEACHER. At least three types of the fungi should be studied, one of the molds (Mucor or Rhizopus), a powdery mildew (Microsphæra), and a mushroom. Other examples in each class of the Fungi can be used as illustration, or where more time can be given to the practical work the teacher can select suitable examples from those described in the text. One lichen should also be studied.

396. The vegetative or growing part of the fungi.—In nearly all the fungi, the growing or vegetative part consists of delicate filamentous or thread-like growths. These threads are called *mycelium*, or a single thread of the mycelium is often called a *hypha*, which may be simple or somewhat branched. A mat or tangle of hyphæ is spoken of as mycelium. In some fungi the mycelium is scantily developed, while in others dense mats or stout cords are formed.

397. The fruiting stage or part.—In most of the fungi special hyphæ, called *sporophores* (spore bearers), are developed from the vegetative mycelium. These are simple or branched, single or in fascicles, as in the molds and mildews; or united into large and compact bodies, as in the mushrooms. Asexual reproduction takes place, in most fungi, by the formation of asexual spores,* either motile or non-motile. In many species there are several different kinds of asexual spores on separate forms or parts of the fungus (*polymorphism*); sometimes these different forms occur on different host † plants (*heterœcism*), as in the wheat rust. Sexual reproduction is by conjugation in some of the lower forms, or by fertilization of an egg by a sperm. The details must be sought in a study of different types.

398. The three classes of fungi.—While little attention can be given here to the classification of the fungi, it may be well to outline briefly the three great classes. In the lower fungi the mycelium is siphon-like, i.e., similar to the threads of the siphon algæ. The characteristic fruit structure is a spore case (sporangium) with usually a variable and indefinite number of spores. These fungi form what is called the *sporangium series* and make up the *Class Phycomycetes* (alga-like fungi). Here belong the molds, water molds, downy mildews, etc.

399. In the higher fungi the mycelium is *septate*, i.e., there are numerous cross walls in the mycelial threads. There are two classes.

400. First. The characteristic fruit structure is a sac-like body called an *ascus*, which contains usually a regular and definite

---

* *Conidia*, or *gonidia*, or *chlamydospores*.

† The host is the plant on which a fungus is parasitic.

number of spores. In the great majority there are eight spores in an ascus, while in some there are 16, 32, 64, 128, or even 6, 4, 2, and in a few 1, or a variable number. These asci are usually grouped together in extended surfaces or in conceptacles. These make up the *Class Ascomycetes.* Here belong the cup fungi, morels, black fungi, etc.

401. Second. In the other class the characteristic fruit structure is a short and specialized cell or hypha, which is single-celled, or four-celled in the lower forms, and which bears on the outside a definite and regular number of spores, usually four. This specialized cell or hypha is called a *basidium*, which is the Latin word for club, since this specialized cell is usually club-shaped. These make up the *Class Basidiomycetes.* Here belong the smuts, rusts, mushrooms, toadstools, bracket fungi, puffballs, etc. In studying examples of the fungi it will be convenient to select them from these three classes.

ALGA-LIKE, OR SPORANGIUM-FRUIT FUNGI.

(Class Phycomycetes.)

The Conjugating Molds.

402. The bread mold.*—This fungus is very widely distributed over the world and grows on a great variety of dead vegetable substances, and is, therefore, a *saprophytic* fungus. It sometimes approaches the life habits of a parasite, for it is often found causing a serious rot of stored vegetables, especially sweet potatoes, beets, etc., when the storehouse or cellar is not well ventilated and the temperature is too high. It is called the bread mold, or black mold (*Rhizopus nigricans*), because it often occurs on stale bread in close or damp places, in age becoming black because of the dark spore masses and hyphæ.

---

* To the Teacher. If there is time for the practical study of only one of the fungi of this class there is no better example than the bread mold. The molds can be further illustrated by some examples of the white rust, the downy mildews, etc., preserved on sheets, and of the water mold in culture. Where more time is available for practical study these will serve as examples.

The spores are very numerous and float readily in the air, so that if a piece of bread or cooked potato is left exposed in a room or out of doors for a day or less, and then covered in a pan with some moist paper, in a few days the mold will appear. The mycelium is white and forms an abundant growth of threads forming the white glistening mat which spreads over the bread or other substances.

403. Asexual reproduction.—The mycelium is the vegetative or growing stage of the fungus. Within a day or so after the mycelium begins to form, asexual reproduction begins and at the same time the mycelium continues to spread. Here and there upon a thread of mycelium, erect hyphæ arise in tufts of three to five or more (fig. 208). The ends of these branches become enlarged into a rounded body, the *spore case* or *sporangium*, and the protoplasm is separated from that of the stalk, or *sporophore* (sometimes called *sporangiophore*), by an arched wall, the *columella.*

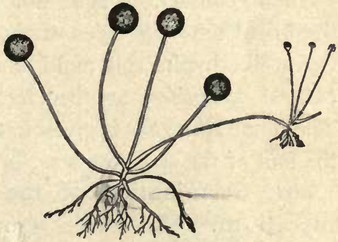


Fig. 208.

Group of sporangia of a mucor (Rhizopus nigricans), showing rhizoids and the stolon extending from an older group.

Fig. 209.

A mucor (Rhizopus nigricans); at left, nearly mature sporangium with columella, showing within; in the middle is ruptured sporangium with some of the gonidia clinging to the columella; at right, two ruptured sporangia with everted columella.

At maturity the sporangium wall disintegrates so that the spores are easily set free. The columella is often very large and might be mistaken for the sporangium after the spores are scattered. It sometimes collapses as shown in fig. 209. At the base of the clusters of sporophores is a tuft of delicate, branched, rootlet-like threads called *rhizoids*. These as well as the sporophores become blackish in color. The larger number of these clusters of sporophores are borne at intervals on distinct creeping hyphæ, which rise into the air and then touch the substratum here and there like the stolon of the strawberry vine, or the leaf of the walking fern, developing a cluster of sporophores at each point of contact. These stolon-like hyphæ will spread off from the bread onto the sides of the vessel. Because of this peculiar stolon-like hypha this mold is sometimes called the stolon bearer (*Mucor stolonifer*, another technical name sometimes applied). The name *Rhizopus* is given to the plant because of the rhizoids at the foot of the sporophores.

404. Germination of the spores and character of the mycelium.—The spores germinate when the temperature and moisture conditions are suitable. They absorb water and swell to a large size, then a protuberance appears on one side, which is the beginning of a hypha or mycelial thread. This is called the *germ tube*, because it resembles a short tube from the germinating spore. This elongates quite rapidly, and branches profusely, sending branches radially in all directions in the food substance, and others into the air if the air is moist. The mycelium is continuous, i.e., it is not divided up into cells by cross walls. The

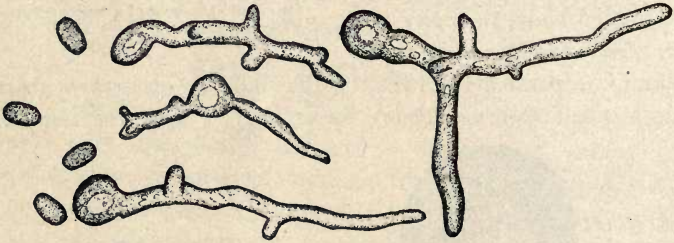


Fig. 210.
Spores of Mucor, and different stages of germination.

protoplasm is coarsely granular and shows numerous vacuoles of varying size (fig. 210). The protoplasm shows streaming movements. It flows along in a thread-like stream, or in other cases there may be smaller currents up and down the thread. There are large numbers of nuclei in the protoplasm, but they cannot be demonstrated without careful treatment according to certain technical methods. Cross walls appear where reproductive bodies or organs are formed, and rarely here and there in old mycelia

405. Sexual reproduction.—Sexual reproduction takes place by conjugation. This occurs between two threads or branches of mycelium which are of an opposite sex nature. One cannot distinguish between male and female according to the size and appearance of the conjugating branch, though sometimes at a later stage one becomes much larger than the other. The branches meet at their ends, and each swells into a club-shaped body. A cross wall now cuts off a body of protoplasm in the end of each branch.

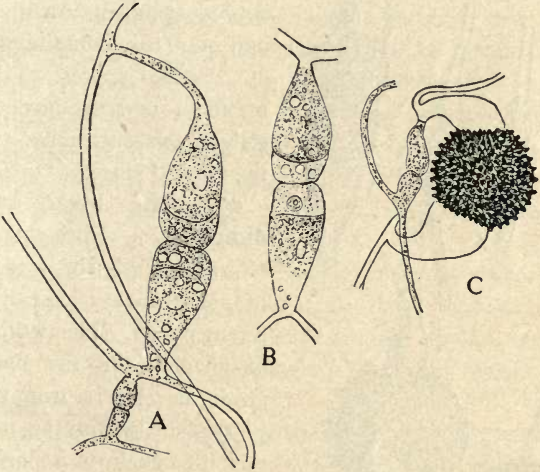


Fig. 211.
Rhizopus nigricans. Different stages in conjugation of + and − strains to form zygospores.

This cell is the gamete case (*gametangium*) and the protoplasm in each is a gamete (fig. 211). The remaining part of each branch is a *suspensor*, so called because it suspends the gamete cases. The walls between the gametes dissolve so that there is a mixing or fusion of the protoplasm of the two gametes. This united body enlarges, and the wall becomes thick, black, and rough with small wart-like protuberances. This is the zygospore.

406. Germination of the zygospore.—The zygospore of the bread mold has not yet been found to germinate, but that of a related mold (*Mucor mucedo* Linn.) has. When it germinates it produces at once a sporophore and spore case containing numerous asexual spores. These are scattered and produce the mycelium and successive cycles of the asexual stage.

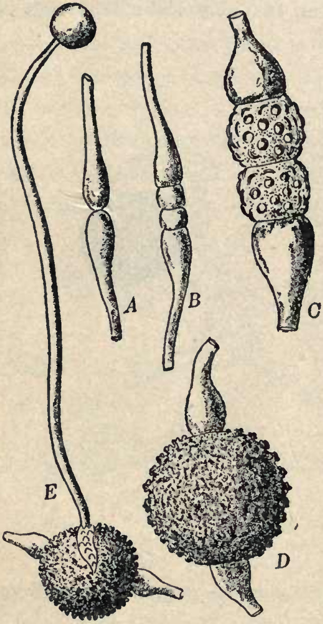


Fig. 212.

Formation of zygospores in a mold (*Mucor mucedo*). *A*, two hyphæ in contact, end to end; *B*, the terminal gametes; *C*, later stage, the gametes fusing; *D*, a ripe zygospore; *E*, germination of a zygospore, the filament forming a sporangium at once in this case. (After Brefeld.)

407. The bread mold is diœcious.* — In the bread mold (*R. nigricans*) the conjugating branches always arise from different plants. The two branches of an opposite sex nature, or strain, never arise from the same plant, that is from the mycelium which came from a single spore. There must be two different colonies of mycelia, each from a single spore of opposite sex natures, one corresponding to the male and one to the female. These two must be growing side by side or mixed so that branches which would be of opposite sex natures can meet and conjugate. Under

---

* *Heterothallic,* because there are two sorts of thalli, male and female.

natural conditions these two strains or sets of mycelia of opposite nature are sometimes growing mixed together, but more often, probably, the two strains are growing separately. If one obtains a culture of only one strain on the bread no zygospores will be produced. But if the mixed strains are obtained, then zygospores will be produced in number down in the lower part of the vessel where it is moist, usually in small spaces between the paper and the wall of the vessel or bread. It will be remembered that the plant body of an alga or a fungus is called a *thallus*. The mycelium from a single spore, then, is a thallus. Since two different thalli of the bread mold are necessary to bring about conjugation and produce zygospores, such a thallus plant is said to be *heterothallic*, because other or different thalli must be brought together for sexual reproduction. They are also said to be diœcious. The *Mucor mucedo* above mentioned is also diœcious. In some of the molds there is a difference in the size of the two different thalli; the one supposed to represent the female is larger and is by some indicated as +. The other being smaller is indicated by −. By extension + and − are applied to corresponding strains in species where the thalli are of equal size.

408. Monœcious Mucors.*—Some of the mucors are monœcious,† i.e., both sexes are present in the mycelium from a single spore. This is true in the mushroom mold (*Sporodinia grandis*), a common mold growing on decaying mushrooms in the woods.

409. Nature of the spores in the germ sporangium.—The name *germ sporangium* is by some applied to the spore case which is formed from the germinating zygospore. Since the sexes become mixed in the zygospore of the diœcious species they must be separated again, otherwise the species would become monœcious. This separation takes place in *Phycomyces nitens* in the formation of the spores in the germ sporangia, so that there are + and − spores mixed in a single spore case. In *Mucor mucedo* they are

---

* Mucorineæ, or Mucorales. The order containing different genera and many species of Mucors is called *Mucorineæ*, or *Mucorales*.

† *Homothallic*, because all the thalli are alike sexually.

separated before the formation of the germ sporangium, so that the spores in one germ sporangium from a single zygospore are all + while in another they are all −.

The Water Molds.

410. The water mold.—These fungi grow on dead insects or other animals in the water, or even on dead plant parts. They are very common on dead insects, and sometimes are seen growing on living but weakened fish and other aquatic animals. They are easily obtained by collecting algæ with some of the ditch or pond water in which they grow, and throwing dead flies into it. The mycelium grows through the body of the fly, and then long white threads radiate out in the water all around the insect. The mycelium is coarsely granular, vacuolate, and continuous.

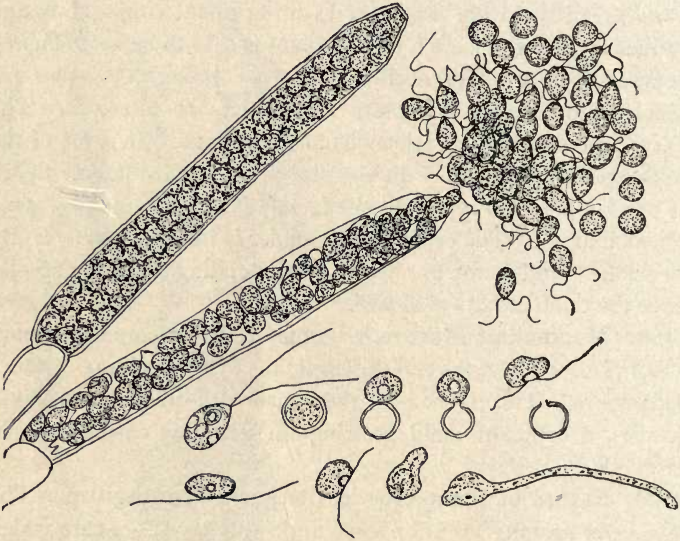


Fig. 213.

Sporangia of Saprolegnia, one with zoöspores escaping and passing through the first swarming period. Below, passing through second swarming period and then germinating.

411. Asexual reproduction.—This takes place by the formation of spore cases. In the common water mold (*Saprolegnia*), the spore cases are long and cylindrical. They are formed in the ends of threads or branches by a cross wall which cuts off the protoplasm from the rest of the thread. The spore case is usually stouter than the thread which bears it. The spores are oval, with two cilia on the smaller end. The spores swim out of an opening at the end and after passing through a first swarming period round up and pass a resting period. Then they slip out of the thin membrane surrounding the protoplasm, and are bean-shaped, with two cilia on the concave side. They now pass through another swarming period. Then they come to rest and germinate, if they have found a suitable substratum.

412. Sexual reproduction.—Sexual organs, sperm and egg cases (antheridia and oögonia), are formed on the mycelium of the water molds, but it is a disputed question if fertilization takes place. The egg case in some species is round, in others elongate. It is formed on a short branch or directly in a thread, and is separated by a cross wall. In *Saprolegnia* several eggs are formed in a single egg case. The sperm case is a slender branch which coils partly around the egg case and sends a fertilization tube inside and in contact with the eggs. Some claim that a sperm nucleus from the sperm case unites with the egg nucleus to bring about fertilization, while others deny it. It is certain that in some species sperm cases are not formed, and yet the eggs ripen without fertili-

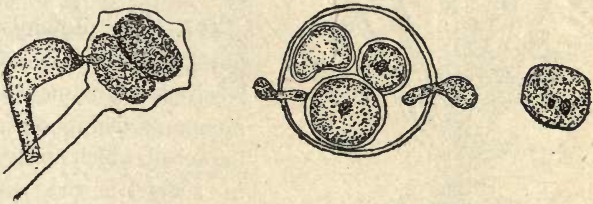


Fig. 214.

Fertilization in Saprolegnia, tube of antheridium carrying in the nucleus of the sperm cell to the egg. In the right-hand figure a smaller sperm nucleus is about to fuse with the nucleus of the egg. (After Humphrey and Trow.)

zation and germinate.* This ripening and functioning of eggs without fertilization is known to occur in some animals, notably the plant lice, and in some of the flowering plants.

413. Stoppage of drain pipes by water molds.—Some of the water molds (notably *Leptomitus lacteus*) grow in waste pipes and drains from refrigerators, cider presses, etc., and cause annoyance by stopping the flow of the waste water. Flushing with water often clears the drain, but if the fungus continues to be troublesome its growth can be prevented by flushing the drain now and then with a weak solution of blue vitriol.

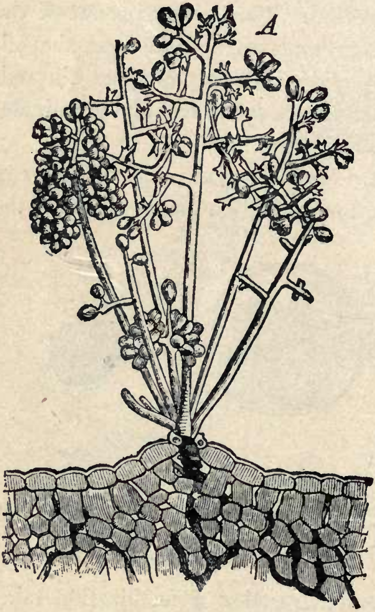


Fig. 215.

Downy mildew of grape (Plasmopora viticola), showing tuft of gonidiophores bearing gonidia, also intercellular mycelium. (After Millardet.)

The Downy Mildews and White Rust.

414. The downy mildews.—The downy mildews received this name from the numerous sporophores, often branched, which are crowded in spots on the parts of plants which they attack. These crowded sporophores look like so much down, and the affected areas have also a mildewed appearance. They are true parasites, since they attack living plants and often cause serious diseases of cultivated plants, entailing thousands of dollars of loss to the horticulturist or farmer. Some of the important diseases caused by them are downy mildew of the grape and cucumber, onion

---

* This germination of eggs which have not been fertilized is sometimes called *parthenogenesis*.

blight, early potato blight,* etc. During 1849 the potato blight caused almost the complete loss of the potato crop in Ireland, and a serious famine resulted.

415. The mycelium.—The mycelium attacks the leaves, stems, and fruit. The germ tube from a spore enters at a stomate of the leaf or between epidermal cells. The mycelium grows between the cells in the intercellular spaces, and is thus said to be *intercellular*. The mycelium is continuous and multinucleate. It develops short special branches, of different form in different species, which penetrate the cells and take food from the protoplasm (fig. 216). This kills the cells, and dead spots appear on the leaves, fruit, and stems, or the death of leaves, fruit, and stems is the result in some cases.

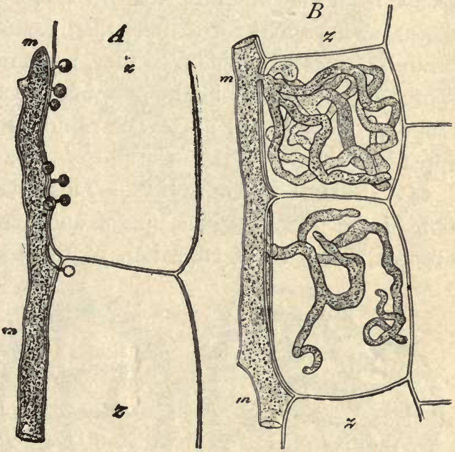


Fig. 216.
Intercellular mycelium with haustoria entering the cells. *A*, of Cystopus candidus (white rust); *B*, of Peronospora calotheca. (De Bary.)

416. Asexual reproduction. — In asexual reproduction branches arise from the intercellular mycelium, which issue through the stomates, often several together. Outside of the leaf these usually branch (in a different manner in different genera). These are the *sporophores* or *conidiophores*. The tips of the branches bear oval spores (conidia). When these fall away they germinate, the manner of germination depending on the genus of

---

* The remedy for these blights is to spray the plants with Bordeaux mixture before they become infested. Spray when the leaves are young, and then at intervals of two to three weeks. In the case of the grape vine the first spray should be applied before the buds burst.

the fungus. In the onion mildew (*Peronospora schleideniana*) the spore germinates by a germ tube which forms the mycelium. In the grape downy mildew (*Plasmopara viticola*) the protoplasm of the spore (conidium) first divides into several smaller bodies which form bean-shaped zoöspores with two lateral cilia. These escape from the conidium (really a spore case in the downy mildews), swim about for a time, then come to rest, germinate and produce mycelium again if they are favorably situated. The spores of the potato blight germinate in both ways. Successive crops of the asexual stage are rapidly formed, and the disease spreads.

417. Sexual reproduction.—This takes place by the formation of the sexual organs, sperm and egg cases (antheridia and oögonia), and the fertilization of the egg. The egg case is a short branch which swells out into a large rounded body. A single egg is formed from the centrally located protoplasm, leaving a layer of protoplasm (*periplasm*) around the outside which does not take part in the formation of the egg. The sperm case is a slender branch which rests against the wall of the egg case and develops a slender fertilization tube, which penetrates to the egg. This carries in the sperm nucleus, which fuses with the egg nucleus to bring about fertilization (fig. 217).

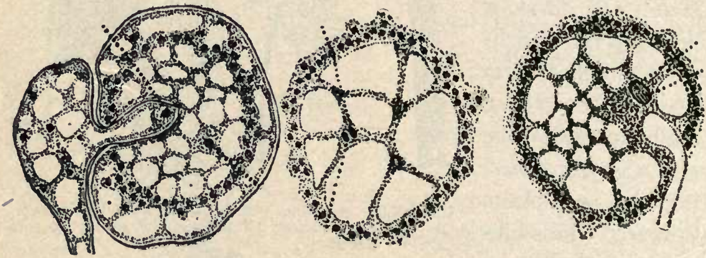


Fig. 217.

Fertilization in Peronospora alsinearum; tube from antheridium carrying in the sperm nucleus in figure at the left, female nucleus near; fusion of the two nuclei shown in the two other figures. (After Berlese.)

418. The white rust.—An example of white rust is the one on cruciferous plants like the mustard, turnip, cabbage and shepherd's purse. This white rust (*Cystopus candidus* = *Albugo* *candida*) is very common on the shepherd's purse, deforming the stems, leaves, flowers, and fruit. The mycelium is intercellular, and branched haustoria penetrate the cells.

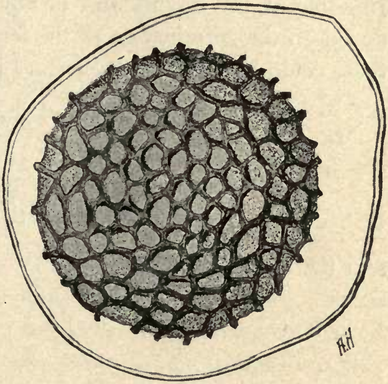


Fig. 218.
Ripe oöspore of Peronospora alsinearum.

419. Asexual stage.—The sporophores are short, are developed in great numbers, and crowded underneath the epidermis. These sporophores bear chains of spores (conidia; fig. 219), and the mass bursts through the epidermis, giving a white rusty appearance. The spores germinate by the formation of zoöspores as in the grape downy mildew.

420. Sexual reproduction.—This process is very much as described for the downy mildews, but in some species many sperm nuclei from the sperm case enter the egg and pair off to fuse with the many nuclei in the egg.

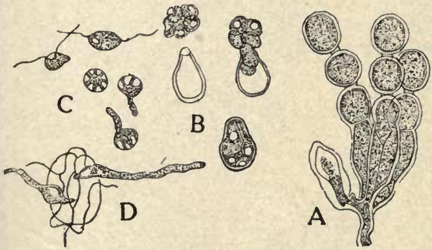


Fig. 219.
From Cystopus candidus, conidial stage. *A*, tuft of conidiophores sorus, showing a few conidia in chains; *B*, conidia forming swarm spores or zoöspores; *C*, zoöspores, some of them germinating; *D*, germinating zoöspores, the hyphæ about to enter stoma. (After De Bary.)

421. Formula * for the life history of the water molds and downy mildews. This can be written as follows, starting with the fertilized egg: Fertilized egg—Plant—asexual spores repeatedly formed—$\left\langle \begin{array}{l}\text{sperm gamete}\\ \text{egg gamete}\end{array}\right\rangle$ fertilized egg, etc., and can be ab-

---

* Not to be memorized. Introduced to represent graphically the life cycle.

breviated as follows: $\mathrm{FE}-\mathrm{P}-\mathrm{asp}-\mathrm{P}-\mathrm{asp}-\mathrm{P}\left\langle\begin{matrix}\mathrm{sg}\\ \mathrm{eg}\end{matrix}\right\rangle\mathrm{FE}$, etc. In some of the blights and downy mildews zoöspores are produced on the germination of the fertilized egg. The formula for these could be written as follows: $\mathrm{FE}-\mathrm{sp}-\mathrm{P}-\mathrm{asp}-\mathrm{P}-\mathrm{asp}-\mathrm{P}\left\langle\begin{matrix}\mathrm{sg}\\ \mathrm{eg}\end{matrix}\right\rangle\mathrm{FE}$, etc. If g is allowed to stand for each of the gametes, the formula could be written as follows: $\mathrm{FE}-\mathrm{sp}-\mathrm{P}-\mathrm{asp}-\mathrm{P}-\left\langle\begin{matrix}\mathrm{g}\\ \mathrm{g}\end{matrix}\right\rangle\mathrm{FE}$, etc. Various methods can be devised to represent the life history.

CHAPTER XXVII.

FUNGI (Continued).

THE SAC FUNGI, OR ASCUS FUNGI.

(Class Ascomycetes.)

422. General characters.—The mycelium is septate, and grows either within the substratum or upon the surface. In the latter case it often sends branches, called haustoria, into the cells of the host, to obtain nutriment. Many of the species are polymorphic, i.e., different stages in the life history of the same species appear under different forms. Some of these forms are asexual stages and bear conidia (asexual spores) which serve to multiply

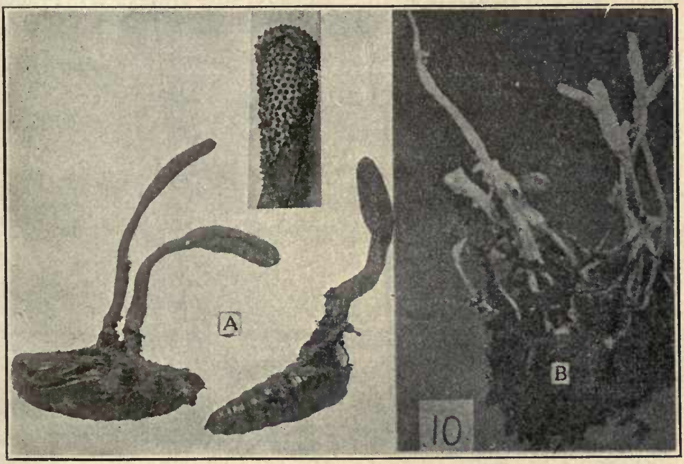


Fig. 220.

A, a perfect fungus (*Cordyceps militaris*) parasitic on pupa of a moth. Head portion of the fungus enlarged, showing fruit bodies (perithecia) containing asci and spores. *B*, an imperfect stage showing conidiophores bearing white masses of conidia.

and propagate the fungus rapidly. These stages are called *imperfect.* Another stage, which is the final stage in the life history, or life cycle, bears the sacs or asci (containing the spores or ascospores) which make the characteristic fruit form of the members of the class. This stage is called the *perfect* stage of the fungus. It is often developed as the result of a sexual act, and thus represents the sexual reproduction in the class. Many of the species, however, are believed to have lost the function of sexuality and are supposed to develop the asci independently of a true fertilization. In a few of the simple forms the asci are scattered without order in loose wefts or knots of mycelium. In the majority of the species the asci are closely crowded into extended surfaces (forming a fruiting surface, the *hymenium*) or grouped in cup-shaped or globose fruit bodies partly or entirely surrounded by a special fungus tissue (*apothecium*), or entirely surrounded by fungus tissue (*perithecium*).* In some species, the lichen fungi, the plant body is made up of an intimate association of fungus mycelium and algal cells.

Fig. 221.
Leaves of willow, showing willow mildew. The black dots are the fruit bodies (perithecia) seated on the white mycelium.

423. The powdery mildews (Perisporiales).—The powdery mildews are very common and conspicuous fungi parasitic upon

TO THE TEACHER. The practical study should include at least one of the powdery mildews. There are other members of the sac fungi which make striking examples for illustration. These can be shown by the teacher, and at his discretion may be included in the practical study where the time devoted to the course will permit. One lichen can be studied and others compared. The yeast should be studied unless this has already been done in Part I.

---

* These fruit bodies of the Ascomycetes are sometimes called *ascocarps,* i.e., sac fruits.

a great variety of plants, on leaves, stems, flowers, and fruit. Many of the common mildews belong here. The mycelium grows on the surface of the host, forming a thin and irregular web-like whitish layer, just visible to the eye. Branches called haustoria penetrate to the epidermal cells, in some species even to the deeper cells, and draw nutriment from the protoplasm. When very young leaves and stems are affected they are often checked in growth. The large number of white conidia (or conidia-spores) in chains or in loose masses give a powdery appearance to the surface of the plants affected, hence the name *powdery mildews*. Some of the important diseases caused by the powdery mildews are the gooseberry mildew; the cherry mildew, growing on cherry, peach, and apple trees, especially injurious to nursery stock; the rose mildew, lilac mildew, etc.

Lilac Mildew (*Microsphœra Alni*).

424. The conidial stage.—This is developed in asexual reproduction. Short erect branches arise from the superficial mycelium which are divided by cross walls into short cells. The branches grow at the base and continue to divide into short cells, raising the older cells farther and farther away from the surface. At the same time the older cells swell out somewhat so that they appear like chains of beads, or small barrel-shaped spores or conidia. The older ones separate and fall upon the surface of the leaf or stem, etc., giving a powdery appearance. These conidia are carried to other plants or other parts of the same plant, there spreading the disease.

425. The ascus stage, or perfect stage.—This is developed after the formation of conidia as the result of a sexual process ending in the formation of minute brown or blackish fruit bodies,* a cellular structure formed of septate threads which envelop the developing asci. These fruit bodies are often very numerous, appearing as minute black specks just visible to the eye. The fruit body is provided with *appendages* of a dark color, consisting

---

* Called here a *perithecium*.

of short septate hyphæ which are branched at the end several times in a forked manner (fig. 224). The sacs or asci are somewhat elliptical in outline. Several are formed in each fruit body, and may be seen by crushing the latter in water and examining with a microscope. Each ascus contains several spores. Other genera of the powdery mildews have different kinds of appendages.

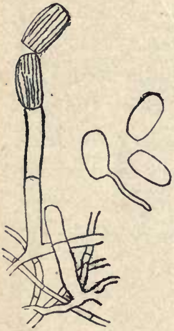


Fig. 222.
Willow mildew; bit of mycelium with erect conidiophores bearing chains of conidia; conidium at left germinating.

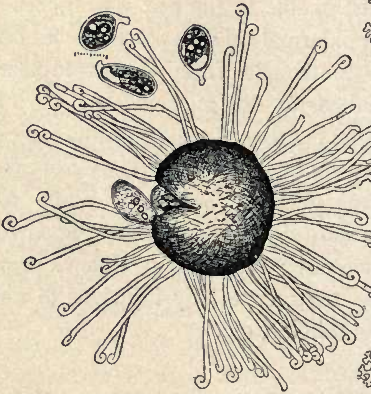


Fig. 223.
Fruit of willow mildew, showing hooked appendages. Genus Uncinula.

Figs. 223, 224. — Perithecia (perithecium) of two powdery mildews, showing escape of asci containing the spores from the crushed fruit bodies.

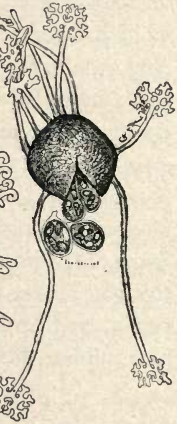


Fig. 224.
Fruit body of another mildew with dichotomous appendages. Genus Microsphæra.

426. The sexual process in the powdery mildews.—The sexual organs are short branches of the mycelium, a sperm case and an egg case. The processes here described occur in the genus *Sphærotheca.* These branches arise close together and their ends come in contact. At the point of contact an opening is dissolved through the walls. The sperm nucleus in the sperm case moves into the egg case and fuses with the egg nucleus (figs. 225–226). The egg-case cell now grows into a short branch of five or six cells. In the last cell but one are two nuclei. These fuse into one, and the cell grows out into a large globose cell, the ascus. The nucleus now divides to form eight nuclei which become centers in the protoplasm for the formation of eight ascospores.

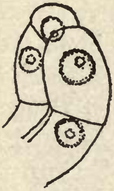


Fig. 225.
Contact of antheridium and carpogonium (carpogonium the larger cell); beginning of fertilization.

Fig. 226.
Disappearance of contact walls of antheridium and carpogonium, and fusion of the two nuclei.

Fig. 227.
Fertilized egg surrounded by the enveloping threads which grow up around it.

Figs. 225-227. — Fertilization in Sphærotheca; one of the powdery mildews. (After Harper.)

427. The black fungi (Sphæriales).—The black fungi include a vast number of the sac fungi, with many genera and species. The fruit bodies (perithecia) are black or dark brown; they occur singly, in troops or in masses, and sometimes are imbedded in a black stroma (a compact sterile fungus tissue). Many are saprophytes and many others are parasites on other plants, causing leaf spots, blights, rots, cankers, knots, etc. Many of these produce serious diseases of vegetables, farm crops, orchard and forest trees. Many of them have "*imperfect*" stages on which asexual spores (called conidia) are borne on free hyphæ of a great variety of form and association, or in other cases the asexual spores are borne on short hyphæ enclosed in bottle-shaped or oval cases resembling the sac fruit bodies. The perfect stage is represented by the true sac

Fig. 228.
Black knot of plum (Plowrightia morbosa), showing deformities of the stems.

fruits, or fruit bodies, containing the sacs or asci, the greater number of the species having sacs each containing eight spores.

428. Examples of the black fungi.—A few only are briefly mentioned here. The *black knot* of plum and cherry (*Plowrightia morbosa* or *Otthia morbosa*). This produces black rough excrescences on the limbs of living cherry and plum trees, which spread from year to year, finally encircling the limbs and killing them. When a tree is badly infected it is an ugly sight. In early summer the knots are covered with a black velvety growth of short erect hyphæ bearing the conidia. During the winter the sac fruits are formed, and are thickly crowded over the surface of the knot, the spores ripening along in February. These knots should be cut out and burned, or badly infested trees removed and all diseased branches burned.

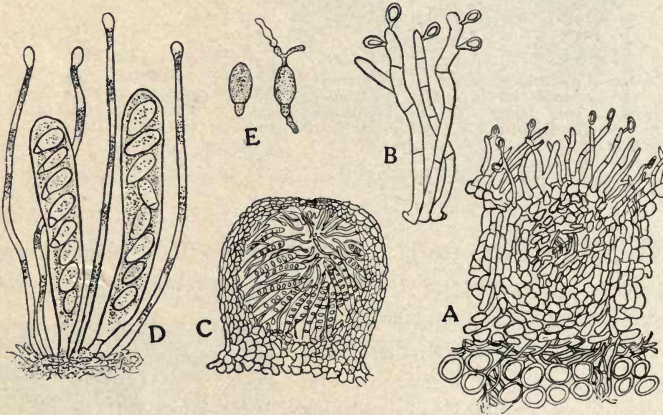


Fig. 229.

Plowrightia morbosa, showing details of the fungus which causes the galls. *A*, section through the velvety stroma, showing conidia bearing stroma. *B*, conidiophores and conidia still more enlarged. *C*, a single perithecium containing asci and paraphyses. *D*, paraphyses and asci containing spores still more enlarged. *E*, ascospores, one germinating. (After Farlow.)

429. The cup fungi.—These include a large number of sac fungi which are mostly saprophytic, and grow on the ground, rotten and dead wood, leaves, etc. Many of these belong to the old genus *Peziza*. The asci are crowded over the upper surface of the cup, and surrounded below and on the sides by the sterile

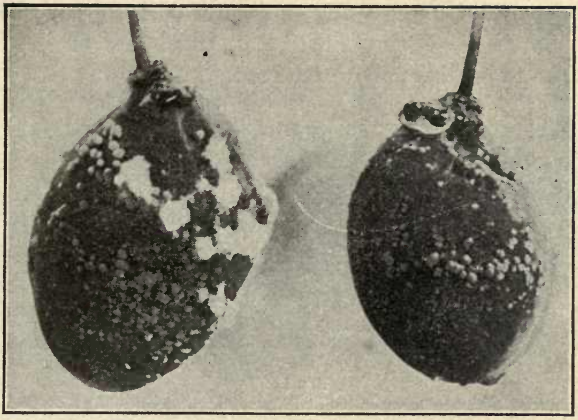


Fig. 230.

Plum rot (Sclerotina fructigena), showing the conidial stage (Monilia fructigena) of the fungus, on the surface of the plums, which causes the rot. Natural size.

tissue of the fruit body or *ascoma*. A few are parasitic. One of the most injurious (*Sclerotinia fructigena*) causes the common brown rot of cherries, plums, peaches, and sometimes of apples also. The asexual stage (*Monilia*) causes the rot of the fruit. The conidia are borne in long chains. The rotted peaches and plums become dried and "*mummified*," and many hang on the trees for a large part of the winter and the following summer. They fall to the ground, and after passing another winter, half

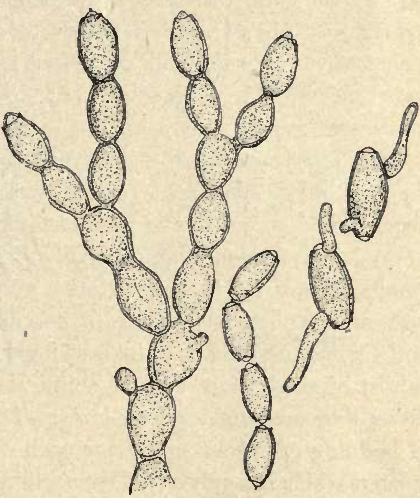


Fig. 231.

Monilia fructigena, showing chains of conidia, also showing how the conidia separate from each other in the chains. Two conidia at the right germinating. (After Woronin.)

or completely buried in the ground, the dormant mycelium in the "mummies" develops the cups, which are supported on long stalks to lift them above the ground.

Fig. 232.

Sclerotina fructigena, the trumpet-shaped fruit bodies growing from old peach mummies which were affected with the rot. Natural size.

430. The morels.—These are large fleshy fungi with a stout stalk bearing a large head which is covered with numerous shallow depressions separated by ridges. The entire surface of the head is covered with the asci intermingled with numerous sterile hyphæ (paraphyses). The morels (*Morchella*) appear in damp places in early spring and are prized as edible fungi. They are sometimes called mushrooms, but do not belong to the true mushroom group.

431. The yeast fungi.—The yeast fungi, or sprouting fungi, as they are often called, are by some classed among the sac fungi as degenerate forms. The yeast plant is remarkable for its activity in producing fermentation especially of solutions containing sugar (see paragraph 192 for fermentation by yeast), giving off CO_2 and forming alcohol; one yeast (*Saccharomyces cerivisece*) is used both in bread-rising and in brewing beer. The yeasts usually consist of single cells, oval or elliptical in form, and in this condition they are single-celled plants. They multiply by a process of budding or sprouting. Near each end of a cell a small bud appears which has only a frail connection with the parent yeast cell. This bud increases in size, and soon separates, forming a new yeast plant. Sometimes these buds remain connected for a time, forming small colonies, which soon separate into the separate cells if disturbed. When the air is largely excluded from sugar solutions in which the yeast is growing, fermentation goes on rapidly

Fig. 233.

Edible Morel. Morchella esculenta. The asci, forming hymenium, cover the pitted surface.

and the growth and multiplication are retarded. With the introduction of more air fermentation is retarded, while growth and multiplication are accelerated. Under proper conditions of temperature and with very free access of air, spore formation takes place. The protoplasm in a yeast cell condenses into three or four small globose shining bodies which are retained in the yeast cell, the nucleus having previously been divided into four nuclei. The yeast cell with the enclosed spores is regarded as an *ascus*. The yeast plant, however, is supposed to be a degenerate form, for some of the other sac fungi as well as some of the spore-case fungi (or alga-like fungi) under certain conditions degenerate into yeast forms. No one, however, has ever succeeded in changing the true yeasts into any of these better organized forms, though some yeasts form a temporary mycelium which later breaks up into yeast cells. The yeast used in bread "rising" and in brewing beer is now a domestic or industrial form. There are, however, many wild yeasts, which are abundant on all sorts of vegetables and multiply in decaying parts. Some of these wild yeasts are associated with certain bacteria, forming little nodules which have been used by natives of certain countries in making fermented drinks, as "ginger beer" from the "ginger-beer" plant, or "kumiss" from mare's milk fermented by throwing in some of these grains, which is used by some of the tribes of the Caucasus.

The Lichens.

432. Nature of lichens.—The lichens are curious structures composed of the elements of two different kinds of plants, a fungus and an alga. The plant body of the lichen is made up of fungus threads in the meshes of which the algæ are enclosed. Many of the lichens are greenish in color, this color being imparted to the lichen thallus by the algal cells underneath the outer layer of fungus threads. Others are brown, reddish, etc. Their method of nutrition is interesting and illustrates one of the forms of *symbiosis* (paragraph 206). The algal cells perform the function of photosynthesis, so that the fungus element as well as the algal is provided with the necessary carbohydrates. The fungus is thus entirely dependent on the alga for its organic or carbohydrate food. On the other hand the fungus, being external in most cases, and forming the "rhizoids" and holdfasts, supplies the solution of mineral and nitrogenous substances, protects the alga during dry seasons and holds it in place on steep slopes. Many lichens are multiplied and propagated naturally by small specialized bits of the lichen thallus (*soredia*) which become separated from the main body. The fruiting stage, however, is that of the fungus. The fruit of the perfect stage in nearly all of the lichens is that of the sac fungi with which they are classed. There are a few tropical forms with basidium fruit fungi. A large number of the lichen sac fungi have fruit bodies like those of the black fungi, while in many others they are like the cup fungi. Other peculiarities of the lichens can be noted after the study of a few forms.

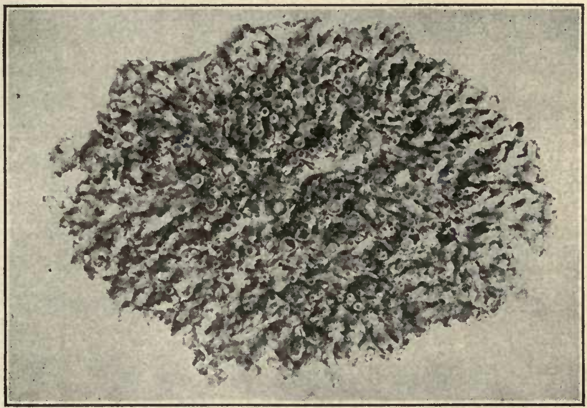


Fig. 234.
Foliaceous lichen (Physcia stellaris). Natural size.

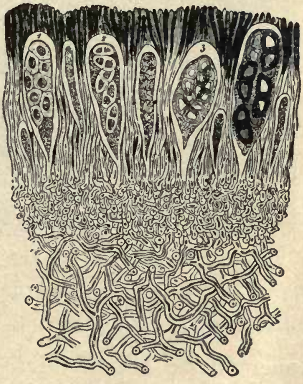


Fig. 235.
Much enlarged section of portion of lining layer, showing the asci (1, 2, 3, 4) with their contained spores. (After Sachs.)

433. The foliaceous lichens.—These are leaf-like, and grow on rocks, fences, tree trunks, or on the ground, where they are more or less loosely attached. A common one on board and rail fences as well as on other woody structures is the star-shaped *Physcia* (*Physcia stellaris*). The plant is circular, rather closely appressed to the wood, and the margin is radiately divided into narrow irregular lobes, giving it a star-shaped form. It is dull gray in color. Scattered over the central portion are a number of cup-shaped or saucer-shaped bodies, the fruit bodies, or the *apothecia*, as they are called in the lichens. This fruit body is like that of the cup fungi. The sacs or asci are mingled with numerous sterile hyphæ (*paraphyses*) which overtop the asci and broaden out, thus forming a covering (epithecium) over the ends of the asci.* *Parmelia* is another very common foliaceous lichen growing on rocks, sometimes very common on small stones in the field. *Peltigera* is a common one growing on leaf mold in the forest.

434. The fruticose lichens.—These are more or less erect forms and often very much branched. Some species of *Cladonia* grow on rotting wood, and one species with bright red rounded tops is very common on rotten stumps and logs. The bright red bodies are the fruit bodies (apothecia), which here are arched instead of cup-shaped. Another species of *Cladonia* (*C. rangiferina*) is the reindeer moss. It is profusely branched into slender grayish green branches. It is very common on the ground of the arctic tundra, sometimes covering extensive areas. It is eaten by the reindeers. Another common

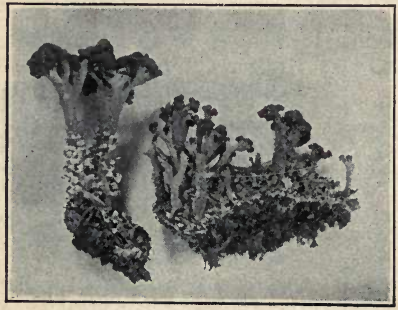


Fig. 236.

Fruticose lichen (Cladonia cristatella), thallus grayish green, the tips bright red. Grows on rotten logs, etc. Natural size.

---

* The fruit body of the lichen is the *ascoma*. The sterile wall outside of the group of asci is the *excipulum;* the broadened ends of paraphyses united above the asci form the *epithecium;* the tissue beneath the asci is the *hypothecium.*

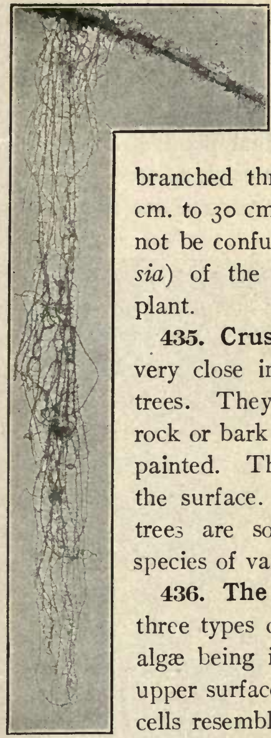


Fig. 237. Lichen (*Usnea barbata*), often called hanging moss.

fruticose lichen is the "hanging moss" of the Northern States (*Usnea barbata*), often found hanging from the limbs of trees in damp or swampy woods. It consists of very fine, grayish, much-branched threads, sometimes reaching a length 20 cm. to 30 cm. or more, but usually smaller. It should not be confused with the "hanging moss" (*Tillandsia*) of the Southern States, which is a flowering plant.

435. Crustaceous lichens.—These form thin and very close incrustations on rocks and the trunks of trees. They are often so closely connected with the rock or bark that it looks as if the latter were merely painted. The minute fruit bodies are scattered over the surface. The trunks of young beech or birch trees are sometimes nearly covered with different species of various colors.

436. The gelatinous lichens.—In the above three types of lichens the fruit body is stratified, the algæ being in a layer a short distance below the upper surface. The algæ present are usually isolated cells resembling the alga *Pleurococcus*. In the gelatinous lichens the algal element is more evenly mixed with the fungus element. The algæ here are often of the *Nostoc* type. *Calluna* is an example.

437. The work of lichens in soil building.—The lichens are believed to be among the most important early agencies in soil making. Growing as many of them do on bare rocks where scarcely any other vegetation can hold, especially on sloping surfaces, their disintegrating bodies mingle with the finely weathered and disintegrated rock which lodges in crevices. Here many ferns, grasses, and other plants can find a foothold and obtain nourishment. The algæ can also grow on moist rocks, but are killed when long exposed to dry air in these situations. But when the alga is surrounded by the close mat of fungus elements in the lichen body it is prevented from injurious desiccation and is held on even to steep slopes or perpendicular rock faces.

438. The relation of the algæ and fungus in the lichen thallus.—In the early history of the study of lichens it was thought by some that the lichen was an individual plant (autonomous plant), and that the algal cells were special spores (*gonidia*) which were cut off from the colorless threads of the mycelium.

Fig. 238.

Lichen tundra, showing the "reindeer moss" or lichen, Alaska. (Copyright by E. H. Harriman.)

Opposed to this theory another one came to be accepted by some students, i.e., that the alga and the fungus are distinct plants, and this theory has finally prevailed. The most important arguments presented for this theory were furnished by some investigators who separated the spores of the lichen and grew them free from the algæ, and also separated the algal cells and grew them as separate algæ. In this way it has been possible to identify some of the algæ with those which are found in a free state. *Pleurococcus vulgaris*, so common in cool shady places, is one of these. The blue-green alga *Nostoc*, with cells like a chain of beads, has been found to be a component of many of the gelatinous lichens. When the spores of these lichens are germinated in the presence of these algæ, the mycelial threads coil around the algæ, envelop them, and finally a complete lichen thallus is developed which ultimately bears the fruit bodies and asci.

439. Uses of lichens.—As mentioned above, the "reindeer moss" in the arctic regions is eaten by the reindeer. In lower latitudes where it is abundant it is often used as packing material to protect furniture or frangible wares. Some arctic lichens (*Cetraria*), called "Iceland moss," are used for food by grinding them and mixing them with ground wheat. Others which contain purple or blue or crimson pigments are used for making dyes called "archil," also orchil or cudbear. This lichen (*Roccella tinctoria*) grows on rocks in the Canary and Cape Verde Islands. Litmus paper is made from the litmus dye prepared by treating orchil with soda or potash.

440. The life history of the sac fungi which produce the fruit bodies (perithecia, or ascocarps, a more general term) as a result of a sexual act can be represented as follows, starting with the mycelium as the plant. Plant — asexual spores — Plant — asexual spores — Plant — $\left\langle \begin{matrix}\text{sperm gamete}\\ \text{egg gamete}\end{matrix} \right\rangle$ ascocarp — ascospore — Plant, etc., abbreviated as follows: P — asp — P — asp — P $\left\langle \begin{matrix}\text{sg}\\ \text{eg}\end{matrix} \right\rangle$ asc — sp — P, etc. Where the asexual spores are not formed in the life history they would be omitted from the formula.

CHAPTER XXVIII.

FUNGI (Continued).

THE BASIDIUM FUNGI (CLASS BASIDIOMYCETES).

*The Smuts.**

441. General characters.—The smuts are a group of fungi parasitic chiefly on the flowering plants. The mycelium lives in the interior of its host. The spores have usually rather thick brown walls, and are usually produced in great masses in the fruiting part or stems of the host, after the mycelium has consumed these parts. These masses break down into a fine dark powder mixed with the minute dark spores, which gives a smutted appearance to the affected parts of the host.

442. The corn smut.†—The corn smut (*Ustilago zeæ*) is one of the most common and conspicuous species of the smuts. Nearly every field of Indian corn shows a number of examples and often many plants are affected. It forms large excrescences on the ears, the tassel, the joints of the stem, and even on the leaves. These are at first whitish, but later become black as the spores ripen. The masses of smut then are often very large. The spores in this smut-mass are rounded, minute, spiny bodies. When these spores germinate a short hypha or germ tube is formed which has a few cross walls. Small elongated spores are formed on the sides of this hypha (called here a *promycelium*) near the joints or cross walls. These are called *sporidia*. When these sporidia fall

---

* The smuts are not true basidiomycetes. The promycelium formed by the germination of the smut spore is believed by some to be an elementary, or "beginning," basidium. If so, the smuts would belong to the basidium series representing very low forms of the same.

† To the Teacher. The corn smut may be used for the practical work and others may be introduced for comparison.

down between the young blades at the end of a growing corn stalk they germinate, producing a germ tube which enters the tissues of the corn plant and about six or eight weeks later produces the smut masses again. The *infection* is *local* in the case of the corn smut, any of the embryonic tissues of the corn being susceptible if the germinating sporidia are present. The infection which produces the smut at the lower joints of the stalk takes place earlier than that in the ear or that on the tassel. The corn smut is often relished by cattle, and does not seem to injure them unless they eat too great a quantity.

Fig. 239.
Corn smut (Ustilago zeæ), affected ear, stalk, and blades.

443. Other species of smut.—Other examples of smut are the loose smuts on the grains, as the loose smut of oats (*U. avenæ*), the loose smut of wheat (*U. tritici*), and the loose smut of barley (*U. hordei*). The only part of the host injured is the flower, the young kernels (ovary) and parts of the palets being reduced to a black smutty mass consisting of disintegrated parts of the flower, the mycelium, and the spores. They are called loose smuts because the mass of spores not being covered, even by any delicate membrane, the spores are easily scattered. Although only the flower parts are injured, the mycelium travels all through the host while it is growing, from the seedling up to the full-grown plant. The method of infection is very interesting. In the case of the oat plant the smut spores clinging to the seed oats germinate at the same time that the oat grains do. The sporidia

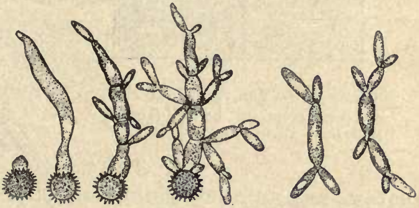


Fig. 240.
Corn smut, spore germinating and producing sporidia. At the right, sporidia budding and producing secondary sporidia. (After Brefeld.)

formed on the promycelium germinate and the germ tube enters the oat seedling at the base of the first leaf sheath. In the case of the loose smut of wheat and barley the method of infection is different. At the time the wheat or barley is in flower, the smut on the affected plants in the field is just ripening, and spores are blown from the smutted heads to the open flowers of healthy plants. The spores lodge on the feathery style of the flower and germinate. They do not produce a promycelium, but the germ tube of the spore enters directly into the style, and passes down into the ovary, where it forms a small amount of dormant mycelium which, however, does not injure the grain, so that it ripens with the dormant mycelium of the smut imprisoned. When these grains of wheat are sown, the dormant mycelium begins to grow as the seed germinates, and passes through the scutellum into the shoot. It then continues to grow along with its host, as in the case of the oat smut. Beside the loose smut of barley there is another, the *covered* smut,

Fig. 241.
Loose smut of barley (Ustilago nuda). ½ diameter.

Fig. 242.
Bunt or stinking smut of wheat (Tilletia tritici). Note the flaring position of the palæ.

so called because there is a thin membrane, the remnant of the palets, which covers the mass of smut, so that it does not so readily scatter. There is also another kind of wheat smut, the *stinking* smut (two species), so called because of its foul odor. This smut injures only the interior of the wheat grain, which it changes to a greasy mass of black smut spores covered by the uninjured seed coats and ovary wall. The grains have the appearance externally of being perfectly sound, but they are somewhat stouter than the normal grains. Infection takes place as in the case of the oat smut, but the promycelium of the germinating spore is undivided, and the sporidia, which are narrow, long, and slightly curved, are borne in a cluster at its apex.

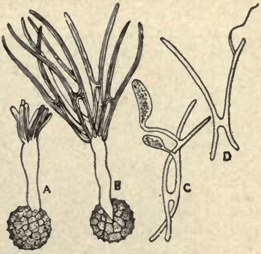


Fig. 243.
Spores of "bunt," or "stinking smut" of wheat (*Tilletia tritici*) germinating. *A*, spore producing promycelium and young sporidia. *B*, later stage, sporidia mature and conjugating in form of letter *H*. *C–D*, germinating sporidia forming secondary spores.

444. Treatment for the prevention of smut.—To prevent the loose smuts of wheat and barley, seed should be selected from fields free from smut. Oat smut and the stinking smut of wheat can largely be prevented by treating the seed wheat with formalin, or by a solution of copper sulphate, or by hot water (at 128°–132° F. for a few minutes). In the case of corn smut infected stalks should be cut out and destroyed before the smut masses ripen.

Rust Fungi (Uredinales).[*]

445. The rust fungi.—There are a large number of species of rust fungi on grasses, cereals, herbs, trees, and ferns. All of them are parasites, and some cause great injury and loss. The loss to the wheat crop in the United States is estimated variously from $20,000,000 to $60,000,000 annually. The yellowish or blackish spore masses, often thickly scattered over parts of the

---

[*] The wheat rust can be used for the practical study. If the cluster cup on barberry cannot be had, use other cluster cups.

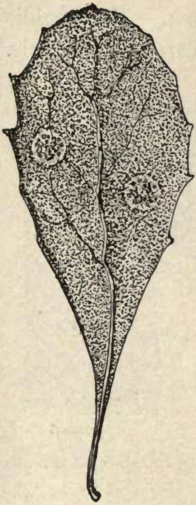
host, give a rusty appearance to them, hence the name. The mycelium is within the host and intercellular. It sends short haustoria into the cells, where they absorb nutriment. In many cases it causes hypertrophy of the host, i.e., stimulates the affected part of the host to abnormal growth, forming witches' brooms in one form on the balsam, or galls as in the case of the cedar apples (paragraph 456), etc. Some of these abnormal growths are edible, as the branches of an acacia in India deformed by *Æcidium esculentum*, and in Scandinavia the branches of the fir deformed by *Æcidium corruscans*. The life history is very complicated in some species and is well illustrated by the wheat rust.

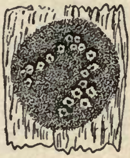
Fig. 244.
Witches' broom on balsam (Abies balsamifera) caused by a parasitic fungus (Æcidial stage of Melampsorella cerastii), from northern Michigan.

Wheat Rust (*Puccinia Graminis*).

446. The wheat rust produces one of the common rusts on cereals and grasses in many parts of the world, and one stage in its complete life history occurs on the barberry.

447. The cluster-cup stage on the barberry.—The diseased spots on the leaves of the barberry are yellowish and round. Upon the under side of the leaf there can be seen minute cup-shaped structures (æcidia) distributed over the spots. These are better seen with the aid of a pocket lens. In figures 248, 249, a section of the barberry leaf through one of these spots shows its relation to the host and the mycelium between the cells. The cup is formed of a bundle of stout hyphæ with stout short cells growing out from this mycelium and bursting through the epidermis of the





Figs. 245–247. Cluster-cup stage of wheat rust.

Fig. 245.
Barberry leaf with two diseased spots. Natural size.

Fig. 246.
Single spot, showing cluster cups enlarged.

Fig. 247.
Two cluster cups more enlarged, showing split margin.

leaf. The hyphæ of the outer layer are sterile, and remain united laterally to form the wall (peridium) of the cup, which is first closed over the top but later opens out. The cells of the central bundle of hyphæ, in chains, separate at maturity and form the cluster-cup spores (æcidiospores). Upon the upper side of the spot are much smaller, yellow, conical elevations, seen in cross section at fig. 249. These are the *spermogonia*. They produce numerous very tiny, rod-shaped structures which ooze out at the opening of the flask-shaped spermogonia in a gelatinous mass, sweetish to the taste. Fertilization takes place by the fusion of two cells in adjacent rows at the bottom of the young cluster cup in some cases, and by the migration of a nucleus from a basal cell into the one above, or laterally situated in other cases. The cluster-cup spores develop in chains from this, each having two nuclei which do not fuse until the final stage of the life cycle is reached in the *teleutospore* (paragraph 449).

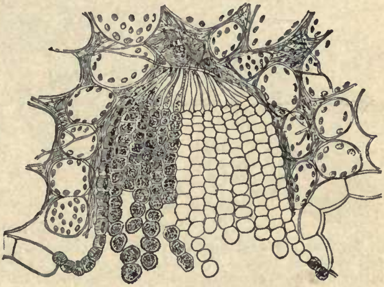


Fig. 248.
Section of an æcidium (cluster cup) from barberry leaf. (After Marshall-Ward.)

448. The red rust of wheat (uredo stage). — The æcidiospores from the cluster cup on the barberry are carried by the wind to the wheat (also to the other cereals and some grasses). Here they germinate and the mycelium enters at a stomate and produces the intercellular mycelium. At certain points under the epidermis of the leaf, or stem, a group of short spore-bearing hyphæ are formed, each of which bears a broadly elliptical spore with minute warts on the wall, and with a yellowish oil in the protoplasm. These spores are the *uredospores.* The pustule formed

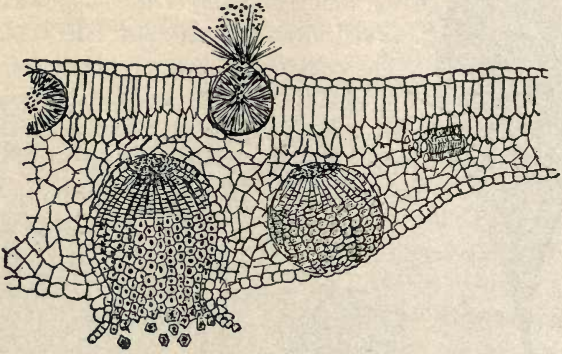


Fig. 249.

Section through leaf of barberry at point affected with the cluster-cup stage of the wheat rust; spermogonia above, æcidia below. (After Marshall-Ward.)

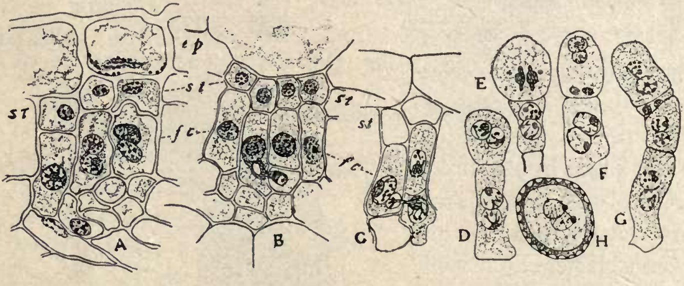


Fig. 250.

Fertilization and development of æcidiospores in a rust, Phragmidium violaceum. *ep*, epidermis of host. *st*, sterile cells at ends of æcidial thread. *fc*, fertile cells. *A*, part of æcidial stroma, showing two binucleate, fertile cells. *B*, showing nucleus of sperm cell at base of fertile cell passing into the fertile cell at the side. *C*, similar stage. *D–G*, different stages in formation of æcidiospores. *H*, mature æcidiospore. (After Blackman.)

here is called a *sorus*. The epidermis is ruptured by the growth pressure of the hyphæ and spores, and thus the spores are set free. These uredospores are carried by the wind to other wheat plants, starting new centers of the disease, and thus several successive crops of uredospores are formed in one season. The uredo stage is the propagative stage.

Fig. 251.
Wheat leaf with red rust. Natural size.

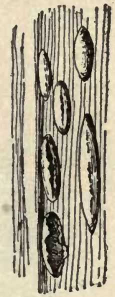


Fig. 252.
Portion of leaf enlarged to show sori.

Fig. 253.
Natural size.

Fig. 254.
Enlarged.

Fig. 255.
Single sorus.

Figs. 251–252. Puccinia graminis, red-rust stage (uredo stage).
Figs. 253–255. Black rust of wheat, showing sori of teleutospores.

Fig. 256.
Uredospores of wheat rust, one showing remnant of the pedicel.

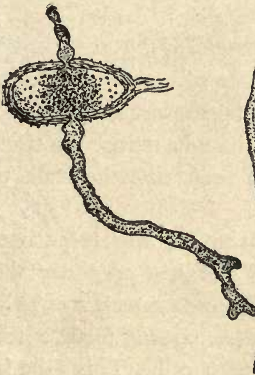


Fig. 257.
Germinating uredospore of wheat rust. (After Marshall-Ward.)

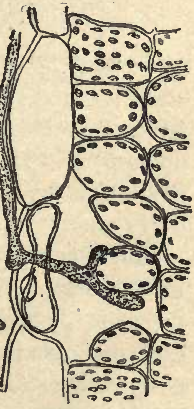


Fig. 258.
Germ tube entering the leaf through a stoma.

449. The black rust of wheat (teleuto stage).—On the mycelium which originates from the æcidiospores, in less abundance on that which originates from the uredospores, another kind of spore is formed, the *teleutospore*. These are either in separate sori (a teleutosorus) or they are mixed in with the uredospores. In the wheat rust the teleutospores are two-celled, with thick brown walls, and the stalk usually remains attached (fig. 259).

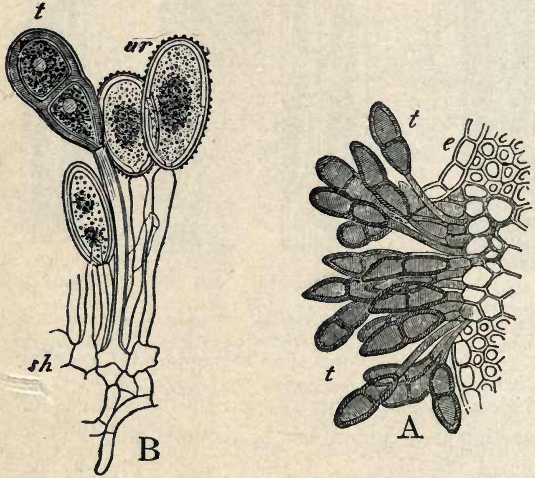


Fig. 259.

A, section through sorus of black rust of wheat, showing teleutospores. *B*, mycelium bearing both teleutospores and uredospores. (After de Bary.)

450. Germination of the teleutospores and infection of the barberry.—The teleutospores of the wheat rust rest during the winter on leaves and stems lying on the ground. In the spring each cell germinates, putting forth a tube through a *germ pore* near the apex of each cell. This tube is the *promycelium*, which divides quite regularly by three cross walls into four cells, each of which forms a small pointed outgrowth, the *sterigma*. Through this the protoplasm in the cell moves out and forms a small spore, the *sporidium*. This sporidium is carried by the wind to the barberry, where it germinates, the tube enters between epidermal cells into the barberry leaf, and starts the cluster-cup stage again, thus completing the life cycle.

Fig. 260.
Teleutospore germinating, forming promycelium.

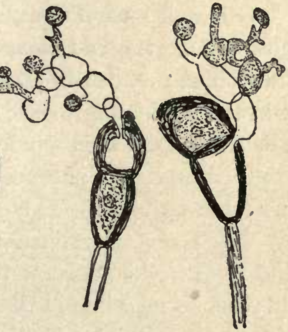


Fig. 261.
Promycelium of germinating teleutospore, forming sporidia.

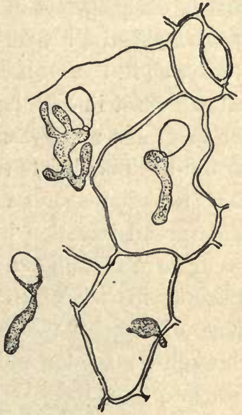


Fig. 262.
Germinating sporidia entering leaf of barberry by mycelium.

Figs. 260–262. Puccinia graminis (wheat rust). (After Marshall-Ward.)

451. Races of the wheat rust.—There are some peculiarities in the life of the wheat rust, which as stated above occurs on oats, barley, rye, and many grasses. For example, the uredospores formed on the oats can infect oats but cannot infect wheat, rye, barley, and some grasses; and the same is true with the uredospores from the barley, rye, and some of the grasses, — they cannot infect the oats and members of the other groups. The uredo- and teleuto-spores on these different plants cannot be distinguished as to form, size, etc. They constitute physiological races which have become confined to certain groups of hosts. In the case of all of these races, however, the sporidia from the teleutospores can produce the cluster cups on the barberry. But cluster cups originating from oat teleutospores cannot infect wheat, barley, rye, etc., but only oats and the members of the oat group.

452. How the wheat rust passes the winter in regions where the barberry is absent.—It has long been known that the wheat rust can live through the winter in the teleutospore stage. Since the sporidia from the teleutospores cannot infect the cereals or grasses but only the barberry, the appearance of the wheat rust in early spring, in regions where the barberry does not exist, has long been a mystery. It is well known that in southern latitudes, as in the Gulf States in America, and along the Mediterranean coast in Europe, the wheat rust can live through the winter in grains and grasses in the uredo stage, since the climate is so mild. This led to the belief that southern winds in the spring bore the uredospores northward and thus produced sudden and widespread infection in northern latitudes. This probably does occur to a certain extent. But recent investigations in northern Europe, in Wisconsin and North Dakota show that the uredo stage of some of the grain rusts, formed late in the autumn, lives through the winter and the spores germinate in the spring. The few infections from these early in the spring produce centers from which a second widespread and serious infection follows. In places in the northern peninsula of Michigan the ground is covered so deeply with snow that the ground does not freeze in the wheat fields. Fall wheat which has the uredo stage on it can thus carry the disease over the winter. The *mycoplasma* theory, propounded by the Swedish botanist Eriksson, according to which the protoplasm of the host and fungus is blended during the winter, and in the spring the fungus plasma can withdraw from this mycoplasma blend and form the mycelium, is not generally accepted.

453. Early history of our knowledge of the wheat rust.— This history makes a very interesting chapter of the story of botanical investigations, which is fascinating to read, but a brief account only can be given here. A half a century ago it was supposed that the four forms of the wheat rust described above (Æcidium, spermogonium or Æcidiolum, Uredo, and the teleutostage, or Puccinia) were distinct genera of plants, and that the two former belonged to a distinct family of plants. Prior to this time, the farmers of England, in the early part of the 18th century, believed the barberry plant caused wheat rust, because wheat was always more badly rusted on the leeward side of barberry bushes. As early as 1760 laws were passed in Massachusetts requiring barberry bushes to be destroyed. A little later a Swedish schoolmaster, Schoeler (in 1816), carried barberry leaves with the cluster cups into a rye field and rubbed the leaves on to the rye, so that he could see the masses of yellow cluster-cup spores on the rye leaves. These rye plants became badly infected, while the remaining plants around them remained healthy. Finally, in 1864–5, de Bary, a celebrated German botanist, demonstrated by experimental studies the connection of the cluster cup on barberry with the uredo and teleutospores on wheat, his investigations undoubtedly being stimulated by those of a renowned French botanist, Tulasne, who had previously shown the connection of the uredo and teleuto stages. These studies have since been verified, both in Europe and in the United States, in regions where the barberry grows.

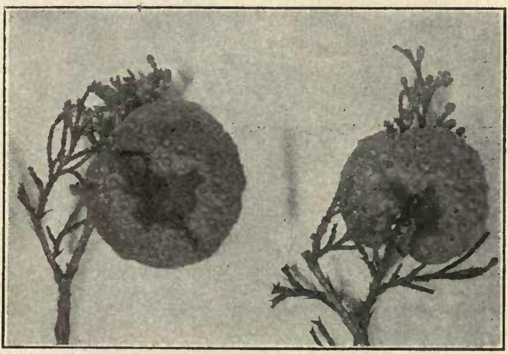


Fig. 263.

Cedar apples, the winter condition. Abnormal growth of the cedar caused by a fungus (Gymnosporangium macropus). The masses of spores ready to ooze out are in the little pits with the conical elevations.

454. Other grain rusts.—There are a number of other rusts which attack wheat and other cereals. One of the most destructive of these in this country is *Puccinia rubigo-vera*. In some regions in the United States this rust is more abundant and does more injury to the wheat than the *Puccinia graminis*.

455. Prevention of wheat rust.—No practical method has been found of successfully combatting the wheat rust. Formerly laws were enacted in England and Massachusetts requiring the destruction of the barberry, but this did not materially lessen the disease. The selection of resistant varieties gives promise of solving the problem. The "Marconi" wheats are more resistant than many other varieties, and experiments in crossing are being made with the hope of obtaining still more resistant strains (see paragraph 663).

Fig. 264.

Cedar apples after the spring rains begin. The mass of gelatin swollen by the rains is oozing out in strings and carrying with it the teleutospores of the fungus (Gymnosporangium macropus).

456. Cedar apples and cedar rust.—"Cedar apples" are galls formed on the leaves and young twigs of the cedar, through the stimulus of the mycelium of one of the rust fungi. These belong to the genus *Gymnosporangium*. In early spring, the teleutospores formed in the gall the previous year, in little nests, ooze out in strings in wet weather, because of the large amount of gelatinous substance formed in connection with the teleutospores, which absorbs water and swells. These gelatinous strings of teleutospores are yellow in color. The teleutospores germinate while in the mass, and the sporidia are carried to the apple, to hawthorns, and other trees where they produce the cluster-cup stage known as apple rust, etc., which occurs both on the leaves and fruit.

457. Life history of the wheat rust.—The complete life history of the wheat rust described above in abbreviated form is as follows, remembering that the mycelium or plant is present in all spore forms except in the formation of the sporidia on the promycelium.

Fig. 265.

Æcidial stage (Roestelia) of *Gymnosporangium*, showing tube of the cup split into numerous slender divisions which are recurved against the leaf. On leaves of *Crataegus*.

Æcidial stage with spermogonia on the barberry. Æcidiospores carried to the grasses and cereals. Uredo stage with repeated crops of uredospores, the uredo stage being the propagative stage, mycelium finally producing teleutospores. Teleutospores after a period of rest * produce a promycelium from each cell with four sporidia. The sporidia pass to the barberry, infect it, produce mycelium which gives rise to more spermogonia, æcidia and æcidiospores. The cycle of the life history may be represented by the diagram III A, and in diagrams B, C, D are

---

* In some species the teleutospores germinate as soon as they are mature, example, the hollyhock rust.

shown the life cycles of rusts having fewer spore forms. For example, some lack the uredo stage, as in *Puccinia podophylli* on the mandrake; others lack the æcidial stage, as in *Puccinia taraxaci* on the dandelion; while still others lack both æcidia and uredo, having only the spermogonia and teleuto stage, as in *Puccinia malvacearum*, the rust of the hollyhock.

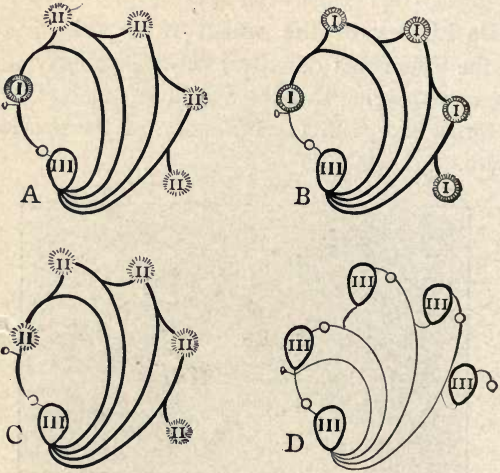


Diagram III. Illustrating life cycle in the development of the four different form cycles in the rusts. The heavy-walled oval bodies enclosing the bold face No. III represent the primary teleutospore. The circles with the bold face No. I represent the primary æcidium. The circles with the short radiations or spines with bold face No. II represent the primary uredo, and the lighter Nos. I, II, III in the figures represent the corresponding secondary æcidium, uredo and teleutospore stages which are propagative, and thus repeat the cycle. The small circle connected with the teleutospore by a short, narrow line represents the promycelia and sporidia. The narrow line issuing from the sporidium represents the mycelium of the æcidial stage, the cells of which are uninucleate. The small elliptical body connected with this line by a narrow, short line represents the spermogonium; the cells of this are also uninucleate. The broad lines represent the mycelium produced by the germination of the æcidio- and uredo-spores. In reading the cycle pass from left to right.

A represents the cycle of those species having all four spore forms. *B* represents the cycle of those species in which the uredo stage is absent. *C* represents the cycle of those species in which the æcidium is absent. *D* represents the cycle of those stages in which both the æcidium and uredo are absent.

CHAPTER XXIX.

FUNGI (Concluded).

BASIDIUM FUNGI (Concluded).

Mushrooms, Bracket Fungi, Puffballs, etc.

458. The mushrooms.—The word mushroom was formerly applied to certain of the fleshy gill-bearing fungi, and probably was first used for the common cultivated mushroom (*Agaricus campestris*), which also grows in pastures, lawns, etc. Some use the word as synonymous with all the basidium fungi. But this seems too

Fig. 266.
A poisonous "mushroom" (Amanita muscaria), the fly agaric.

To the Teacher. Either the common mushroom (which usually can be obtained in the market during the winter) or one of the other agarics should be studied. The group of fungi can be farther illustrated by a number of the bracket fungi, fairy clubs, puffballs, earth stars, etc., which are easily obtained and preserved dry. It would be an excellent plan to have one or two of the poisonous Amanitas preserved dry, or in alcohol, for illustration.

broad. Others use it for all the fleshy larger fungi, including the morel, one of the sac fungi. This appears to be a better use of the word. The word toadstool is used by some to denote the poisonous species, while mushroom is applied by the same persons to denote the edible fungi. But few of the advocates of this distinction between mushroom and toadstool know what constitutes a toadstool, and call many edible fungi, toadstools. Most botanists make no distinction between the words but use them synonymously, and speak of edible and poisonous mushrooms.

Fig. 267.
An edible "toadstool" (Amanita cæsarea), Cæsar's agaric.

These higher members of the basidium fungi we will treat under the following heads: 1st, the Gill Fungi; 2nd, the Bracket Fungi or Pore Fungi; 3rd, the Coral Fungi, or Fairy Club Fungi; 4th, the Hedgehog Fungi, or Tooth Fungi; 5th, the Puffballs, etc.

The Gill Fungi.

459. The gill fungi.—The gill fungi are provided with thin narrow leaf-like outgrowths on the underside of a "cap." These gills, or lamellæ, stand close together and radiate from the central part of the under surface of the cap, or from its point of attachment with a stem, or wood when the fungus lacks a stem and the cap is attached directly to the substratum. These thin plates, or *lamellæ*, are covered with the club-shaped structures, or *basidia*, which are characteristic of the basidium fungi. Where these basidia stand side by side covering extensive surfaces, as in the higher basidium fungi, they form a fruiting surface or *hymenium*. The surface of the gills then is the fruiting surface of the gill fungi. Two to four spores, usually four, are borne on each basidium.

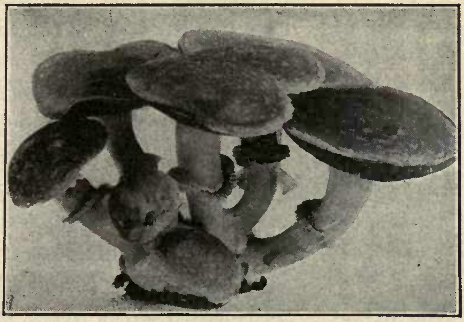


Fig. 268.
The cultivated mushroom (Agaricus campestris).

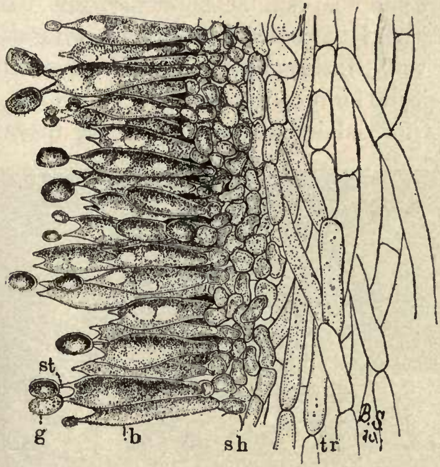


Fig. 269.
Portion of section of lamella of Agaricus campestris. *tr*, trama; *sh*, subhymenium; *b*, basidium; *st*, sterigma (*plural* sterigmata); *g*, basidiospore.

460. The common mushroom (Agaricus campestris).—The parts of the common mushroom are as follows. A cylindrical *stem*, or *stipe*, supporting a circular convex *cap*, or *pileus*. The gills, or lamellæ, are attached to the underside of the pileus and are closely crowded, extending radially from near the stem to the margin of the pileus, the V-shaped spaces between the larger ones being filled in by shorter ones. On the stem is a thin membranous collar, the *ring* or *annulus* (fig. 268). In fig. 269 is a section of the gills showing the club-shaped basidia with the sterigmata bearing the spores. In the cultivated forms there are often only two spores to a basidium, while in the field form there are usually four.

461. Development of the mushroom.—The development of the mushroom is briefly as follows: The mycelium spreads through the soil or substratum, forming fine white cords. This is known as the spawn. When this is well established small rounded compact masses of mycelium are formed on the cords. These are the young fruit bodies which are to develop into the mushroom. When they become from 3 mm. to 5 mm. in diameter, the parts of the mushroom are differentiated, the upper part into the cap, the lower part into the stem, and the outer portion midway forms the *veil*. Inside of this veil the hymenium begins to form on the underside of the cap, and a circular opening is formed by the parting of the tissue between the veil, the upper part of the stem and the cap. This leaves room for the development of the gills which grow downward from the cap. This is the "button" stage of the mushroom. All parts continue to expand, the stem elongates, the cap broadens, and the veil becomes well formed. Finally the veil ceases to grow,

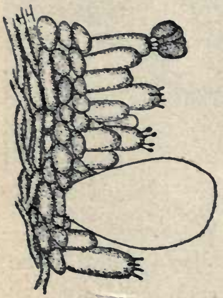


Fig. 270.

Portion of hymenium of Coprinus micaceus, showing large cystidium in the hymenium.

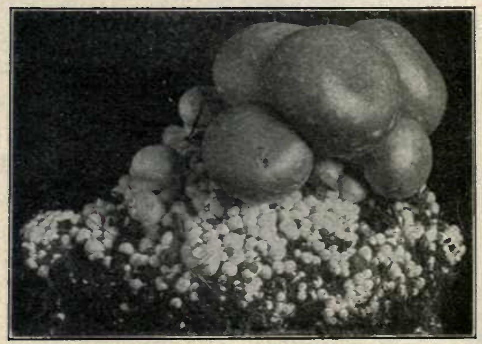


Fig. 271.

Cluster of young mushrooms, a few of the larger ones developing to maturity.

becomes stretched, breaks away from the margin of the cap, and is left as a collar or ring on the stem. The gills are first pink, then become dark brown or blackish as the spores with brown walls ripen. The spores then fall from the gills. Under favorable conditions these spores germinate and produce more mycelium and spawn. Besides the common mushroom there are several hundred edible ones in many genera but they cannot be discussed here.

462. Some poisonous mushrooms. — The most dangerous poisonous mushrooms belong to the genus *Amanita.* The genus *Amanita* has white spores, a cap, stem, and ring which comes from the veil as in the common mushroom. The gills are free from the stem or lightly attached and the stem is usually easily separable from the cap. In addition there is present a distinct envelope, surrounding the entire plant in the young or button stage, known as the *volva*, which should be clearly understood in its different forms in order to be sure of the genus. Only three forms of the volva will be described here in the following species. *Amanita phalloides*, and its forms or closely related species, is the most dangerous one, being "deadly" poisonous. The species in its typical form in Europe has a greenish or greenish-brown pileus. The volva splits at the apex as the plant emerges and is left as a

Fig. 272.

A poisonous mushroom (Amanita mappa), cap pale yellow with patches of a delicate, floccose, pale brownish substance; veil, stem and gills white; under-surface of veil sometimes very pale lemon yellow; upper portion of bulb saucer shaped. × ½ diameter.

prominent sack or bag around the base of the stem. *Amanita verna* is considered by some as a white form of this species. This is common in America. *Amanita mappa* has a pale yellow cap; the volva splits transversely, leaving portions on the cap in the form of floccose patches or warts. The lower part is left as a narrow rim on the outer edge of the broad bulb of the stem. The poisonous principle in the above three species is *phallin*, a substance thought to be of an albuminous nature. It dissolves the blood corpuscles and the serum escapes into the alimentary canal. No antidote is known. Another poisonous species is *Amanita muscaria* (fig. 266), the " fly agaric." It has a red, or yellowish red cap, white gills and stem. The volva splits transversely, the upper part being left as coarse white warts on the pileus which is striate on the margin. The lower part of the volva is left near the base of the stem, as one to three coarse rings on the bulb. The poisonous principle in the fly agaric is *muscarine*. It paralyzes the nerves which control the action of the heart, and if not counteracted results in death. Hypodermic injections of small doses of *atropin* stimulate the heart to greater activity, thus counteracting the poison until its effect has disappeared.

Bracket Fungi or Pore Fungi.

463. The bracket fungi.—These are the firm fungus growths of a shelving form so common on dead or living trees, stumps, logs, etc., in the forest. The under surface is very finely honeycombed with minute tubes or pores (characteristic of the family *Polyporaceæ*). The fruiting surface or hymenium lines all these pores. Some of these bracket fungi are hoof-shaped, or tongue-shaped. They grow singly or in clusters. In some of them the age can be determined by counting the number of concentric rings on top, as in the pine-inhabiting polyporus which grows on the conifers, the charred polyporus growing on birch, beech, maple, oak, apple, etc. One of these has been found which was eighty years old. This one, and related bracket fungi, were used in early times as " tinder " for holding and lighting fire. Some are peeled into thin strips and made into garments by peasants of some European countries. In some species there are several rings formed each year on the surface so that this will not indicate the age, as in the flattened bracket fungus, so often used for sketching or writing on the under surface. But the age of this fungus can be determined by splitting it in two along the middle, since there is one stratum of tubes formed each year on the underside. Some of the bracket fungi are annual, that is, they die during the same season in which they are formed, but the mycelium may live in the trunk many seasons, a century or longer, every now and then producing new fruit bodies. Many of these bracket fungi are called wood-destroying fungi, because the action of the mycelium is so destructive to timber (see paragraph 215). Some of them are called "wound" parasites, since they can only enter living trees through a wound in the cambium layer, or when a limb is broken off, or carelessly pruned. The heart wood being dead the mycelium can then enter, and produce heart rot, thus destroying the timber and weakening the tree and its roots. Many of the pore fungi are not bracket forms. Some are spread out on the surface of wood, and many have a cap and central stem. The largest number of those with central stem are quite large fleshy fungi belonging to the genus *Boletus*. Some of these are edible as the "*Steinpilz*" of Germany, or the "*cèpes*" of France (*Boletus edulis*). Some are said to be poisonous. Many have bright

Fig. 273.
Pine inhabiting Polyporus (Polyporus pinicola) growing on fallen hemlock log.

Fig. 274.
Charred Polyporus (Polyporus igniarius) growing from knot hole on beech. × ¼ diameter.

and beautiful colors. The flesh of some quickly changes to blue, green, or red, when bruised or cut.

464. The coral fungi, or fairy clubs (Clavariaceæ).—The fairy clubs are the small, club-shaped, fleshy, basidium fungi, growing on the ground in forests and groves. The largest one, "*Hercules' club*," is 10–20 cm. (4–8 inches) long and 1–3 cm. in diameter. The smallest can just be seen with the eye. The fruiting surface covers the entire surface except the lower part of the stem. They grow singly or in clusters, and many of the species are very much branched, suggesting a coral-like growth. None of these are known to be poisonous.

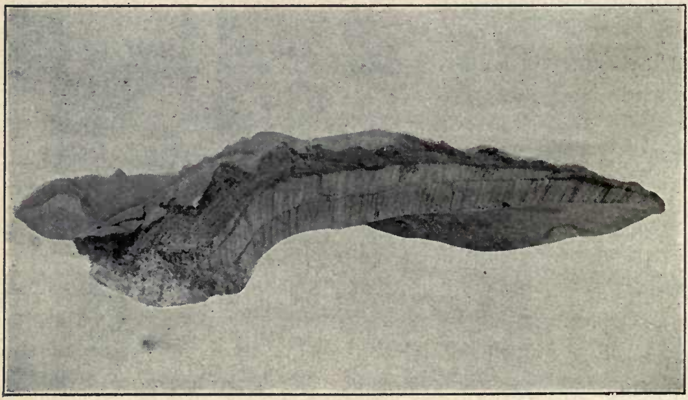


Fig. 275.
Section of the flattened Polyporus (Polyporus applanatus), showing two layers of tubes, one layer developed each year.

465. The hedgehog fungi, or tooth fungi (*Hydnaceæ*).—The members of this family are called "hedgehog" fungi, or "tooth" fungi because they bristle with long spines which hang downward. Some of the much branched forms are also popularly called coral fungi. The fruiting surface covers the surface of the spines which are often called *teeth*.

466. Puffballs, earth stars, etc.—These make up a large group of fungi containing several orders. They grow on the ground, or on rotting wood, and a few on the bark of living trees. A few are subterranean. They are mostly rounded or oval in shape, and a few have short or long stems. In nearly all, the fruit body has an envelope, the wall or peridium, which opens irregularly in some, as in the giant puffball, or with a minute pore at the apex. In the "earth stars" the outer layer of the wall splits regularly and turns back in the form of a star, while the inner layer opens by a pore at the apex. The interior of most of the puffballs is a many chambered structure, on the walls of which the fruiting surface is formed. At maturity the internal tissue mostly breaks down into a powdery mass which, with the spores, makes the "smoke" of the puffballs. The "stink horn" fungi are related

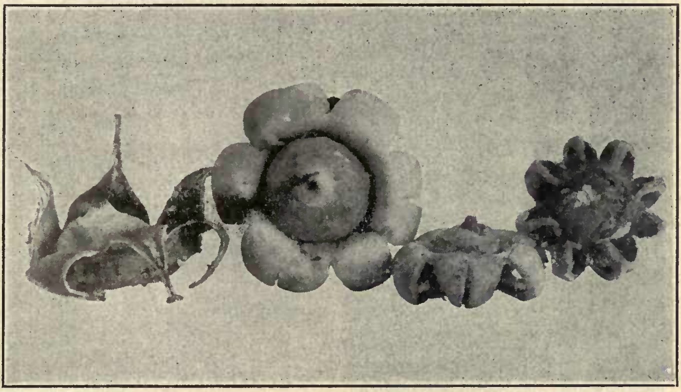


Fig. 276.

Earth stars (Geaster triplex), showing the outer layer of the wall divided in a star-shaped manner and recurved. The opening where the spores escape is in the conical apex of the inner layer.

forms in which the fertile interior tissue is elevated at maturity by an expanding structure called a *receptacle*, leaving the wall at the base in the form of a sac-like volva.

COMPARATIVE REVIEW OF THE FUNGI.*

467. The three general types of fructification.—While there are great variations in the special methods in the fruiting of the fungi, i.e., in the production of the spores, they can all be assembled into three general types of fructification. In each of these types of fructification there are structural elements in the fruit bodies which are peculiar to the fungi possessing that method of fructification, and which bear the spores. These are as follows: 1st, the spore case (*sporangium*) in the Class *Phycomycetes*; 2nd, the sac (*ascus*) in the Class *Ascomycetes*; and 3rd, the *basidium* in the Class *Basidiomycetes*.

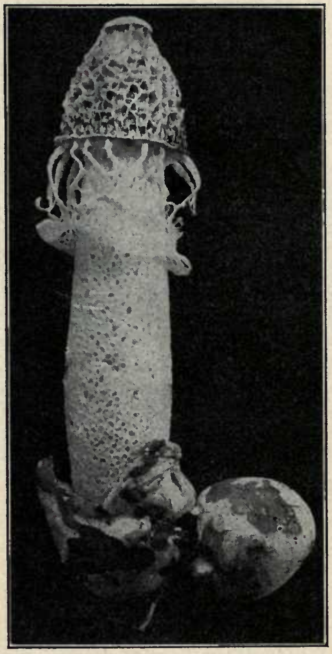


Fig. 277.
"Stink horn," or "buzzard's nose" (Dictyophora duplicata). × ½ diameter.

468. The Class Phycomycetes.—The members of this class include the forms in which the spore case is the characteristic fruit structure. Together they make up the *sporangium series* or spore case series of the fungi. The spore case contains the spores, and is for the most part what is called a *generalized* structure, because it contains often a large and usually a variable number of spores even in the same species. A generalized structure is, in all organ-

---

* For reference.

isms, regarded as indicating a low type of organization for the plants or animals possessing it, or a low and early stage in the evolution of that organ. The Phycomycetes further possess a mycelium in which there are few or no cross walls dividing it into distinct cells. In extensive portions of the mycelium the protoplasm is continuous and contains many nuclei. The mycelium is *cœnocytic*, or the plant is a *cœnocyte*,* just as the siphonaceous algæ-like *Vaucheria* are *cœnocytes*. This peculiarity of the mycelium of the Phycomycetes, together with the method of sexual reproduction by antheridia and oögonia, which in such forms as the water molds greatly resembles that of such algæ as *Vaucheria*, has led many to believe that such fungi as the water molds are very closely related to such algæ as *Vaucheria*, and that the water molds may have had their origin from the siphon-algæ, by some of these algæ ages ago, becoming parasitic, or becoming adapted to a saprophytic life, as a result of which they lost their chlorophyll. From this point of view there is a twofold reason for calling the Phycomycetes, the *algal fungi*.

469. The Class Ascomycetes.—In this class of fungi the ascus, a sac-like structure, containing the spores, is the characteristic fruiting structure. The number of spores has become, in most

---

* Cœnocyte means a colony of naked cells, or a colony of protoplasts which are not separated from one another by cell walls, each protoplast containing one of the nuclei. Such a plant as *Vaucheria*, or the mycelium of a colony of a fungus like the bread mold, was formerly believed to represent a single cell, since the definition of a cell at that time predicated a cell wall for its boundary. This theory is still advocated at the present time by some. The argument in favor of this view in the case of such extensive cœnocytic thalli, as is found in the mucors and *Vaucheria*, that a certain amount of cytoplasm does not remain permanently associated with individual nuclei, that the nuclei move about in the cytoplasm more or less, does not appear to be very convincing. There is nothing really remarkable in this exchange of cytoplasm. In many multicellular plants it is well known that the protoplasts of different cells are connected by strands of protoplasm through minute perforations in the intervening cell wall. In many of the red algæ these cytoplasmic communications are often of considerable size and there is probably cytoplasmic interchange between the different protoplasts, so that the nuclei here are not permanently associated with the same cytoplasm.

cases, definite in number, usually eight, but in some cases containing multiples of eight, and in others containing regularly six, or four, or two, and in rare cases one, while there are a few in which the number is variable, being from two to three or four or five. This indicates a more specialized condition than in the Phycomycetes. The mycelium is regularly septate. All of these characters indicate an advance over the Phycomycetes. The fruit body of the Ascomycetes, the *perithecium* or *asocarp*, recalls the cystocarp of the red algæ, and there are several peculiarities in connection with the form of the sexual organs and in fertilization in some of the sac fungi, which resemble those of the red algae. This has given rise to the theory that the sac fungi have had their ancestors among the red algæ of the past, and that they have lost chlorophyll and the function of photosynthesis by becoming parasites, or in an adaptation to a saprophytic mode of life.

470. The Class Basidiomycetes.—The *basidium* is the characteristic fruit structure in this class of fungi. It is a single cell of a specialized form in the higher members of the class. In the lower forms it is divided into four cells by cross divisions, or perpendicular divisions, as in many of the trembling or jelly fungi. In the latter there is one spore from each cell, while in the former there are usually four spores from the single cell, rarely two or six. In the smuts the number of cells of the promycelium (which is basidium-like) varies. This specialized structure, with the definite and limited number of spores, also indicates a higher stage of development than is found in the Phycomycetes. The mycelium is septate, often there are buckle joints at the cross walls, while the large and highly specialized fruit bodies are in great advance over the Phycomycetes. The fungi of this class also are believed by some to have originated from some of the higher algæ in the past. The cluster cup of the rust fungi may possibly represent the cystocarp, but there is little else to suggest an ancestral relationship, unless the basidiospores represent tetraspores, and in the rust fungi they do stand in the same position in the life cycle as the tetraspores do in some of the red algæ.

471. Two theories of the evolution of the fungi.—There are two theories of the evolution of the fungi. The *first* theory is that the fungi have had their origin at different points from the algæ, i.e., certain groups of fungi being developed off from certain groups of algæ as suggested above. The *second* theory is that the fungi represent a natural group of plants, and that this group has followed a line of development of its own, the higher forms being developed from the lower, just as it is believed that the higher algæ have developed from the lower. There are a number of reasons for holding this theory. One of the foremost of these reasons is, that there are, within each of the three classes, such manifest evidences of lines of evolution tending to show that the higher forms of each group have had their origin among lower members of the same group. The resemblances to the algæ may be accidental; they may represent cases of parallel evolution, which it is generally believed has occurred both in certain groups of plants and animals. While these resemblances are strong in some points, there are still connected with them certain structures and processes, which are not present in the algæ. We probably can never decide which theory is the correct one. These theories may continue to exist side by side as interesting topics for speculation. The author does not commit himself wholly to either. But it is generally accepted that, in the study and classification of the fungi and algæ, it is more convenient to arrange the classification according to the second theory.

CHAPTER XXX.

LIVERWORTS (HEPATICÆ).

472. General characters.—The name liverwort refers to certain plants which were supposed to simulate by their form the organ of the human body known as the liver. (The *hepatica*,* a flower of the woods in early spring, is known as the "liver-leaf," or noble liverwort, because of the three-lobed leaf.) The *liver-*

Fig. 278.
Thallus of liverworts (Riccia).

To the Teacher. If the length of the course will not permit the practical study of any of the liverworts, several of them may be used for illustration for the student to observe the general habit and character after the study of a moss. Where there is time for the study *Marchantia* may be used, and some of the foliose liverworts can be examined to note the differentiation of a thin strap-shaped thallus or body into one with stems and leaves. The teacher can use discretion in the employment of other examples in the practical work, according to the length of time which can be devoted to the study.

---

* *Hepatica triloba* = *Hepatica hepatica*.

worts make up a class of low, flowerless plants standing above the algæ and fungi. They all possess chlorophyll. In many of them the plant body is flattened and leaf-like, more or less rounded in some, or strap-shaped in others, and lobed or forked in various ways. These lobed forms suggested the name liverwort which has been adopted as the name of the class, with the technical name, Class *Hepaticæ*. This plant body is a *thallus*, a word applied to those low plant forms which are not divided into a true stem, leaf and root.* They are attached to the ground, to tree trunks, or rocks by slender thread-like outgrowths called *rhizoids*, through which much of the water and mineral foods are absorbed. Nearly all of the liverworts grow in damp situations, or float on the water. The male and female organs are a sperm case (*antheridium*) with motile sperms, and an egg case (*archegonium*) with an egg. The egg case of the liverworts is a more

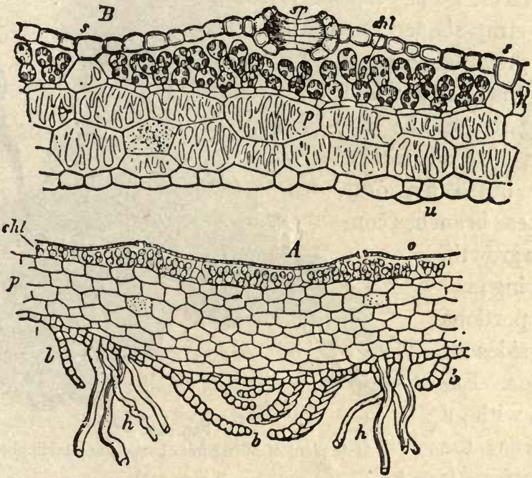


Fig. 279.

Section of thallus of Marchantia. *A*, through the middle portion; *B*, through the marginal portion; *p*, colorless layer; *chl*, chlorophyll layer; *sp*, stomate; *h*, rhizoids; *b*, leaf-like outgrowths on under side (Goebel).

---

* The word *thallophyte*, however, technically applies only to the algæ and fungi, which are the thallus plants *par excellence*.

highly developed organ than the egg case of the algæ and fungi, as will be seen in the study of examples. The fruit of the liverworts is a capsule containing spores, usually borne on a stalk.

THALLOSE* LIVERWORTS.

473. Marchantia.—The thallose liverworts may be represented by a study of *Marchantia*. This plant grows on damp soil, or rocks in swampy or moist, shady places. The thallus is rather broadly strap-shaped, notched at the end, the growing point residing in the notch. There is a "midrib" extending along the middle line. The plant branches in a forked manner, but often only one of these branches continues its growth, thus leaving projecting portions on the sides of the thallus. Examined with a hand lens the upper surface is seen to be marked off into regular rhomboidal areas, and in the center of each is a stomate opening (fig. 279). These open into quite large chambers in which most of the chlorophyll-bearing tissue is in the form of short, upright chains of cells. This tissue, with the epidermis, belongs to the upper layer of the thallus. The lower layer lacks chlorophyll, containing some cells with spiral thickenings and bearing the rhizoids. There are numerous slender rhizoids on the under surface, some of which have numerous thickenings on the inside of the wall. There are also thin membranous scales on the under surface

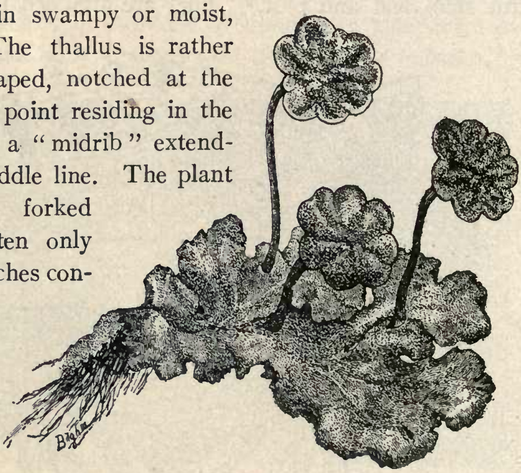


Fig. 280.
Male plant of Marchantia bearing antheridiophores.

---

* Those liverworts in which the plant body is a true thallus.

near the apex, which protect the growing point. The plant is *diœceous* (or *heterothallic*, see paragraph 407), some of them being male and others female. The plant propagates asexually by brood buds developed in little cups with a fringed edge, formed on separate plants (fig. 281). Each of these buds is a miniature thallus of Marchantia, with a growing point in a notch at two opposite points in the flattened nearly circular bud.

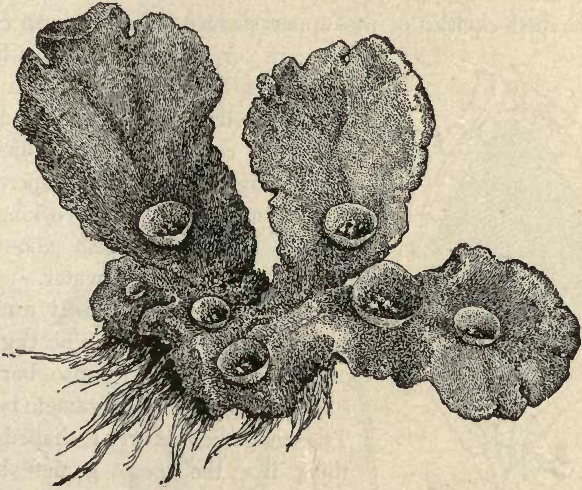


Fig. 281.
Marchantia plant with cupules and gemmæ; rhizoids below.

Fig. 282.
Section of antheridial receptacle from male plant of Marchantia polymorpha, showing cavities where the antheridia are borne.

474. The male plants and sperm cases (antheridia).—The sperm cases are borne on special outgrowths, the gamete bearer.* These are disk-shaped and stalked. The sperm cases are in flask-shaped cavities of the upper surface. Each sperm case is a more or less oval body like a stalked capsule with a wall of a single layer of cells. The interior is a mass of minute cells in each of which two sperms are formed. Each sperm is a long, slender body, with two long, very slender cilia which lash about and cause it to move in the water.

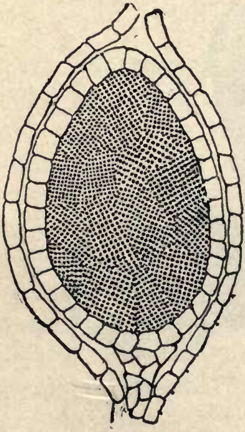


Fig. 283.
Section of antheridium of Marchantia, showing the groups of sperm mother cells.

475. The female plant and egg cases (archegonia).—The egg cases or female organs are also borne on special outgrowths, the gamete bearers. The egg gamete bearer is shaped something like the sperm gamete bearer, but the disk is divided into slender rays and the stalk is longer, giving it an umbrella shape (fig. 285). The egg cases are borne on the under surface of the disk, between the delicate, thin, laminate tissues which hang downward and protect them from drying out. Each egg case is a flask-shaped structure with a swollen base (*venter*), and a long, slender neck with a canal leading down to the egg in the basal part. When the egg is ripe the canal opens, and if a sperm enters and passes into the egg, it unites with the egg nucleus and fertilization results.

Fig. 284.
Sperms of Marchantia uncoiling and one extended, showing the two cilia.

---

* *Gametophore,* because it bears gametes.

476. The capsule (sporogonium).—As a result of fertilization the egg does not develop the marchantia plant again, but develops into a new structure very different from the thallus which bears the sexual organs. This is the capsule bearer (*sporogonium*), which is peculiar to all the liverworts and mosses as well. In Marchantia, as in most liverworts and mosses, it is a stalked capsule. The capsule contains the spores, and in Marchantia and many other liverworts the spores are mixed with sterile cells in the form of long, slender, spirally marked cells called *elaters*. These elaters are very sensitive to changes in the humidity of the air, twisting and coiling in various ways with slight changes in the humidity. This assists in pushing the spores out of the capsule after it opens at the apex. Since the

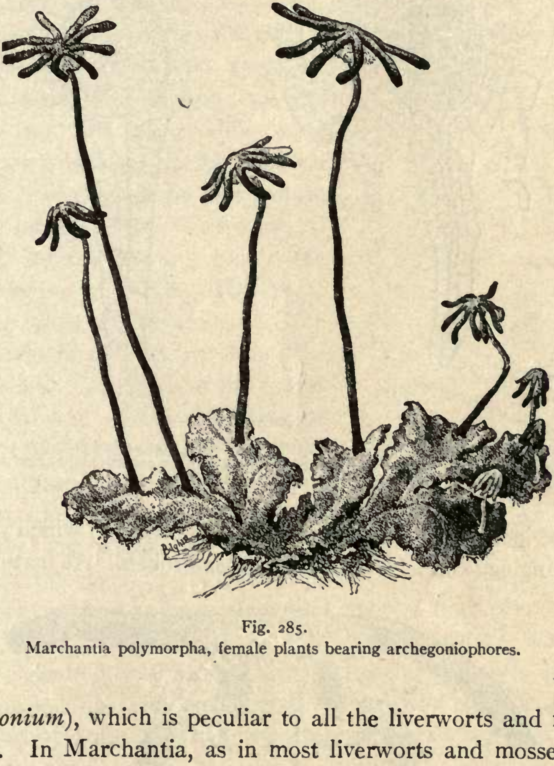


Fig. 285.
Marchantia polymorpha, female plants bearing archegoniophores.

egg cases hang downward from the underside of the gamete bearer, the capsule also grows downward. At first the venter of the egg case increases in size to form a hood (*calyptra*) which protects the young egg case. The hood is later broken. At maturity the stalk of the capsule elongates and pushes the capsule out from between the delicate tissue membranes which protected

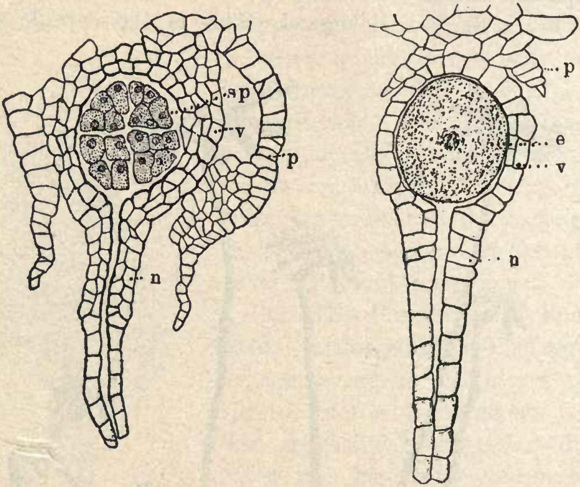


Fig. 286.

Marchantia polymorpha, archegonium at the right with egg; archegonium at the left with young sporogonium; *p*, curtain which hangs down around the archegonia; *e*, egg; *v*, venter of archegonium; *n*, neck of archegonium; *sp*, young sporogonium.

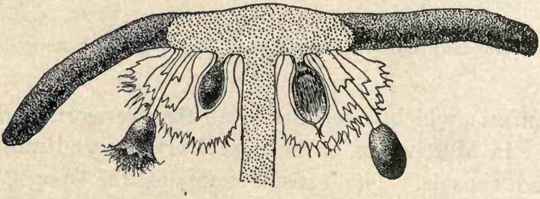


Fig. 287.

Section of archegonial receptacle of Marchantia polymorpha; ripe sporogonia. One is open, scattering spores and elaters; two are still enclosed in the wall of the archegonium. The junction of the stalk of the sporogonium with the receptacle is the point of attachment of the sporophyte of Marchantia with the gametophyte.

the egg case (fig. 287), the capsule opens and the spores are scattered. The spores germinate under favorable conditions and produce the thallus of the marchantia, thus completing the life cycle.

477. Riccia.—*Riccia* is another of the thallose liverworts. The plants are thin and leaf-like, some being nearly circular, others semicircular, others narrowly strap-shaped. They branch in a forked manner so that the circular forms are split or indented inward from the edge, while some of the strap-shaped forms produce rosettes. They grow on wet ground or float on the water. There are no special outgrowths on which the sexual organs are borne. The sperm and egg cases are developed in the upper side of the thallus along the middle line. The form of the sexual organs is very similar to those of *Marchantia*. The capsule, however, is very different. It is a simple globose capsule or spore case, developed from the egg within the enlarging venter of the egg case, The outer layer of cells is sterile, while the inner portion forms nothing but spores, four spores being formed from a single mother cell as in *Marchantia*. All of the mother cells in *Riccia* form spores, while in *Marchantia* some of them form sterile cells, the elaters. *Marchantia* and *Riccia* each represent a group of the thallose liverworts including many other closely related forms.

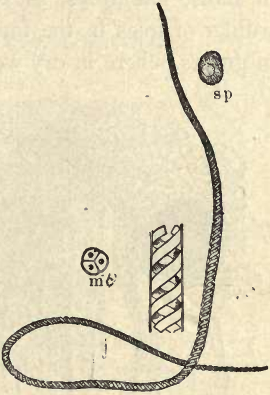


Fig. 288.
Elater and spore of Marchantia. *sp*, spore; *mc*, mother cell of spores, showing partly formed spores.

478. The foliose liverworts.—These are the leafy-stemmed liverworts. Each plant is really a thallus, but is highly specialized by the formation of a distinct slender *axis* (the stem) and thin foliar organs (the leaves). This has probably come about by a lobing of the margins of thallose forms, which became more and more marked and specialized until these leafy-stemmed forms were developed. The prominent leaves are in two lateral rows, but there is an inconspicuous third row on the underside. The stems are creeping or ascending. They are attached to the soil, to logs, or tree trunks, by rhizoids. They are sometimes mistaken for mosses.* Many of the foliose liverworts grow in moist situations, as on the trunks of trees in the forest or in groves, where in dry weather they would be in danger of being killed were it not for some special peculiarity in their form, etc. One of these (*Frullania*) has oval leaves closely crowded and overlapping each other on

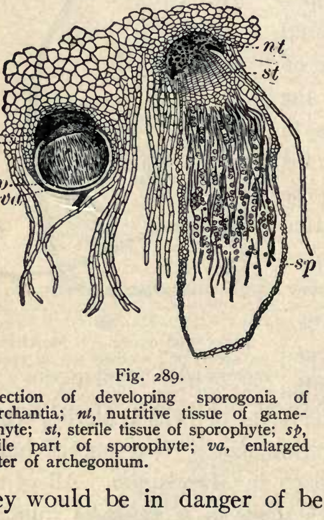


Fig. 289.

Section of developing sporogonia of Marchantia; *nt*, nutritive tissue of gametophyte; *st*, sterile tissue of sporophyte; *sp*, fertile part of sporophyte; *va*, enlarged venter of archegonium.

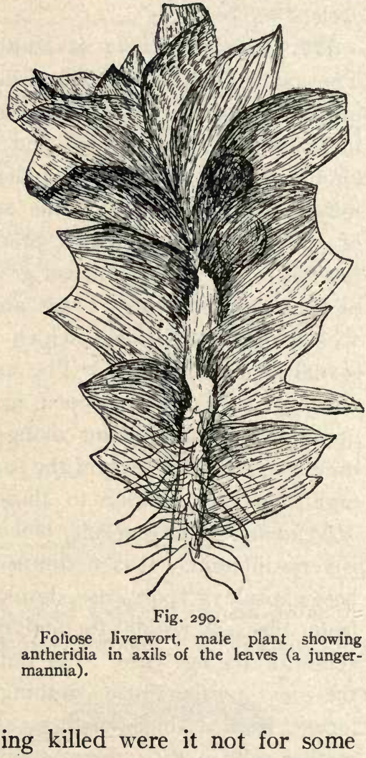


Fig. 290.

Foliose liverwort, male plant showing antheridia in axils of the leaves (a jungermannia).

---

* Most mosses are, however, more or less erect; the leaves are in three distinct rows and equal in size, except in certain forms. Vegetative stems of *Mnium*, one of the mosses, are creeping, and there are two prominent lateral rows resembling a liverwort. So in *Fissidens*, another moss, the prominent leaves are in two lateral rows and the stems are more or less inclined or creeping as in some liverworts. The leaves of liverworts always consist of a single layer of cells, while in the mosses there is a midrib of more than one cell in thickness extending part way into the base of the leaf, or entirely through the leaf, except in the peat mosses.

the stem. The plant clings very closely to the bark of the tree which aids in retaining moisture. In addition each of these leaves has a lobe on the under side (next the tree) which is sac-like and holds water. This water is doled out to the plant during dry periods. It remains so long in these pockets that minute animals belonging to the crustacean group make it their home. In California one of the liverworts growing on the ground forms subterranean tubers which tide the plant over the dry season.

479. The capsule (sporogonium) of the leafy-stemmed liverwort.—This is a stalked capsule, and the capsule splits down to the base into four valves. In some species elaters are mixed with the spores.

Fig. 291. Fruiting plant of a foliose liverwort. Leafy part is the gamete plant; stalk with capsule is the spore plant.

HORNED LIVERWORTS (ANTHOCEROTES).

480. The horned liverworts.—The horned liverworts may be represented by *Anthoceros*. It grows in wet, muddy places. The thallus is thin, dark green, and irregularly branched and overlapping (fig. 292). The sexual organs are immersed in the thallus, the sperm cases in groups in a cavity, while the wall of the immersed egg case is united with adjacent cells of the thallus. The capsule is long, slender and slightly curved, its form suggesting the name of "horned" liverworts. Its base is surrounded by a slender, short outgrowth of the thallus. The growing point of the capsule is near the base, the older portions being constantly raised by growth at the base. The capsule consists of a wall and a column of sterile tissue, between which is a layer of spore-bearing tissue in the form of a tube. Some of the cells of this spore-bearing tissue are mother cells of spores, each mother cell forming four spores. Other cells alternating with them form short, spirally marked elaters. From the nature of its growth the spores at the apex are older than those below. The capsule at maturity splits longitudinally and the spores escape. The wall cells of the capsule contain chlorophyll, and stomates are present in the surface layer. It is thus able to make its own carbohydrate food, but is dependent on the thallus for its water and mineral food. It is thus more highly developed and specialized than in the other liverworts. For this reason the horned liverworts are by some placed in a separate class, *Anthocerotes*.

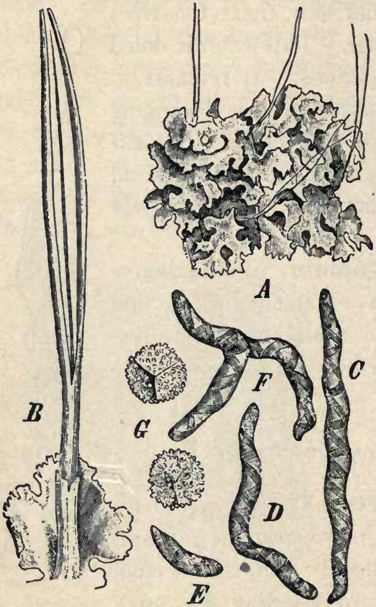


Fig. 292.

Anthoceros gracilis. *A*, several gametophytes, on which sporangia **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.)

481. Comparative review of the liverworts. — The thallus, or plant body, of the liverworts on which the sexual organs are borne presents two forms. First, the thallose forms in which the plant body is simply a green, leaf-like or strap-shaped structure of very different form in different genera. Second, the foliose forms in which the thallus is more specialized, being differentiated into a slender axis with thin, leaf-like expansions. The liverworts are nearly all land forms, adapted to growing on soil and rocks in wet or moist situations, or on logs or tree trunks, some of the latter being adapted to resist dessication in dry seasons. The sperm case does not show much advance over that of some of the higher algæ, but it is a more massive structure, and the sperms are quite different and more highly specialized in form. The egg case shows a great advance in structure compared with the egg case of the algæ, being a multicellular organ, flask-shaped in form. The greatest advance over the algæ is shown in the capsule (*sporogonium*). This is a specialized structure developed from the egg, which is very different in form from the thallus, and its function is the development of spores which produce new thallus plants and serve to propagate the liverworts (a few are propagated also asexually by brood buds as in *Marchantia*). Among the liverworts the capsule shows considerable progress in development, from the simple spherical body in *Riccia*, with a single layer of wall cells surrounding the spore-bearing tissue, and the short-stalked capsule in *Marchantia*, to that of the foliose liverworts, where the capsule is long-stalked and is more highly specialized, splitting at maturity into four valves (except in a few forms). But the highest specialization is reached in *Anthoceros* where the capsule has a definite growing area, the wall is provided with stomates and chlorophyll, and the amount of spore-bearing tissue is very much less in proportion to the sterile portion. These characters of the capsule are of greater importance in showing relationship among the liverworts than the form of the thallus. The marchantia and riccia forms are all thallus plants with a comparatively simple capsule. They belong to the Order *Marchantiales*. The foliose liverworts have a more highly specialized capsule (the capsule four-valved). They belong to the Order *Jungermanniales*, but some members of this order also are thallose liverworts. The highest liverworts are represented by *Anthoceros* with its highly specialized capsule. They belong to the Order *Anthocerotales*. They are also thallose liverworts.

482. Alternation of generations.—It is now time to note an important biological principle in the life history and development of plants, viz., what is usually called "*alternation of generations*." The thallus with its sexual organs is the first generation, while the capsule is the second generation. The capsule is developed from the fertilized egg on the thallus, and the thallus is developed from the spore borne in the capsule. There is thus an alternation of the thallus and capsule, or an alternation of these generations. This does not mean that this alternation is strictly carried out. The thallus is usually perennial and lives for many years, developing capsules perhaps each year.

CHAPTER XXXI.

MOSSES (MUSCINEÆ).

483. General characters.—The mosses are small, leafy-stemmed plants usually growing in dense tufts or mats on the ground, in swamps, moist woods, or in dry places, on rocks, or on tree trunks, etc. Some of those on rocks and in dry places can resist long periods of drought, becoming very dry, and revive with the advent of rains. A few grow in the water. Those not found in the water are nearly all erect, with three distinct rows of leaves, and they are thus easily distinguished from the foliose liverworts (see paragraph 478). The leaves consist of a single layer of cells, except for a more or less well developed midrib, which in some species only extends a short way in the base of the leaf; in other species it is longer and in some extends entirely through the leaf. This midrib consists of narrow cells several layers in thickness. Since the leaf is mostly one cell layer in thickness, the starch grains in connection with the chlorophyll body are easily seen with the aid of the microscope. The spores from the capsule germinate and produce a branched filamentous growth, the *protonema*, from which the leafy stem arises as a branch. The general characters should be studied in one or more examples followed by a study of the life history. The "fruit" of the moss is a stalked capsule (sporogonium); rarely is it sessile. The stalk is inserted in the end of the moss stem

TO THE TEACHER. One moss (*Mnium*, *Polytrichum* or *Funaria*) should be studied in practical work. A very interesting collection of mosses can easily be made and preserved dry on cards to illustrate the different habits of the mosses. In field trips made during the year members of the class will find it interesting to assist the teacher in making such a permanent collection for the school.

or in the end of a short branch in some species. The sexual organs are sperm and egg cases (antheridia and archegonia). They are borne usually in different groups on the end of the stem or a short branch, either on the same plant (monœcious, or homothallic) or on different plants (diœcious, or heterothallic).

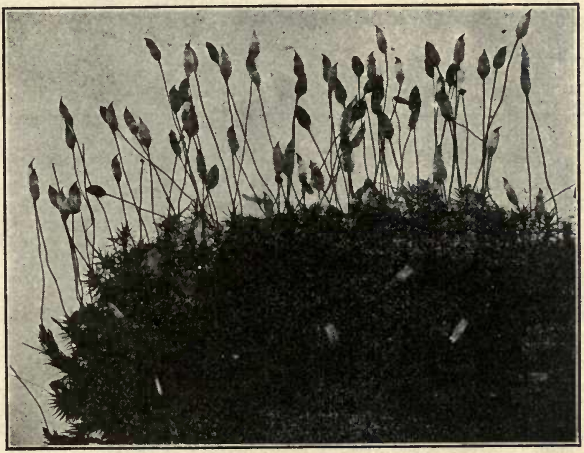


Fig. 293.

Pigeon wheat mass (Polytrichum) in fruit.

484. The hairy-cap moss (Polytrichum).—The hairy-cap moss, or as it is sometimes called the "pigeon wheat" moss, is an excellent one for study because of its common occurrence and wide distribution, its large size, and the striking difference between the male and female plants. It grows usually in moderately moist situations or in swampy ground. The plants form dense tufts or an extensive turf, the male and female plants usually grouped by themselves. The leaves are quite narrowly pointed and rather rigid. The male plants are shorter than the female plants, and at the end of the stem the leaves are crowded into a spreading rosette, in the center of which the sperm cases are crowded. In the female plants the terminal leaves are rather appressed into a tuft so that they protect the egg cases and young fruit body. At the base of the stem are numerous thread-like rhizoids usually brownish in color. In the moss *Mnium*, the male plants are also shorter than the female ones, and the leaves at the apex of the stem form a rosette. There are also prostrate stems with two rows of lateral prominent leaves, the third row on the underside being rudimentary.*

Fig. 294.
Female plant (gametophyte) of a moss (Mnium), showing rhizoids below, and the tuft of leaves above which protect the archegonia.

Fig. 295.
Male plant (gametophyte) of a moss (Mnium), showing rhizoids below and the antheridia at the center above surrounded by the rosette of leaves.

485. The sexual organs.—The sperm cases (*antheridia*) are crowded at the apex of the male shoot, and intermingled with peculiar club-shaped bodies (*paraphyses*) which contain chlorophyll. The sperm case is more broadly clavate, and consists of a wall of a single layer of cells containing the sperm cells. When the sperms are mature the sperm case is ruptured at the apex by the pressure resulting from the absorption of water, and the mass of sperm cells escapes. The sperms uncoil and swim about until some finally reach the egg case. They are long and slender with two long cilia at the smaller end. The egg cases (*archegonia*) are borne in groups on the end of the female shoot. An egg case is flask-shaped, with a short stalk which lifts the base a little distance from the end of the shoot. The base is called the *venter*, and the slender portion the *neck*. A canal is formed in the neck at maturity by the dissolving of the central row of cells, which leads into the venter. In the venter is the *egg*.

486. The moss fruit (sporogonium).—The moss fruit consists of a capsule supported on a slender stalk. In the hairy-cap moss this capsule is a short, four-angled structure, at first covered

---

* Such a stem is *dorsiventral*, and resembles the stems of the foliose liverworts which are also dorsiventral. In the moss *Fissidens* all the stems are dorsiventral.

by a hairy, conical cap or hood (the *calyptra*). When the hood is removed the appearance of numbers of these capsules on their slender stalks perhaps suggested the name of "pigeon wheat."

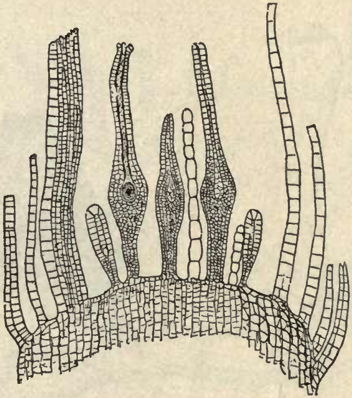


Fig. 296.

Section through end of stem of female plant of Mnium, showing archegonia at the center. One archegonium shows the egg. On the sides are sections of the protecting leaves.

Fig. 297.

Antheridium of Mnium with jointed paraphysis at the left; sperms at the right.

At the apex of the capsule is a minute "lid" (the *operculum*) which is easily removed, exposing the "mouth" of the capsule (the *stomium*). Around the edges of the mouth are numerous minute pointed processes, the *teeth*, 64 in one circle or row. There is another inner row of thinner teeth.

487. Many mosses have a double row of teeth, others have but a single row, while some have no teeth. In one little moss common on decaying logs in woods there are only four teeth (*Tetraphis pellucida* = *Georgia*). Some have 16, others 32, etc. The teeth are usually very sensitive to changes in the humidity of the air, spreading apart in moist weather, thus permitting the spores to escape, or closing in dry weather. The spores are formed in a special spore-bearing tissue, which is in the form of a hollow tube in the middle part of the capsule. The tube is filled with sterile tissue, and also surrounded by sterile tissue. These tissues together form an elliptical body which is suspended in an air chamber within the capsule by delicate threads (fig. 298). The spore-bearing tissue consists of a single layer of *mother cells*, each one of which forms four spores.

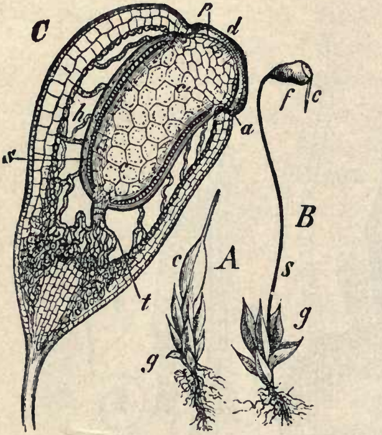


Fig. 298.

Funaria hygrometrica. *A*, a young leafy stem *g*, with the calyptra *c*. *B*, a plant *g* with the almost mature sporogonium, of which *s* is the seta, *f* the capsular portion, *c* the calyptra. *C*, longitudinal section of the capsular portion dividing it into two symmetrical halves; *d* the lid, *a* the annulus, *p* the peristome, *c*, *d* the columella, *h* air-space, *s* archesporium. (After Sachs.)

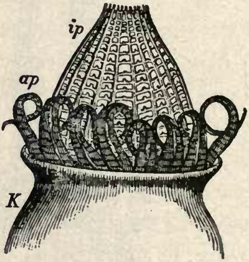


Fig. 299.

The mouth of the capsule *K* of Fontinalis antipyretica. Outer peristome *ap*, inner peristome *ip*. (After Sachs.)

488. Life history of the mosses.—The life history of the mosses is as follows. The spores germinate and produce a much-branched filamentous growth, the *protonema*, which means *first thread*. This protonema resembles superficially some of the filamentous green algæ, but the cross walls are often oblique and this serves at once to distinguish them. The protonema forms a thin or rather dense web on the ground or on rotten wood. The leafy-stemmed moss plant arises from this as a stouter branch, with the oblique walls regular and close together. Rhizoids are developed from the base of the leafy stem and sometimes quite high up on the stem. Numerous leafy stems arise from the protonema, thus making dense tufts. The protonema usually disappears soon after the moss stems arise.* Certain species of the mosses often multiply by branching, by the growth of new

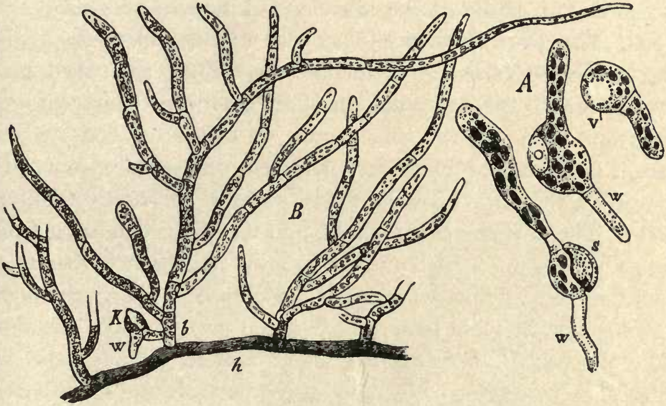


Fig. 300.

Funaria hygrometrica. *A*, germinating spore; *v*, vacuole; *w*, rhizoid; *s*, exosporium. *B*, portion of a developed protonema, about three weeks after germination; *h*, a prostrate primary shoot with brown wall and obliquely transverse septa, from which proceed the ascending branches with limited growth; at *K* the rudiment of a leafy axis with rhizoid *w*. (After Sachs.)

protonemes from the moss plant, and sometimes by bulbils † or by brood buds. After the development of the sexual organs, fertilization is brought about by the sperm passing down the canal of the egg case, and fusing with the nucleus of the egg. The fertilized egg then divides and elongates downward to form a foot, which wedges its way into the upper end of the moss stem, while the upper part elongates upward to form the stalk and capsule. At the same time the egg case enlarges to form a pro-

---

* In one genus, *Pogonatum*, the protonema exists for a long time, even until the fruit of the moss appears. Here the protonema is more conspicuous than the moss plant and covers extensive patches of the ground along the roadside in woods. The protonema in a few of the higher mosses is partly thallose, as in *Tetraphis*.

† In the mosses these " bulbils " are small, rounded masses of cells.

tective covering for the capsule while it is young. Finally the egg case is torn away at its base and is raised aloft on the capsule to form the hood or cap (the *calyptra*). With the ripening of the spores in the capsule, the life history is complete, and the capsule opens by the lid to permit their escape. In some of the lower mosses there is no lid on the capsule, and it opens irregularly.

489. The peat mosses.—The peat mosses belong to a distinct order (*Sphagnales*) of the mosses. They are called peat mosses because the accumulation of the dead parts for centuries forms one kind of *peat*. They grow in moors (or bogs) where there is an abundance of water, or in very damp places in woods, or even on the faces of rocks where water is constantly trickling down. The protonema is thallose, and the leafy stem arises from this as a branch. They continue to grow and branch year after year, the stems dying away below. Because of the great quantity of water in their tissues and in the ground, decay is slow and only partial, because the water largely excludes the air which is necessary for the activity of the bacteria and fungi which cause the decay of vegetation. Their partially decayed remains then form the peat. The quantity of water held by the peat mosses can be seen by squeezing a handful, when an abundance of water is wrung out. The peculiar character of the peat mosses which enables them to hold water is as follows: There are numerous lateral feathery-like branches which stand out straight from the main stem. These are the primary branches. Secondary branches arise from these close to the main stem and hang downward around it. In the leaves there are dead cells alternating with the green living ones. These dead cells have lost their protoplasm, have numerous perforations in their walls and also thickenings. As the plants stand close together in dense tufts or swards, and the leaves are crowded together especially on the pendent branches, capillarity draws water up from below and it is stored in these empty dead cells.[1] With the partial decay of the vegetation in these peat moors there is an abundance of humic acid which also assists in preserving the material from further decay. Peat is sometimes pressed into firm blocks and used for fuel. Peat, especially fern peat, is often used by florists for mixing in soil for growing certain plants. The peat mosses are collected and used for packing plants and other objects for shipment.

490. Fruit of the peat mosses.—The fruit of the peat mosses is a capsule with a broad foot inserted in a naked stalk which is an outgrowth of the leafy stem. The naked stalk of the peat mosses, then, is not a part of the capsule. The capsule is not so complicated a structure as that of the higher mosses (*Bryales*).

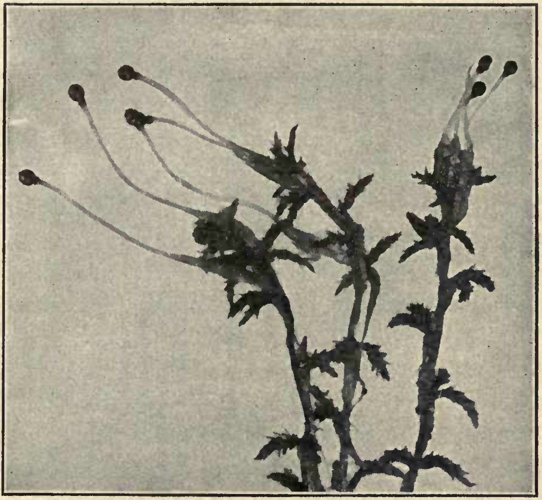


Fig. 301.
Peat mass (Sphagnum) in fruit.

491. Importance of mosses in nature.—The peat mosses, assisted by other plants which grow in similar situations, build up ground in low marshy places. They assist in filling in small or large ponds, beginning on the shore. This they are enabled to do because of the formation of the peat; the plant parts in the water, not being able to decay, build up ground quite rapidly. The mosses of all kinds on the forest floor hold considerable amounts of water, and thus assist the leaves and humus in holding back the water after rains, so that it does not run off so rapidly, thus lessening the danger of floods. On rocks they behave much as the lichens do in holding decaying vegetation, and adding to the humus from their own remains. They are thus important as early soil builders.

492. Alternation of generations.—The alternation of generations in the mosses is similar to that in the liverworts. The protonema, and the leafy-stemmed moss plant with the sexual organs, make the first generation, while the capsule (with its stalk) is the second generation. In a continuance of the complete life cycle there is an alternation of these two generations. The first generation is independent of the second when once started, and can live from year to year, often multiplying vegetatively and spreading by branching, by new protonema, and by bulbils. The capsule, however, is dependent on the first generation, since it has no roots or rootlets by which it becomes free and established as an independent plant. This is an important biological principle in the life history and development of plants. Very few of the algæ show it. The fertilized egg usually at once develops the first generation again. In Coleochæte there is a second generation. In some of the red algæ (as in *Polysiphonia*, *Rhabdonia*, etc.) the tetraspore plant represents a second generation. It is, however, independent, and of the same form as the sexual plant and grows under the same conditions. In plants showing an alternation of generations between a sexual stage and an asexual stage developed from the fertilized egg, the first generation is often spoken of as the *gamete plant* (*gametophyte*), because it bears the *gametes* or sexual organs. The second generation is likewise called the *spore plant* (*sporophyte*), because it bears the spores. The capsule (and stalk when present) of the liver worts and mosses is, therefore, the spore plant stage (*sporophyte*) of these plants, while the thallus with the sexual organs, the leafy-stemmed plant of the foliose liverworts, the protonema and leafy-stemmed moss plant, is the gamete plant stage (*gametophyte*). Each one of these stages begins and ends with a single cell. The gamete plant begins with the spore and ends with the unfertilized egg in the egg case. The spore plant begins with the fertilized egg and ends with the mother cell (of the spores) in the capsule.

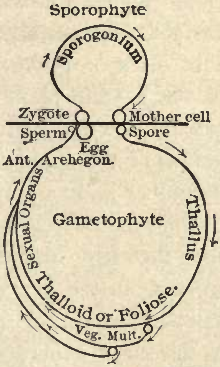


Diagram No. IV. Illustrating the life cycle of the Bryophytes (a liverwort or moss). Course of development follows the direction indicated by arrows. The zygote is the fertilized egg. Vegetative multiplication by buds and filamentous outgrowths of the thallus. Note increase of sporophyte.

493. Comparative review of the mosses.—The first generation (or gametophyte) of the mosses begins with the spore which produces the protonema, either a branched filamentous green growth, or a thallose one as in the peat mosses. This suggests that the ancestors of the mosses were plants resembling the algæ or liverworts, though no alga or liverwort is now known which could be regarded as an ancestor of the mosses. From the protonema the leafy-stemmed moss plant is developed as a branch. This bears the sexual organs. The second generation (or sporophyte) is developed from the fertilized egg. It remains dependent on the leafy stemmed plant for its food, the stalk being wedged into the tissues of the stem. The capsule of the mosses is a much more highly developed and complex structure than that of the liverworts, and shows that the mosses stand higher in the scale of classification and development than the liverworts.

494. Relationship of the liverworts and mosses.—There are, however, taken as a whole, very close relationships between the liverworts and mosses, shown in the character of the sexual organs, and especially in the capsule, though there are great differences between such a simple one as is found in *Riccia*, where the egg develops into a rounded mass of spores surrounded by a single layer of sterile cells, and the very complicated capsule (spore plant stage) of the higher mosses supported on a stalk. The intermediate forms show intermediate steps in this specialization. The spore plant (or sporophyte) in all agrees, however, in being dependent on the gamete plant for its nourishment, in not possessing leaf-like outgrowths, and in the formation of a capsule for the production of the spores. For these reasons the liverworts and mosses together make up one of the great branches of the plant kingdom, called the *Bryophytes*, or moss-like plants.

495. * Formula for the life history of liverworts and mosses.—The asexual stage in the liverworts and mosses is the capsule (with the stalk when present) or spore plant (sporophyte), and alternating with the first generation, the gamete plant (gametophyte). The formula may be represented thus

$$\text{Gametophyte} \left\langle \begin{matrix} \text{antheridia — sperm gamete} \\ \text{archegonia — egg gamete} \end{matrix} \right\rangle \text{Fertilized egg —}$$

Sporophyte — asexual spores — Gametophyte, etc., which reduced becomes

$$\text{G} — \left\langle \begin{matrix} \text{s} \\ \text{e} \end{matrix} \right\rangle — \text{FE} — \text{S} — \text{asp} — \text{G., etc.}$$

---

* For reference.

CHAPTER XXXII.

FERNS (CLASS FILICINEÆ).

Fig. 302.
Walking fern (Camptosorus rhizophyllus). Young ferns developing from the slender tips of the leaves.

496. General characters.—The ferns, because of the attractive foliage of many species, are often grown for ornament, and this has led to their being most generally known, though comparatively few persons know their structure and the course of their life history. The fern plant has a true stem, roots and leaves, and in this respect is very different from the moss plant, where the stem and leaves have resulted from the differentiation of a thallus. The leaves (often called *fronds*) possess chlorophyll, and perform the function of photosynthesis, while the roots are in

To the Teacher. One of the ferns should be studied carefully in the practical work. Prothallia can often be found growing spontaneously on the soil of pots in greenhouses where ferns are kept. If not they can be grown from the spores. Often one can interest a gardener in the greenhouse to assist in growing them or they can be grown in the laboratory. A permanent collection of a number of the local ferns, which the students could assist in making, can be used to illustrate variations in habit, dimorphism, etc. Where greenhouses or conservatories are near the students can visit them to inspect tropical ferns as well as other interesting plants. If the time allotted to the course is too short for practical study of the higher fern plants dried examples of the horse tail, club mosses, etc., can be used for illustration.

the soil and supply the water, and mineral and nitrogenous foods. The fern plant, then, lives independently of any thallus. The stems are very short and erect as in the Christmas fern, or are creeping or underground rhizomes as in the polypody, the sensitive fern, or the common brake, while in some tropical ferns there are tall, massive trunks as in the tree ferns. The leaves have a simple blade as in the "heart's tongue" (*Scolopendrium vulgare* = *Phyllitis scolopendrium*), or are once pinnate as in the polypody and Christmas fern, or twice pinnate as in many others, while in the common brake they are palmately branched, the main branches being twice pinnate. The leaves of ferns are more conspicuous than the stems, and the leaf stalk is often mistaken for a stem by some. The ferns have no flowers nor seeds. They are propagated chiefly by spores, though a few develop bulbils.* In the "walking" fern the long, slender tips of the leaves touch the ground, take root and develop a new stem and leaves, thus acting like a stolon. The spores are developed in spore cases (sporangia) usually clustered on the underside of the leaves in groups or lines. The fern plant is the second generation (spore plant or sporophyte). The first generation (gamete plant or gametophyte), which is developed


Fig. 303.
"Fruit" dots of the common polypody fern.


Fig. 304.
"Fruit" dots of the maidenhair fern.

---

* *Cystopteris bulbifera* (= *Filix bulbifera*) which grows along moist, shady banks, and *Asplenium bulbiferum* which is often grown in greenhouses. In the former species these bulbils fall to the ground and grow to new fern plants. The bulbil of the fern is a bud developed on the leaf.

from the spores, is *thallose*, and called a *prothallus* or *prothallium.* It is quite small, thin and heart-shaped in many species, and bears the sexual organs on the underside. There are also rhizoids which attach it to the substratum and supply water and mineral foods, while chlorophyll in the prothallium enables it to make its own carbohydrate food. It is thus able to lead an independent existence. The character of ferns can be observed by the study of a few examples.

SOME OF THE COMMON FERNS.

497. The polypody fern (Polypodium vulgare).—This is one of the common ferns. It grows in the open woods, often near cliffs, on the ground or on rocks. The stem is creeping (a root-stock). On the ground the stem often lies just beneath the leaves, while on the rocks it is usually exposed. Near the growing end it is covered with numerous brown scales. The roots are numerous, finely fibrous and black. The leaves are very conspicuous and arise in a cluster from the apex of the stem. They are once pinnate, the blade being divided to the midrib on either side into numerous linear divisions. Some of the leaves are sterile while others are fertile. In the fertile ones the spore cases are collected into roundish groups (sori, a single one a sorus), these groups forming two rows, one on either side of the mid-vein of each pinna.

Fig. 305.
Christmas fern (Aspidium acrostichoides).

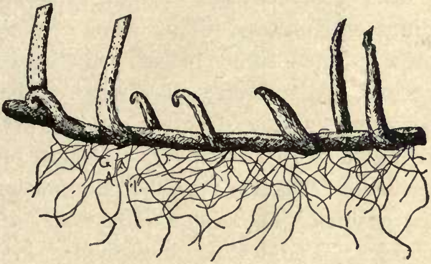


Fig. 306.
Rhizome of sensitive fern (Onoclea sensibilis).

498. The Christmas fern (Aspidium acrostichoides = Polystichum acrostichoides).—This is one of the shield ferns. It grows in shady woods. The stem is very short and upright. The leaves are pinnate, and are of two kinds, sterile and fertile. The outer ones are often sterile, while the inner ones in a cluster are often fertile. These are easily distinguished from the sterile ones, because the pinnæ which bear the spore cases are very much shorter and are narrower than the sterile ones, even on the fertile leaves. It is only the upper third, or half, of the leaf, which bears fertile pinnæ. The sori form two crowded rows on the underside of each pinna. Each sorus is covered by a shield-shaped structure called an *indusium*, which protects the spore cases when they are young, but dries and withers as they ripen, so that the spore cases dry out, open, and scatter their spores.

499. The bracken fern or brake (Pteris aquilina = Pteridium aquilinum).—This is one of the large, coarse ferns which grow in open sunny places, sometimes covering large areas and becoming a nuisance as a weed. The stem is a hard, black, somewhat woody structure, and grows as a root-stock several centimeters (8–12 cm. = 3–5 inches) under the surface of the ground. The leaves are the only portion of the plant seen above the ground. They have long, stout, shining, blackish stalks or petioles. The leaf is first divided in a palmate manner into three stout branches (ternately divided) and each of these branches is bipinnate, the final pinnæ forming narrow, thin lobes. The spore cases (sporangia) form a long sorus near the margins of the underside of the pinnæ, and the margin is incurved over them for protection.

500. Structure of the spore cases (or sporangia) of ferns.—In most of our common ferns (in the family *Polypodiaceæ*) the structure of the spore case is as follows. There is a slender stalk consisting of about three rows of cells. This supports the spore case. This is a rounded, somewhat compressed or biconvex structure, with a wall of a single layer of cells. As seen from a side view there is a row of specialized cells which extends from the stalk upward and over the top about three-fourths the distance around. This row of cells is known as the ring (*annulus*). The inner walls of the cells are thick and firm. The perpendicular walls are thick next the inner wall and taper outward, but are quite rigid. The outer and lateral walls are thin and membranous, this ring standing out quite prominently above the lateral faces of the spore case. On the opposite edge of the spore case from the ring are two cells near the middle of the edge which fit together somewhat like lips. They are called "lip" cells, and the point between them is the "mouth" (or *stomium*), for when the spore case opens, it opens between these two cells. In the interior of the spore case are usually sixteen spore mother cells in this family. Each of these forms four spores, so that there are sixty-four spores in a spore case.

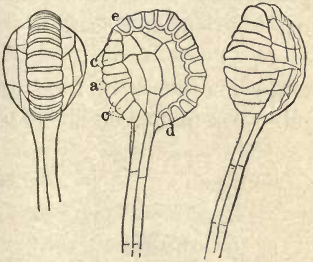


Fig. 307.
Rear, side, and front views of fern sporangium. *d*, *c*, annulus; *a*, lip cells.

Fig. 308.
Dispersion of spores from sporangium of Aspidium acrostichoides, showing different stages in the opening and snapping of the annulus.

501. Opening of the spore case and scattering of the spores.—When the spores are ripe, the *indusium*, or other covering of the sorus, dries and withers, exposing the spore case. These then begin to dry. In doing so the water evaporates from the cells of the ring. The air cannot enter these cells, consequently there is great air pressure from the outside as the water slowly escapes. The inner walls of the ring cells, as well as the perpendicular walls between its cells, are firm and do not bend inward. But the outer and lateral walls being thin and membranous are pressed inward. This exerts a pull on the outer edges of all of the perpendicular cell walls, which act as so many fulcra, and the outer edges of these different walls are brought nearer and nearer together. This causes the inner walls to curve slowly outward in unison. The result is that the entire ring begins to straighten out. The lower end is held firmly at the base of the spore case. The lip cells are torn apart, the upper one being raised by the straightening ring. At the same time, the two lateral faces of the spore case are torn across, and as the ring curves backward it carries with it the upper half of the spore case and nearly all the spores. When the ring has curved back so that it is almost doubled on itself, it suddenly snaps back again nearly to its former position, and scatters the spores (fig. 308).

502. Structure of the fern stem.—The stems of ferns are provided with a well-developed fibro-vascular system which serves for transport of water and also strengthens the stems. The bundles are, however, usually *concentric* instead of *collateral* as in the higher plants (see paragraphs 94, 98). The wood is in the center and is surrounded by the bast, the bast by the bast sheath, and this by the *endodermis*, thus giving a concentric arrangement (fig. 309). While the bundles strengthen the stems, they are comparatively weak, and in many fern stems there are large

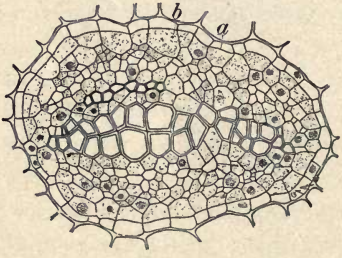


Fig. 309.

Concentric bundle from stem of Polypodium vulgare. Xylem in the center, surrounded by phloem, and this by the endodermis. (From the author's Biology of Ferns.)

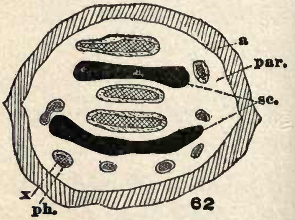


Fig. 310.

Section of stem (rhizome) of Pteris aquilina. *sc*, thick-walled sclerenchyma; *a*, thin-walled sclerenchyma; *par*, parenchyma.

areas of stony tissue (*sclerenchyma*) which give the chief mechanical support (fig. 310).

503. Structure of the fern leaf.—In many respects the leaves of ferns are similar in structure to the leaves of the flowering plants (paragraphs 140–145). The blade of the leaves is thin and expanded, and shows the same light relation as the leaves of the higher plants. There is a layer of epidermal cells on either side of the leaf, which are quite regular as seen in cross section of the leaf, but meet by very irregular edges in surface view. There are numerous stomates which are protected by two crescent-shaped guard cells as in the higher plants. The mesophyll of the leaves consists usually of a *palisade layer* next the upper epidermis, while the rest is made up of the *loose parenchyma* or *spongy tissue* with large intercellular spaces which communicate with the stomates. The disk-shaped chlorophyll bodies lie in the cells of the loose parenchyma, the palisade and guard cells, and sometimes in cells of the epidermis. In the veins are the vascular bundles. In the arrangement of these veins is shown one of the differences in structure from that of the higher plants. The veins branch in a forked manner, which sometimes is very striking. The vascular system strengthens

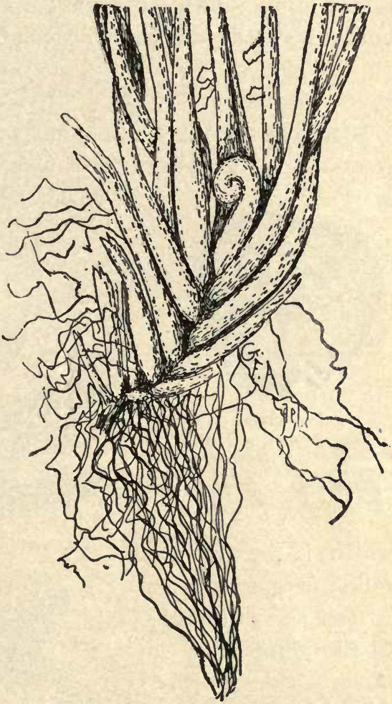


Fig. 311.
Rhizome with bases of leaves, and roots of the Christmas fern.

the leaves and leaf stalks, and provides for transport of water and food solutions. The development of the leaf also differs, in that the basal portion develops first and the apical portions are successively developed. The leaf is *circinate* in its development. The leaf is *coiled*, and as it develops it gradually uncoils. This is very striking in some of the large ferns grown in greenhouses, but is also easily observed in our ordinary ferns.

LIFE HISTORY OF FERNS.

504. The prothallium and sexual organs.—The spores from the spore cases germinate and produce the prothallium, which is the first generation or gamete plant. At first a short thread of two to three cells, containing chlorophyll, is developed from the spore. This is called the *protonemal* thread. A rhizoid is developed from the first cell of this thread. The terminal cell divides in two directions, forming a flattened green body, the young prothallium. Later it becomes more or less heart-shaped in outline, one cell layer in thickness on the sides, but several cells thick over the middle part, forming a thin cushion. Rhizoids are developed from the underside near the smaller (pos-

Fig. 312.
Spore of Pteris serrulata, showing the three-rayed elevation along the side of which the spore wall cracks during germination.

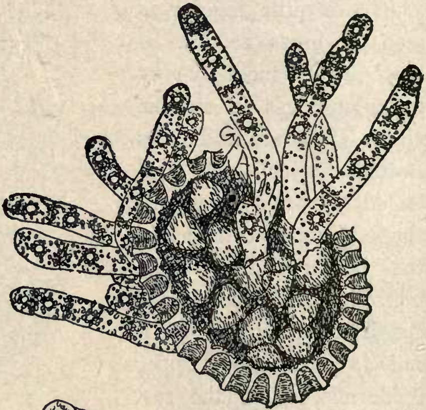


Fig. 313.
Germinating spores of Pteris aquilina still in the sporangium.

terior) end. Among these are the sperm cases (*antheridia*). The sperm case is in the form of a rounded protuberance from the underside of the prothallium. The wall consists of a single layer of thin cells. The central portion develops a number of sperms.* The sperms are coiled in the form of a screw, with numerous delicate cilia over the smaller end, by the vibration of which the sperms swim rapidly for a half hour or so in the water like a moving screw. The egg cases (*archegonia*) are borne also

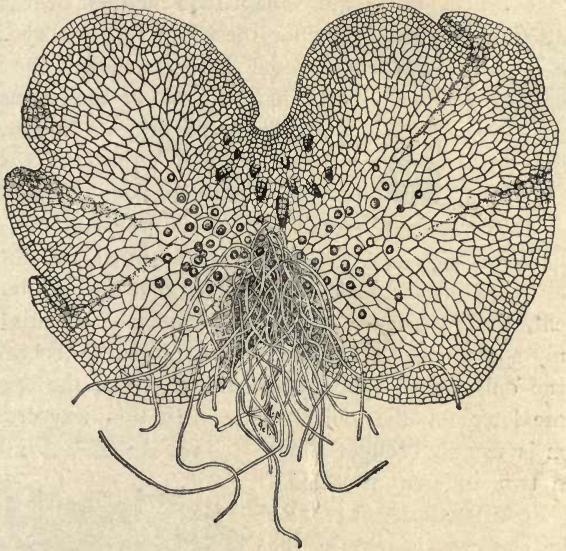


Fig. 314.

Prothallium of fern, underside, showing rhizoids, antheridia scattered among and near them, and the archegonia near the sinus.

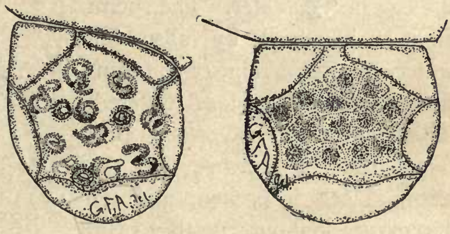


Fig. 315.

Section of antheridia, showing sperm cells, and sperms in the one at the left.

---

* The motile sperms of plants are sometimes called "*antherozoids*."

on the underside of the prothallium, from the thicker or cushion portion, since they are larger than the sperm cases and need more plant food for their own growth, and for the young fern embryo. The egg case is flask-shaped, the venter sunk in the tissue of the prothallium, while the neck projects beyond, and in our common ferns (*Polypodiaceæ*) curves slightly backward toward the small end of the prothallium. When the spores are crowded and the light is very weak, so that they get but little nutriment, they often produce only protonemal threads which bear only sperm cases. On the normal prothallia, sperm cases are borne only on the young prothallium, while the egg cases are borne later on the older tissue. In this way cross fertilization is usually brought about between two different prothallia.

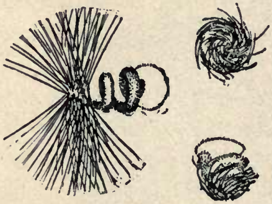


Fig. 316.
Different views of sperms; in a quiet condition; in motion (Adiantum concinnum).

505. Fertilization.—At the time the egg case is mature, the cells in the canal of the neck dissolve into a gelatinous substance, which oozes out at the opening, leaving a canal down to the egg in the venter. The sperm case is ruptured by absorbing water, as after a rain, or in greenhouses when they are watered. This absorption of water produces such a pressure that the terminal cell is broken, and the sperms are shot out. As they swim around in the water some come in the vicinity of an open egg case (usually of another prothallium), are more or less entangled in the slime, and make their way down to the egg. One sperm enters and unites with the nucleus of the egg and completes fertilization.

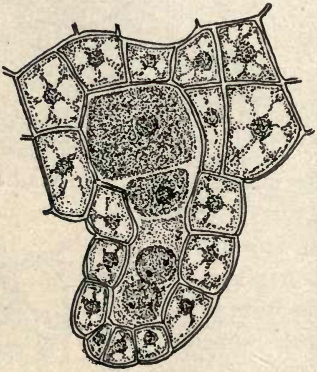


Fig. 317.
Archegonium of fern. Large cell in the venter is the egg, next is the ventral canal cell, and in the canal of the neck are two nuclei of the canal cell.

506. Development of the embryo fern plant.—The fertilized egg is the beginning of the second generation or spore plant (sporophyte), which is the fern plant as we know it. The egg divides by successive divisions, first into two cells and then into four. These four cells, or quadrants of the embryo, give rise to four parts of the embryo. The anterior upper quadrant gives rise to the *stem*, the anterior lower one to the *leaf*, the posterior lower one to the *root*, and the posterior upper one to a haustorium-like organ called the *foot*, through which food substances are passed from the prothallium to the embryo until the latter has established itself on the ground. The egg case grows for a time with the embryo, encloses and protects it. It becomes, therefore, a hood (*calyptra*). The root grows quite rapidly, breaks through the hood, and enters the ground. The leaf

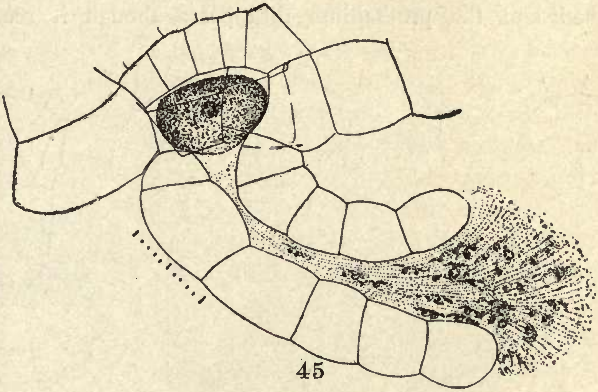


Fig. 318.

Mature and open archegonium of fern (Adiantum cuneatum) with sperms making their way down through the slime to the egg.

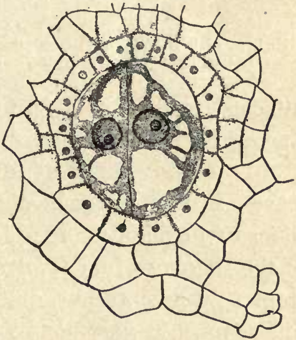


Fig. 319.

Two-celled embryo of Pteris serrulata. Remnant of archegonium neck below.

breaks through later, and curves upward in the sinus of the heart-shaped prothallium, and takes on a green color as it comes to the light. The stem grows more slowly. The embryo is now established and the prothallium disappears, though it remains attached to the young fern for some time. As the fern reaches the age for spore production the life cycle is completed.

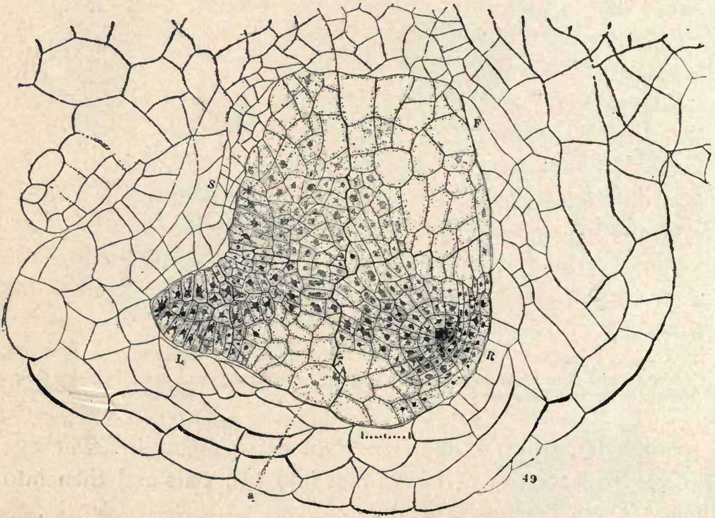


Fig. 320.

Embryo of fern (Adiantum concinnum) still surrounded by the archegonium, which has grown in size, forming the "calyptra." *L*, leaf; *S*, stem; *R*, root; *F*, foot.

507. Dimorphism in ferns.—Some ferns have two kinds of leaves, that is, leaves of different form, each kind performing a different function for the plant. An interesting example is seen in the stag-horn fern (*Platycerium alcicorne*). This grows in the tropics on tree trunks quite high up from the ground. It is often grown in greenhouses in this climate. One kind of leaf is narrow, and branched something after the fashion of the antlers of a stag. These leaves are either fertile or sterile. Another kind of leaf is broad and hugs closely against the base of the plant and the tree trunk. Here it catches falling leaves which decay, hold water for the use of the fern, and the fern roots spread through the decaying mass of leaves obtaining also some food. Another kind of dimorphism is present in several of our common ferns. Here, as in the sensitive fern (*Onoclea sensibilis*), there are certain leaves with large, expanded green blades. These perform the function of photosynthesis. Other leaves have stalks (or petioles) equally long, but the blade of the leaf is very much contracted and the pinnæ inrolled. These are the fertile leaves, and bear the spore cases in crowded sori within the roll of the pinnæ. The vegetative leaves arise early in the season, while the spore-bearing leaves (*sporophylls*) are developed later, some time in June. Cutting off the vegetative leaves as fast as they appear in the spring will change the spore-bearing leaves to vegetative ones, and many of them will be intermediate between the two, if the vegetative leaves are allowed to get about 20–30 cm. (8–12 inches) high before they are cut off. The vegetative leaves will need then to be cut twice.

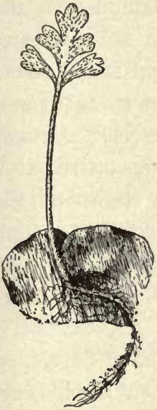


Fig. 321.
Young plant of Pteris serrulata still attached to prothallium.

Fig. 322.
Staghorn fern (Platycerium alcicorne).

The ostrich fern (*O. struthiopteris = Matteuccia struthiopteris*) presents a similar dimorphism of the leaves, and also the cinnamon fern (*Osmunda cinnamomea*). But in the cinnamon fern the spore-bearing leaves are formed during the late summer and autumn. They are hidden in the crown of the leaf stalks at the end of the stem during winter. In the spring they elongate and unroll before the appearance of the vegetative leaves. Parts of the spore-bearing leaves are often expanded into vegetative parts. In the royal fern (*O. regalis*) the dimorphism is shown on the same leaf, the tips of the divided leaves being contracted and bearing spore cases, while the basal portions are expanded. In Clayton's fern (*O. claytoniana*) the middle part of the leaf bears the spore cases.

508. Apogamy and apospory.*—Some ferns have developed the habit of doing away with certain stages in their life history. For example *Pteris cretica*, a common fern grown in greenhouses, does away with the sexual organs and fertilization.† The fern plant (sporophyte) grows directly out of the tissue of the prothallium (gametophyte). This is called *apogamy*, which means without marriage. Some other ferns can produce prothallia directly from the leaves without the spores. This is *apospory*. It is not a rare occurrence in the common *brake*, though the prothallia never become more than protonemal threads in this fern. The pinnæ which bear these are very much contracted and wrinkled, and can be easily distinguished from the normal form of

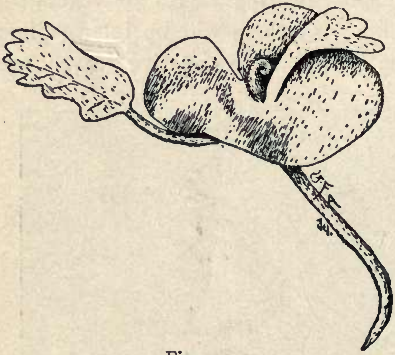


Fig. 323.
Apogamy in Pteris cretica.

---

* For reference.

† Recent investigations suggest that fertilization here takes place in two adjacent prothallial cells by the nucleus migrating from one into the other.

the fern. When the sporophytes of the sensitive fern are forced to grow into vegetative leaves, large numbers of young prothallia are formed on the intermediate leaves in place of the sporangia.*

509. Comparative review of the ferns.†—The ferns show a striking advance in the evolution of the sporophyte over the sporophyte of the liverworts and mosses. The principal features in this progress or higher development are as follows:

First. The sporophyte has become an independent plant and can obtain its own food without the aid of the gametophyte, while in the liverworts and mosses it is dependent on the gametophyte.

Second. The sporophyte is much larger in size and differentiated in form into roots, stem and leaves.

Third. Its structure is more complex with highly developed tissue systems for aeration, interchange of gases, and a well-developed vascular system for the transport of water and food.

Fourth. The sporophyte or second generation has become the prominent stage, or generation, in the life cycle of the plant, whereas the first generation, the gametophyte, is the larger and more prominent stage in the liverworts and mosses.

Fifth. Another evidence of the advance and increasing importance of the sporophyte in the ferns is the decrease in size of the prothallium or gametophyte, which is much smaller than the majority of the gametophytes of the liverworts and mosses.

Sixth. The sporophyte of the ferns is a structure better adapted to live on dry land and to obtain great size, thus enabling it to compete successfully over all the lower plants because it can rise above them to obtain the light relation.

Seventh. The differentiation of the leaves in some species bringing about a division of labor between vegetative leaves and spore-bearing leaves (sporophylls).

510. Formula for life history of the ferns.‡—The gametophyte is the prothallium or first generation, and bears the sexual

---

* See Chapter XXVIII, College Botany, by the author.

† For reference. ‡ For reference.

organs, sperms and eggs; the fertilized egg develops the sporophyte, the fern plant which bears the asexual spores. The formula may be written as follows:

Gametophyte $\left\langle \begin{matrix}\text{sperm}\\ \text{egg}\end{matrix} \right\rangle$ Fertilized egg — Sporophyte — asexual spores — Gametophyte, etc. This formula abbreviated is

$$\text{G}—\left\langle \begin{matrix}\text{s}\\ \text{e}\end{matrix} \right\rangle \text{FE} — \text{S} — \text{asp} — \text{G, etc.}$$

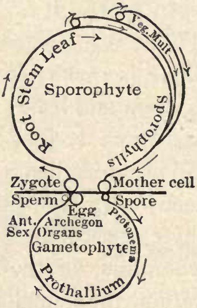


Diagram V. Illustrating the life cycle of a fern or Pteridophyte. Course of development follows the direction indicated by the arrows. Zygote equals fertilized egg. Vegetative multiplication by buds. Note the increase of the sporophyte and decrease of the gametophyte.

CHAPTER XXXIII.

OTHER FERN-LIKE PLANTS.

THE HORSETAILS (CLASS EQUISETINEÆ).

511. General characters.—The horsetails are very peculiar plants, their form being so different from other living plants that one would not suspect their relationship to the ferns were it not for the method of spore production, and the characters of the prothallium or gamete plant (gametophyte). The stems possess the chlorophyll and are green, with stomates in the epidermis, while the leaves lack chlorophyll. The stems are marked with longitudinal furrows and ridges which gives them a fluted appearance. The stems in some species are branched, the branches arising in whorls at the nodes. In other species the stems are unbranched as in the scouring rush (*Equisetum hyemale*). Their stems are well infiltrated with silica which makes them rigid and rough, so that some, as the scouring rush, have been used to polish certain metal work, and by country housewives for scouring kitchen tables and floors. The stems are hollow except at the nodes. The vascular bundles lie beneath the ridges and there are long canals which lie underneath the furrows. There is also an underground stem or root stock from which the aerial stems arise. At the nodes are membranous sheaths which surround the stem, and their upper edge is toothed. These sheaths represent the leaves; they are devoid of chlorophyll, photo-

To the Teacher. In short courses or first-year courses in the high school it may not be practicable to study any of the plants in this chapter. At the discretion of the teacher preserved specimens may be used for illustration. Horsetails, club mosses, etc., may be seen during excursions, and the selaginellas can be seen in some greenhouses. Where more time is allotted to the study or with more advanced students some of the examples described in the text can be studied.

synthesis taking place in the green stem. The fruiting part of the stem forms a spike or cone at the apex of certain stems. Most of the species of equisetum grow in sandy places, especially along railroad or other embankments, in soil where few other plants grow. This is interesting as it shows how a group of plants which was much more abundant in the past preserves itself from extinction by being adapted to grow under conditions where few other plants can. Some of the equisetums, however, grow in swamps where other vegetation is dense. The genus *Equisetum* is the only genus in this class. It is the only representative of a class of plants which flourished in geological times during the "Carboniferous Age." Many of the representatives then were tree-like forms, and fossil remains are found in the coal beds formed at that time. There are now about twenty-five living species.

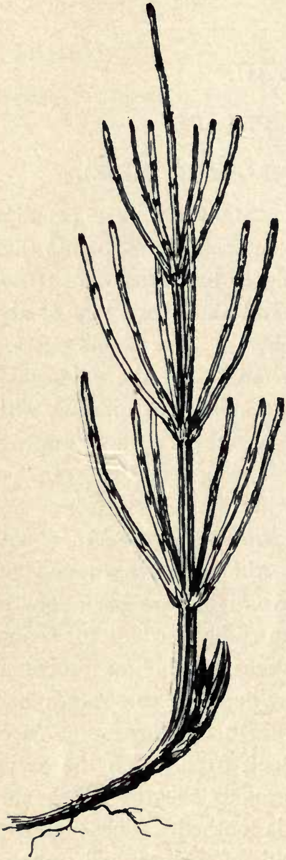


Fig. 324.
Sterile plant of horsetail (Equisetum arvense).

Fig. 325.
Portion of fertile plant of Equisetum arvense, showing whorls of leaves and the fruiting spike.

512. The fruiting spike or cone.—This is well studied in the common field horsetail (*E. arvense*) which is common in damp sandy places in fields and along railroads. There is an extensive underground stem which is much branched. Upon this are formed two kinds of aerial shoots, the fertile and sterile shoots. The fertile shoots are formed during late summer and autumn, but the stem remains short during the winter. Very early in the spring the stem elongates, pushes above the ground, and the spores are scattered. The fertile shoots are devoid of chlorophyll. The sterile shoots are developed all through the summer, are much branched and green. The *fruiting spike* is narrowly cone-shaped and terminates the fertile stem. The spore-bearing leaves (sporophylls) are peculiar, being shield-shaped with a short stalk which attaches them to the stem. They are in crowded circles around the stem, and thus are angular where they fit against one another. Several sac-like spore cases (sporangia) are attached to the inner face around the short stalk. At maturity the axis of the cone elongates, the spore cases crack open, and the spores escape. The spores have a very thick wall. The outer layer splits into four thin bands which are attached to the spore at one point and wrapped

Fig. 326.
Peltate sporophyll of Equisetum (side view), showing sporangia on under side.

Fig. 327.
Spore of Equisetum with elaters coiled up.

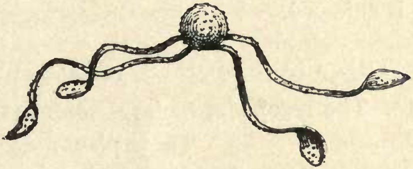


Fig. 328.
Spore of Equisetum with elaters uncoiled.

Fig. 329.
Male and female gamete plants of *Equisetum*. *A*, male plant. *an*, antheridium between lobes. *B*, female gamete plant. *a*, archegonia between lobes. *C*, sperm cell free from the antheridium, showing coiled sperm. *D*, sperm free from its cell. *A–B*, after Hofmister. *C–D*, after Schacht.

spirally around it. These uncoil when dry and coil up when wet. This aids the spore's movement. Several are often entangled together and are thus enabled to form a small colony of prothallia when carried away by the wind.

513. The gamete plant (gametophyte) of Equisetum.—When the spores germinate they form two kinds of prothallia: some produce small prothallia with only sperm cases (antheridia), while others produce larger prothallia with lobes, and egg cases (archegonia) situated near the origin of the lobes. There is thus a *dimorphism* in the prothallia of *Equisetum*, and cross fertilization is enforced.

THE CLUB MOSSES (CLASS LYCOPODINEÆ).

514. The lycopods, or large club mosses (Lycopodium).—These plants are called club mosses because in most species the spore-bearing leaves are grouped into a terminal spike or cone (*strobilus*), somewhat resembling a club, and because the small, crowded leaves, arranged in spirals on the slender stems, give them the appearance of the leafy stem of a moss. But they are not true mosses, since the leafy stem of the lycopods is a spore plant (*sporophyte*) while that of the true mosses is a gamete plant (*gametophyte*). This may help us to understand why the leaves and stems of the mosses and liverworts are *not true* leaves and stems, since true leaves and stems when present are only formed on the spore plant phase of plants. The lycopods occur in damp, moist situations, usually in the forest. Some of them have long, creeping stems in addition to the upright stems.

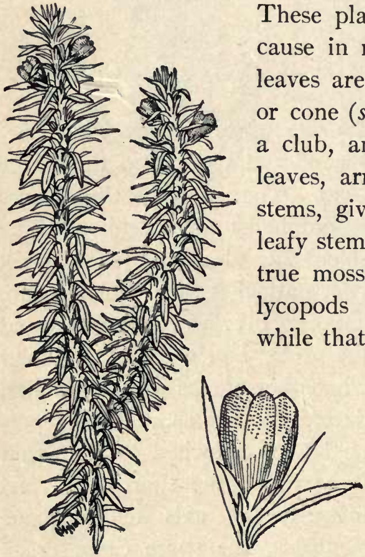


Fig. 330.

Lycopodium lucidulum, bulbils in axils of leaves near the top, sporangia in axils of leaves below them. At right is a bulbil enlarged.

They are frequently called "ground pine," and are often collected for holiday decorations. The branching of the stems is usually forked. Prothallia are not known in northern countries, but have been found for several species in tropical countries. In one of these (*L. cernuum*) the prothallium is a cylindrical body, sunk in the earth, with green lobes at the top where the sexual organs are developed. In others the prothallium is a slender, colorless, branched body, growing saprophytically in the decaying bark of trees. With some of these a fungus is associated, making a structure similar to certain mycorhizæ (paragraph 205). In northern countries where prothallia have not been discovered, the species propagate by vegetative growth, and some by bulbils, as in the case of *L. lucidulum*. These bulbils are specialized buds.

515. The fruiting spike or strobilus.—The spore-bearing leaves (sporophylls) are grouped into a cylindrical spike (a strobilus) at the end of the stem where they closely overlap. At the base of each sporophyll is a spore case containing many small spores. These are shed by the spore case splitting transversely. The spores are produced in great quantity and are pale yellowish in mass. They are sometimes used for various toilet purposes, for pyrotechnics, and for coating certain pills to prevent adhesion.

516. The little club mosses (Selaginella).—Some of the species of *Selaginella* in northern countries resemble *Lycopodium*, and are sometimes called "little club mosses" because they are much smaller in size. The leaves are crowded on the slender stems and in many species are arranged in four or six rows. The stems of many species are dorsiventral, the rows on each side being approximated, giving a flattened appearance. Many of the tropical species are quite large, and are grown in greenhouses for ornament because of the beauty of their form and the metallic colors of some species. They are branched profusely, often in a single plane, thus giving the appearance of a large leaf. One of the tropical species is known as "resurrection" plant, or "resurrection" moss. When it dries it rounds up in a ball. The roots are thus drawn from the soil, and it is often rolled along on the ground by the wind. With the advent of rains it expands and becomes green and fresh. It is often sold in the markets because of this curious habit.

Fig. 331.
Selaginella with three fruiting spikes. (Selaginella apus.)

Fig. 332.
Fruiting spike, showing large and small sporangia.

Fig. 333.
Large sporangium.

Fig. 334.
Small sporangium.

517. The fruiting spike or cone of Selaginella.—The sporophylls are usually in four rows over the end of the stems and branches, making a four-sided cone or strobilus. There is a single spore case at the base of each sporophyll. A few of the lower ones contain each a few very large spores, one to eight. These are called *macrospores* * or *mega-*

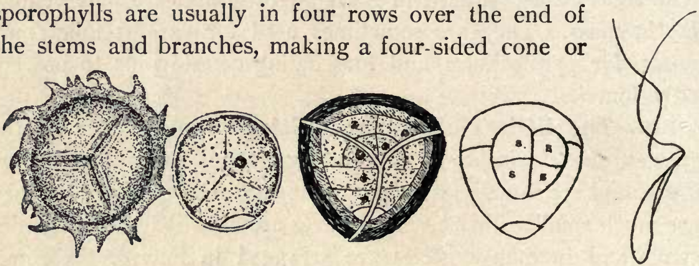


Fig. 335.
Details of microspore and male prothallium of Selaginella; 1st, microspore; 2d, wall removed to show small prothallial cell below: 3d, mature male prothallium still within the wall; 4th, small cell below is the prothallial cell; the remainder is antheridium with wall and four sperm cells within; 5th, spermatozoid. (After Beliaieff and Pfeffer.)

---

* The sporangia which produce the macrospores are called *macrosporangia* or *megasporangia*, while those which produce the microspores are *microsporangia*.

spores, which means large spores. The upper spore cases produce a very large number of small spores (*microspores*). Since the spores are of different sizes, *Selaginella* is said to be a *heterosporus* plant. A plant is *homosporus* when the spores are all alike.

518. The prothallia or gamete plants (gametophytes) of Selaginella.—The gamete plants of *Selaginella* are diœceous (or *heterothallic*). This condition of the prothallium is determined in the spore. The small spores (microspores) produce small male gamete plants. There is only one cell in the prothallium part. The other cell, which is larger, develops into the sperm case with a wall containing a few sperms. The sperms are *biciliate*, as they are in the lycopods, thus being different from those of the ferns and horsetails, and more like those of the mosses. The large spore (macrospore or megaspore) develops the female gamete plant. This never escapes from the spore wall. A mass of tissue is formed which cracks open the spore wall, and the egg cases (archegonia) are developed in the exposed surface. There is no chlorophyll in either male or female prothallia. This accounts for their small size, the larger female prothallium being due to the greater amount of food in the large spore. All the food, therefore, for the gamete plant of *Selaginella*, comes from the spore plant (sporophyte) and was stored in the spores while

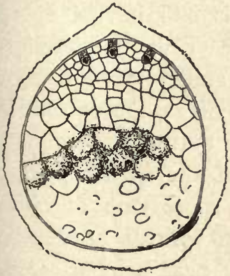


Fig. 336.
Section of mature macrospore of Selaginella, showing female prothallium and archegonia. (After Pfeffer.)

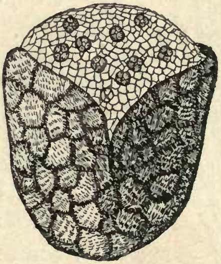


Fig. 337.
Mature female prothallium of Selaginella just bursting open the wall of macrospore, exposing archegonia. (After Pfeffer.)

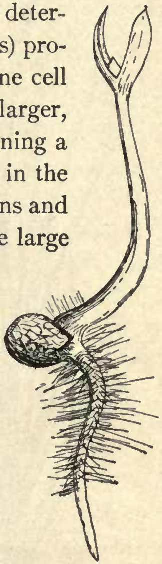


Fig. 338.
Seeding of Selaginella still attached to the macrospore. (After Campbell.)

they were being developed. The gamete plants of *Selaginella* then are entirely dependent on the spore plant for their food, a condition of things entirely different from that in the other fern plants we have studied and in the liverworts and mosses. In one species of *Selaginella* (*S. rupestris*) the large spores sometimes do not escape from the spore case. The spore case cracks open and some of the small spores from their spore cases above fall in. Here they produce the sperms, and the egg in an egg case (archegonium) is fertilized while the female gamete plant is still in the spore case. The embryo develops here also, and when the root and stem emerge, the process is exactly like that of a germinating seed of the higher plants. The large spore case of *Selaginella* then with its large spore comes very near being a seed, and this places *Selaginella* very near the seed plants.

Fig. 339.
Isoëtes, mature plant, sporophyte stage.

THE QUILLWORTS (ISOËTES).

519. General characters.— The quillworts are peculiar plants. They grow in very wet places, or even partly or wholly submerged for parts of the year. The leaves are long, slender and terete except at the base, which is somewhat spoon-shaped. The bases of the leaves overlap on a very short stem, which is sometimes broader than its length. The leaves are thus borne in tufts. The roots extend from the lower part of the broad stem (fig. 339). There are two kinds of spores, large and small, and both kinds of gamete plants lack chlorophyll. The quillworts resemble certain grasses in the form of the narrow part of the leaf.

COMPARATIVE REVIEW OF THE FERN PLANTS.*

520. Relation of the ferns to the liverworts.—Although the ferns are much more highly organized than the liverworts it is believed that they have had their origin from the liverworts, that is, from some liverwort which existed ages ago but which is now extinct. Of those now existing the horned liverworts (*Anthoceros*) come nearest this supposed ancestor of the ferns. The adder's tongue fern (*Ophioglossum*), which is a member of the class to which the true ferns belong (Class *Filicineæ*), is one of the lowest ferns and its sporophyte has some points of resemblance to that of *Anthoceros*. In the adder's tongue fern there is a simple slender stalk, in the upper end of which the spore cases are imbedded and separated by sterile tissue.† On this stalk there is a simple blade, the leaf. This is, of course, far from being the equivalent of the sporogonium of *Anthoceros* but is more like it than is the sporophyte of any other of the fern plants. It suggests, however, that it may have been derived from some *Anthoceros*-like ancestor. Other members of the order (*Ophioglossales*) to which the adder's tongue belong have divided leaves, and members of still other orders which cannot be described here lead up to the condition of our common ferns, from massive and simple sporangia to the specialized sporangium which has been described for the common ferns. From the true ferns

---

* For reference.

† The roots of the adder's tongue and of other members of the order (*Ophioglossales*) to which it belongs are fleshy and have a fungus in their tissues, thus forming a mycorhiza (see paragraph 205). The prothallium of the members of the order is a degenerate, tuberous structure, devoid of chlorophyll and also associated with a fungus.

(Class *Filicineæ*) the progression has gone on as illustrated by the horsetails and the club mosses until a condition is reached which is very much like that of the seed plants. The principal things which have been developed among the fern plants and which mark the progression above the liverworts may be enumerated as follows:

First. The sporophyte has become an independent plant by the development of roots, of special organs for assimilation (leaves), and of a well-developed vascular system for the transport of water and food materials, as well as the differentiation of other tissue systems.

Second. Alternation of generations has reached its highest expression in that both generations, the gametophyte and the sporophyte, can live as independent plants.

Third. Dimorphism of the leaves of the sporophyte which results in a division of labor among the leaves into those for the function of photosynthesis and those for spore bearing. This was begun in a few of the ferns, becomes the rule in the club mosses, but is not present in *Isoëtes*.

Fourth. Heterospory, the development of two kinds of spores large and small, has originated in the higher fern plants. This predetermines the sex of the gametophytes and insures cross fertilization among the gametophytes, which is a distinct advantage, and is one of the characteristics of the seed plants. This dimorphism (or heterothallic condition) of the gametophytes is foreshadowed in the true ferns where varying amounts of nutriment may determine the sex of the prothallia and is almost wholly determined in *Equisetum*. In *Selaginella* and *Isoëtes* it is predetermined in the spore.

Fifth. The sporophyte is the most prominent part in the life cycle of fern plants and is better adapted to existence on the land. It has a decided advantage over the gametophyte generation which is especially adapted to wet or moist situations, and which requires water as a medium for conveying the sperms to the egg. The earliest green plants, the algæ, are almost exclusively of an aquatic habitat. The sporophyte of the fern plants being perennial can live through seasons when the gametophytes would perish. Each season it sheds its spores, so that when a favorable period arrives the gametophytes develop and produce new sporophytes.

Sixth. The gametophyte decreases in size and importance as the sporophyte increases, until in *Selaginella* and *Isoëtes* it becomes entirely dependent on the sporophyte for its nourishment. The gametophytes, it is true, generally become free from the sporophyte, but not until sufficient food is stored up in the spore. In *Selaginella* the female gametophyte nearly completes its development before escape from the sporangium, and in some cases actually remains in the sporangium until after fertilization and development of the embryo, thus really forming a seed which is the special character of the seed plants, which make up the highest branch of the plant kingdom.

Seventh. The supreme position which the sporophyte was destined to occupy in the plant world is shown in the luxuriance and immense quantity of vegetation during what is known as the coal period, or Carboniferous Age.

521. Deposits of coal formed by the fern-like plants.—The fern plants occupy a very minor position in the plant world at the present time compared to their dominant position in past ages. This has been revealed through fossil remains of plants discovered in different strata of the earth's crust and through the immense deposits of coal formed during what is known as the coal period, or Carboniferous Age. The coal is formed by plant remains covered by other strata, and subjected to such great pressure and heat, in the absence of air, that carbon or carbonized matter is formed since oxidation cannot take place. The coal is, therefore, laid down in strata, or seams, between other rock layers. These layers of coal vary from one to three meters (three to ten feet) in thickness in most of the regions where coal is mined, and in some cases is much thicker, from twenty to thirty meters or more in thickness. The pressure which is necessary in changing plant material to coal reduces enormously the thickness of the material, so that it would require beds of plant material 280–450 meters thick (900–1500 feet in thickness). In the United States there are several hundred thousand square miles of coal-bearing areas, of which about fifty thousand are worked. This gives an opportunity to see what an enormous amount of vegetation must have existed during that age, considering the fact also that much of it must have decayed before the geological changes occurred which submerged the material converted into coal. In the coal beds very little of the plant remains is preserved because the great heat consumed them and changed them largely to carbon. But numerous impressions remain which enable the paleobotanist to determine the nature of the plants which flourished on the earth at that time. These impressions and the carbonized remains of stems are more evident in the soft coal, but evidences are also found in the hard coal beds to indicate that they also are the remains of plants.

522. The remains of the fern plants found in the coal measures of the Carboniferous Age are sufficient to show that the number of genera and species was far greater at that time than at the present day. The evidence also shows that they were much larger in size. Besides the tree ferns, the lycopods were of tree size as were the closely related plants *Lepidodendron* and *Sigillaria*. *Equisetum*-like plants called *Calamites* were also of tree size. There were also many other tree forms which are extinct to-day. There was much more moisture and carbonic acid in the air at that age. This probably accounts to some extent for the luxuriance of the vegetation. It is possible that the greater amount of moisture occasioned large areas of swampy and wet ground, for these tree forms of the lycopods, horsetails, etc., flourished in the wet, marshy places. This may have led to a condition of things similar to the peat moors of the present day, where decay of plant parts is only partial and the firmer parts are even preserved from decay. In this way the deep layers of plant material may have accumulated, and later, by the subsidence of the earth's crust at these points, they may have been covered with water for long periods, during which deposits of another character covered them which later formed the rock stratum overlying

Fig. 340.

Idealized landscape of carboniferous times. 1, a tree fern. 2, giant *Equisetum*-like plant (Calamites). 3, 4, giant club mosses (*Lepidodendron* and *Sigillaria*). 5, a primitive gymnosperm (*Cordaites*). (After Potonié.)

the coal seams. Alternate elevation and subsidence of the land, it is believed, provided for the superposed strata of coal and other kinds of rock. The fern plants of to-day are only a relic of the grand fern vegetation of the Carboniferous Age. The fern plants have gradually lessened in importance since that time, both in size and in number. From being the dominant vegetation elements of that time they now occupy a subordinate place, while the sporophyte of the seed plants has gradually risen to be the dominant vegetation element first represented by the Gymnosperms, many of these being now extinct, and now represented by the Angiosperms and some Gymnosperms. It is an interesting picture to represent the rise and fall of these different classes of plants.

523. Formula for life history of the heterosporous Pteridophytes.*—The formula would be similar to that for the ferns, but with two kinds of spores and gametophytes. It will be more convenient perhaps to start the cycle with the sporophyte. Then

$$\text{Sporophyte} \begin{matrix} \nearrow \text{asexual microspore — male gametophyte — sperm} \searrow \\ \searrow \text{asexual macrospore — female gametophyte — egg} \nearrow \end{matrix} \text{Fertilized egg — Sporophyte, etc.} = \text{S} \begin{matrix} \nearrow \text{mi sp — MG — s} \searrow \\ \searrow \text{ma sp — FG — e} \nearrow \end{matrix} \text{FE — S., etc.}$$

---

* For reference.

CHAPTER XXXIV.

THE GYMNOSPERMS.

524. General characters.—The *Gymnosperms* make one of the two large classes of the seed plants (Class *Gymnospermæ*). The name means *naked seeds*, the seeds being formed on the outside of a modified leaf (sporophyll). To the other class belong the *Angiosperms* (Class *Angiospermæ*). These have their seeds enclosed in a pod-like or sac-like structure formed by the infolding of a modified leaf (sporophyll).

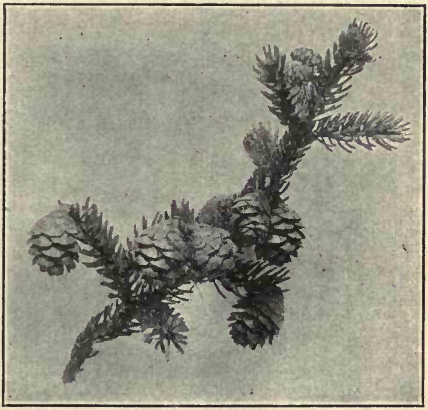


Fig. 341.
Cones of spruce (Picea).

525. The cone-bearing Gymnosperms. — By far the larger number of the Gymnosperms are coniferous (Order *Pinales* or *Coniferales* including some shrubs) or cone-bearing trees, the fruit being called a cone because of its form. There are more than three hundred species of conifers, and many of these are

To the Teacher. One of the pines or spruces should be studied carefully if it has not already been done in Part I. The cycads in conservatories may be pointed out as fern-like Gymnosperms, and where trees of gingko are growing in the neighborhood the location should be pointed out to the students and a branch with the leaves should be preserved for illustration. When fruits and cones can be obtained they should also be studied. *Cycas* sometimes fruits in conservatories. *Zamia* can be obtained from Florida. More advanced classes can make a study of some of these types.

trees of large size widely distributed over different parts of the world, especially the Northern Hemisphere. Many of these grow in great abundance in extreme northern latitudes where the winter season is very cold, while others occur in temperate and in subtropical countries where the heat of the season is often very great. Some of the trees of great size are the giant red woods (*Sequoia*) of the Sierra Nevada Mountains. Others are the pines, spruces, firs, balsams, larches, cypresses, cedars, hemlock spruces, arbor vitæ, etc. The American yew or ground hemlock is an example of a shrubby form. The majority of the conifers have a straight excurrent trunk, with lateral rather subordinate branches, thus forming a large straight boll, making them especially valuable as timber trees, aside from the valuable quality of many of the woods. The branches in the pines, balsams, and some other trees, arise in apparent whorls on the main shoot, from lateral buds grouped just below the terminal bud. It is possible then to determine the age of the tree so far as the branches are retained over the lower part of the trunk. In the hemlock spruce, cedars, and some others the branches are more or less scattered along on the trunk.

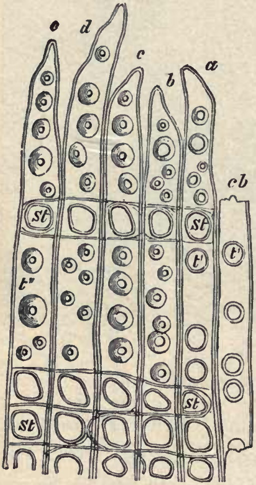


Fig. 342.

Pinus sylvestris; longitudinal radial section through the wood of a rapidly growing branch; *c*, *b*, cambial wood-cells (tracheïdes); *a* to *e*, older wood-cells (tracheïdes); *t'*, *t''*, *t'''*, bordered pits, increasing in age; *st*, large pits where cells of the medullary rays lie next to the wood-cells. X 325. (After Sachs.)

526. The leaves are needle-like and quite long in the pines, shorter and more flattened in the spruces, and scale-like in the cedars, arbor vitæ, etc. In the pines they are in clusters of two to five (rarely one in some western pines) at the end of a very short branch. There are thus two kinds of shoots developed each year, the long ones and the short ones. The long ones correspond in arrangement on the stem to the short ones and this is the reason they are so crowded on the stem as to represent a whorl. The leaves are hard and firm, have a thick rather resinous cuticle, and a thick epidermis. Underneath the epidermis are a few layers of stony (sclerenchyma) cells inside of which is the thin-walled chlorophyll-bearing parenchyma with fluted cell walls. There are one or two vascular ducts in the leaf according to the species, besides the resin ducts. This structure of the leaves, together with their small and compact size, fits them to withstand the drying effect of cold winters, the heat of the sun and severe droughts in summer. Some of the conifers are deciduous, as the bald cypress, larch, etc.

527. The structure of the stem and its development is much as described for woody stems (paragraphs 96–100) but there are no trachea in the vascular system, these being represented by tracheides similar to the trachea but their cross walls not being perforated. The most characteristic feature of the wood is the

Fig. 343.
Staminate cones of American yew (Taxus canadensis).

presence of the "bordered pits" in the wood cells which appear like minute openings in a bordering circle, in one view, and elliptical in edge view (fig. 342), the large pits being on either side of a middle partition, each with a minute opening on the outside. Resin ducts also occur in the wood. The fruit of the conifers is mostly a *cone* fruit, the seeds being borne on the inner face of scales which are united around an axis in the form of a cone. In the ground hemlock or American yew, the fruit is a berry with a red pulp, but here the pollen-bearing sporophylls are arranged in the form of a cone called the staminate cone, much as they are in all of the cone-bearing Gymnosperms.

LIFE HISTORY OF THE PINE.

528. The staminate cones and pollen.—The staminate cones are borne in clusters at the ends of branches occupying the position of a whorl of branches. Each cone consists of a short axis covered by short scale-like structures compactly arranged in a spiral manner. Each one of these scales is a modified leaf, or *sporophyll*. Upon the underside are two sacs which open by a slit at maturity and scatter the pollen. All in a cone, or cluster of a cone, usually open suddenly and simultaneously, emitting a cloud of the pollen. The pollen is so abundant that it sometimes falls as it were in "showers," covering leaves, etc., with a thin, yellow-looking powder, resembling "flour of sulphur." The scales are called *stamens*, hence the name *staminate cone*. The pollen grains, however, are developed, four from each mother cell, precisely as the spores are developed in the spore cases of the ferns, mosses and liverworts. The pollen grains are, therefore, small spores (*microspores*), the anther sacs are small spore cases (*microsporangia*) and the stamens are small spore-bearing leaves (*microsporophylls*). The pollen grain

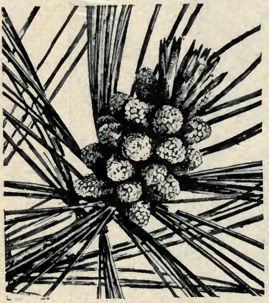


Fig. 344.
Spray of white pine, showing cluster of male cones just before the scattering of the pollen.

of the pines, spruces, etc., has a peculiar structure. The pollen grain has on either side two rounded air sacs formed by a swelling out at these points of the outer layer of its wall. These serve as floats, and the pollen grains are very buoyant, being carried great distances by air currents. The mature pollen grain is a rudimentary male prothallium or gamete plant (gametophyte). While it is developing two sterile prothallial cells are formed which soon disappear in the pines. The rest of the pollen grain is a rudimentary sperm case (antheridium) and consists of two cells, the tube cell (or wall cell) and the sperm case cell (antheridial cell), or *central cell* (see fig. 348).

Fig. 345.
Staminate cone of white pine, with bud scales removed on one side.

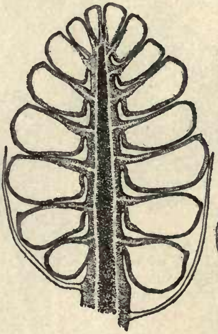


Fig. 346.
Section of staminate cone, showing sporangia.

Fig. 347.
Two sporophylls removed, showing opening of sporangia.

529. The pistillate cone and ovules. — The pistillate cone (or carpellate cone) forms the fruit. These cones are also usually developed in clusters. They are developed from a whorl of buds at the end of the shoots. They begin their development in spring, and the axis is soon covered with spirally arranged scales. On the inner and upper face of each scale, at its base, are two *ovules* which correspond to large spore cases (*macrosporangia*). At the lower end are two horn-like processes, and between these is an opening, the *micropyle*. The wall of the ovule is called the *integument*. The interior tissue of the ovule is called the *nucellus*. It is in truth the real tissue of the large spore case. A large

Fig. 348.
Pollen grain of white pine.

spore (macrospore) is formed inside, which never escapes, but develops the female prothallium or gamete plant (gametophyte), which in the Gymnosperms is known as the *endosperm*. In this prothallium, egg cases (archegonia) are formed near the micropyle, each containing a large egg which is surrounded by a regular layer of cells, the wall of the venter, called *jacket* cells, or a *jacket*. After fertilization the embryo is developed within the ovule. The ovule together with the endosperm and embryo forms the *seed*. The scales have become large and hard. It requires about fifteen months from the time of pollination (during May) to the ripening of the seed (August of the following year). Soon after the ripening of the seed, the cone dries. As this takes place the seed with a thin layer of the scale, in the shape of a knife blade, splits off from the scale. The pine seed, therefore, is a " winged " seed.

Fig. 349.
Section of female cone of white pine, showing young ovules (macrosporangia) at base of the ovuliferous scales.

Fig. 350.
Scale of white pine with he two ovules at base of ovuliferous scale.

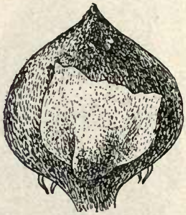


Fig. 351.
Scale of white pine seen from the outside, showing the cover scale.

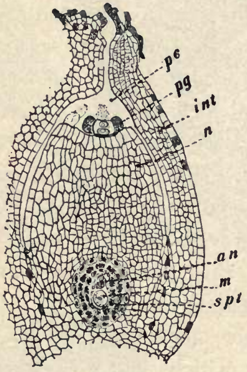


Fig. 352.
Macrosporangium of pine (ovule). *int*, integument; *n*, nucellus; *m*, macrospore; *pc*, pollen chamber; *pg*, pollen grain; *an*, axile row; *spt*, spongy tissue. (After Ferguson.)

530. Pollination and fertilization.—At the time the pollen is scattered the small pistillate cones stand erect, with the scales spread apart. They thus catch the flying pollen, which falls down to the base of the scales and is caught in a drop of a viscid substance exuded through the micropyle of the ovule. When this dries it draws the pollen grains up in the micropyle close against the nucellus. The scales now close, and the cone turns downward, in which position the ovules are better protected from rain and outside changes in the air. The scales become further sealed with resin. This occurs in May or June. The pollen grain then germinates, the tube cell forming a tube which penetrates the nucellus, and usually branches, feeding on the disintegrated cell contents, and quantities of starch grains are found in the pollen tube. During this process the central cell of the sperm case divides into two cells; one is sterile, while the

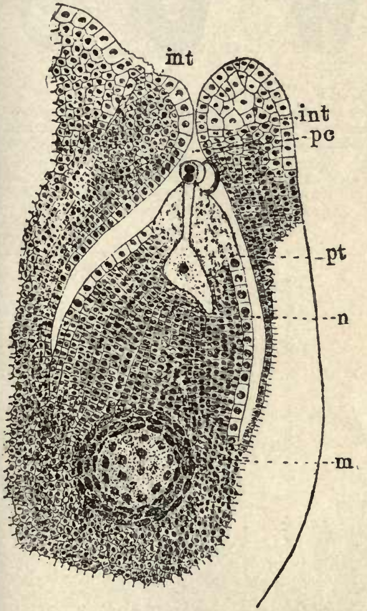


Fig. 353.
Section of ovule of white pine. *int*, integument; *pc*, pollen chamber; *pt*, pollen tube; *n*, nucleus; *m*, macrospore cavity.

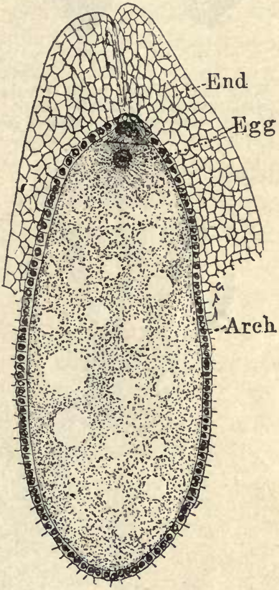


Fig. 354.
Last division of the egg in the white pine cutting off the ventral canal cell at the apex of the archegonium. *End*, endosperm; *Arch*, archegonium.

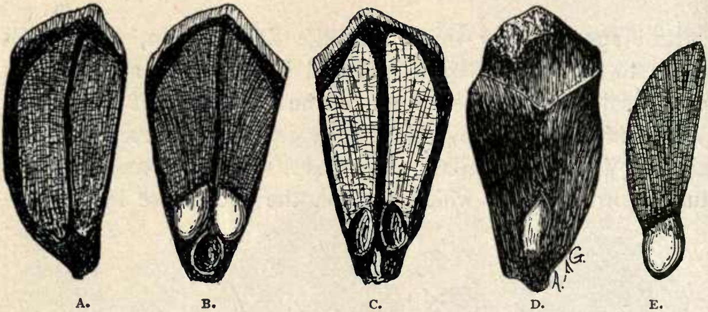


Fig. 355.

White pine, showing details of mature scales and seed. A. Sterile scale, seeds undeveloped. B. Scale with well-developed seeds. C. Seeds have split off from scale. D. Back of scale with small cover scale. E. Winged seed free from scale.

Fig. 356.

Branch of white pine, showing young female cones at time of pollination on the ends of the branches, and one-year-old cones below, near the time of fertilization.

other becomes a sperm mother cell, called the generative cell or the body cell. These cells move along in the apex of the tube. The pollen tube rests in the nucellus during winter. The following spring it begins growth again, and the nucleus of the generative, or body, cell divides into two sperm nuclei in the one cell. The female prothallium (endosperm) is developed in the spore case (nucellus), and when the egg cases are mature the pol-

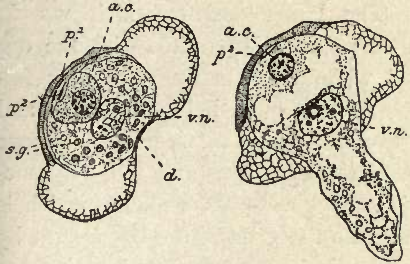


Fig. 357.

Pollen grains of pine, one of them germinating. p^1 and p^2, the two disintegrated prothallial cells = sterile part of male gametophyte; *a.c.*, central cell of antheridium; *v.n.*, vegetative nucleus or tube nucleus of the single-wall cell of antheridium; *s.g.*, starch grains. (After Ferguson.)

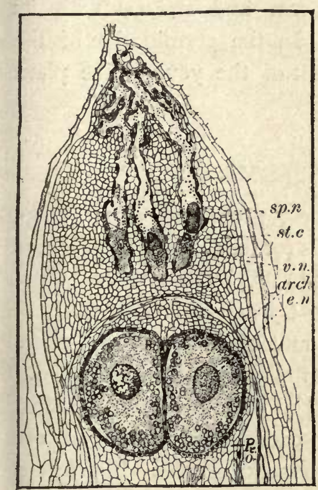


Fig. 358.

Section of nucellus and endosperm of white pine. The inner layer of cells of the integument shown just outside of nucleus; *arch*, archegonium; *en*, egg nucleus. In the nucellar cap are shown three pollen tubes: *vn*, vegetative nucleus or tube nucleus; *stc*, stalk cell; *spn*, sperm nuclei (the larger one in advance is the one which unites with the egg nucleus). The archegonia are in the endosperm or female gametophyte. (After Ferguson.)

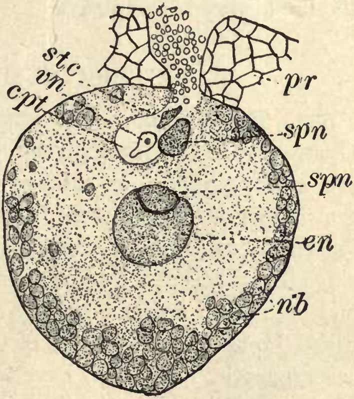


Fig. 359.

Archegonium of white pine at stage of fertilization. *en*, egg nucleus; *spn*, sperm nucleus in conjugation with it; *nb*, nutritive bodies in cytoplasm of large egg; *cpt*, cavity of pollen tube; *vn*, vegetative nucleus or tube nucleus; *sc*, stalk cell; *spn*, second sperm nucleus; *pr*, portion of prothallium or endosperm; *sg*, starch grains in pollen tube. The sheath of jacket cells of the archegonium is not shown. (After Ferguson.)

len tube makes its way into the neck end of an egg case, and empties the cells and sperms into the cytoplasm of the egg (fig. 359). The larger sperm (which was in advance in the pollen tube) unites with the egg nucleus, and without any resting stage the fertilized egg nucleus at once divides into two, and these into two more. These four nuclei move to the base of the egg case, and there by successive divisions organize the embryo, which is pushed down into the mass of the endosperm by certain of its cells in the rear, which elongate rapidly and are called the ***suspensor***. The seed ripens in late summer and consists of the seed coats (coats of the ovule), the remnants of the nucellus, the endosperm and embryo with its rudimentary root, stem and leaves. In the germination of the seed (paragraph 13) and establishment of the young pine plant the life history is completed.

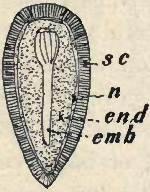


Fig. 360.
Pine seed, section of. *sc*, seed coat; *n*, remains of nucellus; *end*, endosperm (= female gametophyte); *emb*, embryo = young sporophyte. Seed coat and nucellus = remains of old sporophyte.

OTHER GYMNOSPERMS.*

531. The Cycads.—The other most prominent class of the Gymnosperms is made up of the cycads (order *Cycadales*). These are mostly tropical or subtropical plants, but some are often grown in greenhouses, especially the *Cycas revoluta*, sometimes incorrectly called *sago palm* † on account of its trunk and large spreading leaves at the apex, giving it the aspect of the tree palms, and because of a coarse starchy material obtained from the stem called Japanese sago. Some of the cycads like *Zamia* (there are several species in Florida) have tuberous-like trunks. The leaves are large, stiff and feather-like because of their narrow, pinnate divisions, and resemble the leaves of some of the tree ferns. In their fructification they bear a striking resemblance to the ferns, and stand lower in grade of classification than the conifers.

---

* For special assignment or reference.

† The sago palm is *Metroxylon lævis* and *M. rumphii* of the East Indies (Chapter XXXVI).

Fig. 361.
A cycad (Cycas revoluta), showing cluster of fertile leaves (macrosporophylls) in the center.

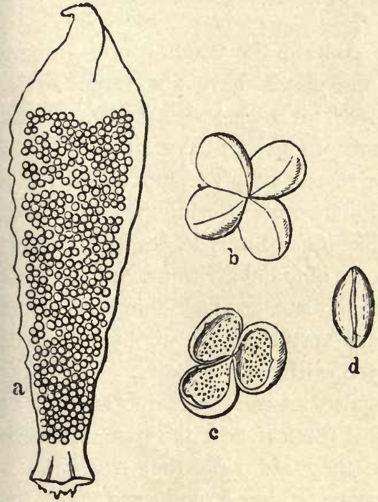


Fig. 362.
A sporophyll (stamen) of cycas; sporangia in groups on the underside. *b*, group of sporangia; *c*, open sporangia. (From Warming.)

Fig. 363.
Macrosporophyll of Cycas revoluta.

532. Cycas.—In cycas the small spore-bearing leaves (microsporophylls) are flattened leaves with true sporangia, similar to the spore cases of some of the ferns, scattered over the under surface of the leaves. These contain the small spores (microspores) (fig. 362). The female plants have the large spore-bearing leaves (macrosporophylls, or megasporophylls). These are produced at certain seasons in a rosette near the apex of the stem. Each spore-bearing leaf is shaped like the ordinary leaves, with numerous pinnate divisions, but they are much smaller, lack chlorophyll, and are very hairy or woolly with pale yellowish brown hairs. The large spore cases (macrosporangia), or ovules, are borne on either side of the leaf near the base, one each in place of a pinna. When they are ripe they resemble a stone fruit with a fleshy exocarp, a stony endocarp, and the meat or kernel within is the female prothallium or endosperm (fig. 365).

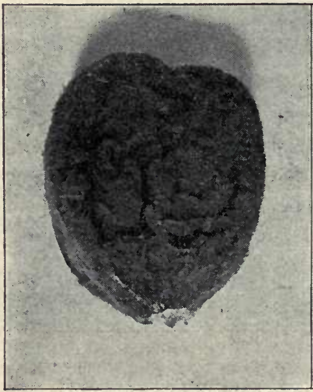


Fig. 364.
Macrosporangium of Cycas revoluta.

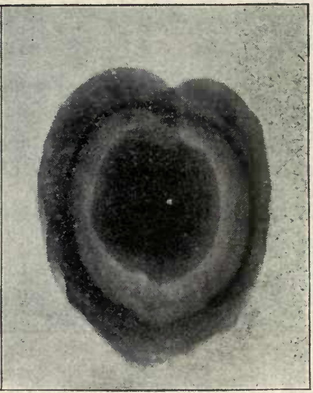


Fig. 365.
Roentgen photograph of same, showing female prothallium.

Fig. 366.
Scales of the staminate cone, a single scale at the left, all showing the small sporangia on the underside.

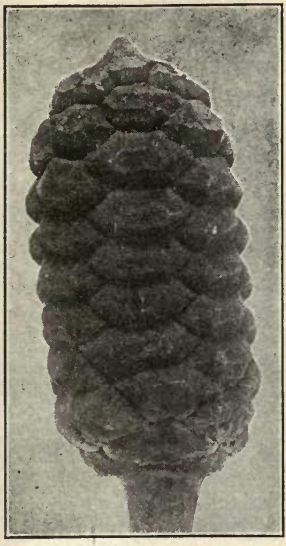


Fig. 367.
Pistillate cone of Zamia.

533. Zamia. — *Zamia* is also diœcious, and the male and female plants both bear cones. In the staminate cones (fig. 366) the spore-bearing leaves are short and stout, somewhat triangular wedge-shaped, and very closely crowded. Upon the underside are numerous small oval spore cases similar to those of cycas and some of the lower ferns, which contain numerous small spores. The pistillate or carpellate cone is similar in external appearance but larger. The spore-bearing leaves are similar in form but bear two large spore cases, one on either side but covered by the broadened outer end.

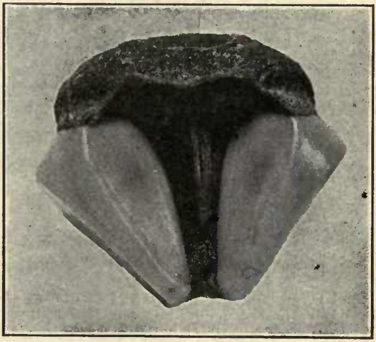


Fig. 368.
Zamia, one scale of the pistillate cone, showing the two ovules.

534. Life history of the cycads.—The life history of the cycads presents many interesting features, but the account here must be very brief. The pollen grain (microspore) is a rudimentary male prothallium as in the pine, but some of the sterile prothallial cells persist in the mature small spore (microspore). After pollination the tube cell grows down into the tissue of the nucellus (in *Zamia*) at one side of the endosperm forming a haustorium which supplies the generative cell with food. The pollen end of the tube then bends down into a cavity in the nucellus which is filled with a fluid and lies next the egg cases in the female prothallium (endosperm). The central cell (or stalk cell sometimes called) has divided, as in pines, into a sterile cell and a generative cell (body cell) which now divides into the two sperm cells,* which are oval in form, and each has a spiral band of numerous cilia around the smaller end (fig. 373). Some of these sperms swim into the egg cases, one unites with an egg nucleus, and the embryo is then formed, thus making a seed.

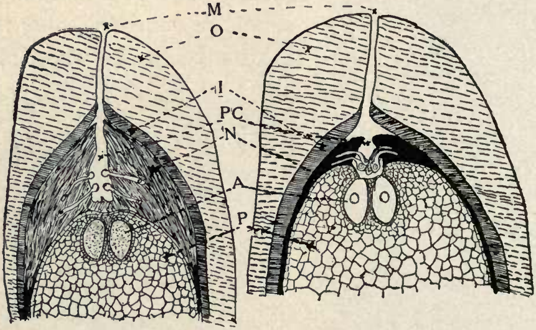


Fig. 369.

A, section of ovule of zamia, partly diagrammatic, showing germinating pollen tubes entering the nucellar cap. *M*, micropyle; *O*, outer portion of ovule (exocarp); *I*, inner stony portion of ovule (endocarp); *PC*, pollen chamber; *N*, nucellar cap; *P*, endosperm (prothallium); *A*, archegonium (pollen grains in pollen chamber are germinating, the pollen tubes growing in the tissue of the nucellar cap). *B*, same a little later, showing basal end of the pollen tubes bending downward as the sperm cells in that end are developing.

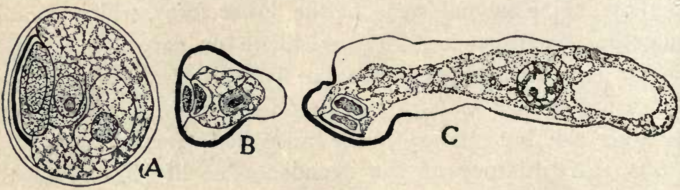


Fig. 370.

Zamia. *A*, mature pollen grain showing within, the tube cell at the right, the central cell in the middle, the prothallial cell at the left; *B*, beginning of germination of pollen grain; *C*, farther stage in the germination of pollen grain, the tube nucleus of cell moving into the tube. (After Webber.)

* Two sperm cells are formed in most cycads as in other seed plants, but in *Microcycas* there are eight generative cells, each of which divides to form two sperms, making sixteen in all for each small spore.

On the germination of this and the establishment of the *Zamia* plant the life history is complete.

535. Gingko.—*Gingko* (*Gingko biloba*) is a very interesting tree. It is a native of China and is now widely grown in Europe, America, and other countries, as an ornamental tree. It is the sole survivor of a group of plants which were very abundant in geological times. The leaves are triangular, radiately veined, and resemble in form the pinnules of the maiden hair fern (*Adiantum*). The large spore cases form a fleshy fruit, about the size of a plum, with a soft exocarp and a stony endocarp, the meat within being the female prothallium or endosperm. There are motile sperms, and the life history is similar to that of the cycads.

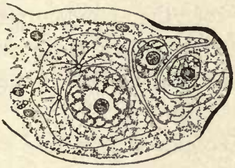


Fig. 371.
Zamia. Germinating pollen grain in more advanced stage, the pollen tube with nucleus of tube cell not shown. The central cell has divided into two cells; the one at the left is the generative or body cell preparing to divide into the two sperms. The prothallia cell at the left is growing out into the other cell (stalk cell) derived from the division of the central cell.

Fig. 372.
Sperms of zamia in pollen tube; *pg*, pollen grain; *aa*, sperms. (After Webber.)

Fig. 373.
Sperm of zamia, showing spiral row of cilia. (After Webber.)

Fig. 374.
Gingko biloba, end of stem with spray of leaves and two fruits.

536. Comparative review of the Gymnosperms.*—The lowest Gymnosperms are represented by the cycads. They bear certain resemblances to the ferns, which indicate that they have had their origin from some fern-like ancestors which are not now known. These resemblances are as follows:

First, the form of the leaves.

---

* For reference.

Second, the arrangement, structure and dehiscence of the microsporangia which are very much like the sporangia of some of the lower families of the true ferns.

Third, the motile sperms.

Fourth, the form and development of the female prothallium with its archegonia which recalls that of Selaginella. In this respect the conifers also resemble the higher Pteridophytes.

The progress in evolution made by the Gymnosperms over the Pteridophytes may be briefly stated as follows:

First. The establishment of heterospory and the permanent division of labor between the two kinds of sporophylls, which was introduced by some of the higher Pteridophytes. This division of labor is even extended further in some species, as in the cycads where the microsporophylls bearing pollen grains (microspores) are on different plants (male) from the macrosporophylls bearing the ovules, which are on female plants.

Second. The complete division of labor between sporophylls for the production of spores, and vegetative leaves for the chlorophyll function.

Third. The aggregation of the sporophylls into groups, which was also initiated by the higher Pteridophytes.

Fourth. The more specialized development of tissue systems, the growth of the parts of the sporophyte by a group of meristem cells instead of growth by a single apical cell.

Fifth. The increasing prominence and importance of the sporophyte and decreasing prominence of the gametophyte.

Sixth. The lessening in the size of the gametophyte, especially in the reduction of the archegonia, the neck being smaller, and the reduction of the male prothallium so that there are very few or no prothallial cells, while the wall of the antheridium has almost completely disappeared, the tube cell alone remaining, and the number of sperm cells is greatly reduced. (In *Mycrocycas*, however, there are sixteen sperm cells, about half the number common in a great many Pteridophytes.)

Seventh. The complete dependence of the gametophytes on the sporophytes, which also was introduced by the higher Pteridophytes but in the Gymnosperms has been carried farther, the female prothallium never escaping from the ovule or macrosporangium. The female prothallium, or endosperm, is parasitic in the nucellus of the ovule (macrosporangium), for when it is mature the nucellus is nearly or quite consumed; only a papery remnant surrounds the endosperm.

Eighth. The introduction of pollination, necessitated by the fact that the female prothallium does not escape from the ovule and is separated from the outside by the nucellus tissue, i.e., a part of the ovule or macrosporangium. The pollen or microspores must be transported to the ovule.

Ninth. The germination of the tube cell, or wall cell of the antheridium to form the pollen tube, which penetrates the nucellus tissue in the case of the cycads and Gingko to provide nutriment for the development of the motile sperms, which then swim from the pollen chamber into the archegonia, while in the conifers the pollen tube penetrates the nucellus, and obtains nutriment for the same purpose, but makes its way directly into the archegonium into which it then empties the sperm cells. The pollen tube is thus parasitic in the nucellus, for its behavior is like that of a parasitic fungus mycelium, obtaining food from the tissues through which it grows.

Tenth. This new feature of pollination and growth of the pollen tube is necessitated because of the more highly acquired land habit of the Gymnosperms and the complete dependence of the gametophyte on the sporophyte, while in the Pteridophytes, the gametophytes, either from the first, or as in *Selaginella*, some time before fertilization, becoming free from the sporophyte are dependent on water as a means of the motile sperms being conducted to the archegonia.

Eleventh. The development of the seed, which is a new structure for the propagation and spread of the plants. It will be recalled that *Selaginella* almost reached the point of forming seeds.

537. Formula for life history of Gymnosperms.*—This could be written as follows, beginning with the sporophyte or second generation.

$$\text{Sporophyte}\left\langle\begin{array}{lll}\text{Microspore} & \text{— Male Gametophyte} & \text{— sperm}\\ \textit{(pollen grain)} & \textit{(pollen grain tube and contents)} & \\ \text{Macrospore} & \text{— Female Gametophyte} & \text{— egg}\\ \textit{(beginning of endosperm)} & \textit{(endosperm with archegonia)} & \end{array}\right\rangle$$

$$\text{— Fertilized egg — Sporophyte, etc.} =$$

$$\text{S} — \left\langle\begin{array}{l}\text{mi sp — MG — s}\\ \text{ma sp — FG — e}\end{array}\right\rangle \text{— FE — S, etc.}$$

If the formula starts with the beginning of one of the alternating stages and represents the beginning and end of each generation it would stand thus, MC = mother cell of spores.

$$\overbrace{\text{FE — S — MC}}^{\textit{2nd Generation}}\left\langle\begin{array}{l}\overbrace{\text{mi sp — MG — s}}^{\textit{1st Generation}}\\ \text{ma sp — FG — e}\end{array}\right\rangle \text{FE, etc.}$$

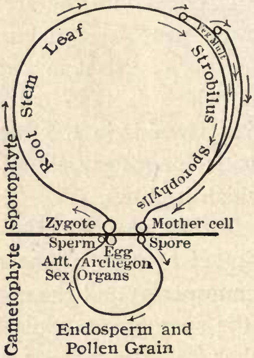


Diagram No. VI. Illustrating life cycle of a gymnosperm. Course of development follows the direction indicated by the arrows. Zygote equals fertilized egg. Vegetative multiplication by off shoots. Note the increase of the sporophyte and decrease of the gametophyte.

* For reference.

CHAPTER XXXV.

ANGIOSPERMS.*

538. General characters.—The Angiosperms include the members of the second class of seed plants (*Spermatophytes*). They are distinguished from the members of the first class, the Gymnosperms, chiefly for two reasons. First, the seeds are enclosed in a vessel or case. This vessel or case is formed from the *ovary* (an ovule case), sometimes with the cohesion also of other parts of the flower (Chapter XX). Second, the presence of the true flower,† usually with a perianth (see Chapters XVI, XVII). The plants (which are *sporophytes*) are adapted to live under a great variety of conditions both in water and on land. There is also a great variation in size, from large tall trees to the shrubs and herbs, some of which are quite minute. The leaf is typically a thin, expanded structure, but varies in plants living

To the Teacher. The first part of this chapter is presented here as a brief text review of some of the work in Part I. The most of the chapter is too technical for any but advanced students, and is included here to round out the text and sum up the brief discussions in former chapters of development, alternation of generations, life histories, etc.

---

* Since members of the Angiosperms were chiefly used for the study of seeds, the different parts and functions of the plant, this chapter will be treated more in the nature of a brief review and in pointing out the position of the different parts in the life cycle when compared with the other groups of plants.

† The aggregation of sporophylls along an axis in the higher Pteridophytes and in the Gymnosperms is sometimes spoken of as a primitive flower. But the "flower" axis is elongated, the members are in spirals, and there is an absence of a perianth of brightly colored members. In a few of the lower Angiosperms some of the members of the flowers are in spirals. In the magnolias and tulip tree (*Liriodendron*) the axis of the flower is considerably elongated, and it is believed to represent a primitive condition. But there is a highly developed perianth.

under peculiar conditions to stouter structures, which may be quite large, or others reduced to scale-like bodies. The tissues are very highly developed, and the presence of true vessels also marks the Angiosperms off from most of the Gymnosperms.

THE FLOWER.

539. The flower represents the highest stages in evolution of plants.—The flower is the most characteristic feature of the Angiosperms. It was foreshadowed in the higher fern plants where spore-bearing leaves (the sporophylls) are massed together at the end of a shoot, forming a strobilus. The Gymnosperms show an advance upon the strobilus of the fern plants, because of the development of the ovule, which encloses permanently the macrospore and secretes a viscous substance which holds the pollen grain (microspore) in position where it can germinate, so that the sperms may be carried to the egg. In addition to the ovule, and the contrivances for enabling the sperms to reach the egg, the flower of the Angiosperms presents several important features which indicate an advance in plant evolution. These may be enumerated as follows:

First. **The appearance of a perianth.**—The development of floral envelopes (sepals and petals) which serve to protect the essential organs (stamens and pistils) in the bud.

Second. **The showy perianth.**—The showy character of the floral envelopes, because of size and color, which serves to attract insects to aid in pollination. In some cases where the flowers lack a showy perianth there are colored bracts or leaves just below the flower, or cluster of flowers, which serve the same purpose, as in the flowering dogwood, the dwarf cornel or bunchberry, the painted cup, etc. A striking example is the *Poinsettia* grown in greenhouses or conservatories. This coloration of bracts and leaves at the base of the flower suggests how the perianth may have been developed from leaves.

Third. **Dimorphism, and special adaptation.**—Monœcism, diœcism, dichogamy, and the many peculiarities in structure of the members of the flower which enforce cross pollination and fertilization.

Fourth. **The structure of the flower.**—The form of the flower, the number and relation of its members and relation of the flowers in mass, which show an advance from simple and generalized flower types to specialized types and specialized arrangements, form the basis for the grouping of the Angiosperms into classes, subclasses, orders and families. *The more primitive flower types* probably possessed a large and indefinite number of floral elements, which were arranged in a spiral manner on the floral axis following the arrangement of the leaves, since the floral elements are regarded as modified leaves. Among the lowest of the dicotyledons the buttercup family (Ranunculaceæ) illustrates a simple type of flower structure and arrangement. In some species there are numerous stamens and simple pistils in spirals. The white water lilies show a similar arrangement of the numerous members of the perianth and stamens. Among the higher angiosperms there is a tendency to a definite and small number of plant elements. In the monocotyledons this is shown in the *trimerous* flowers (parts in three's) of so many families, and in the dicotyledons by the *tetramerous* (parts in four's) and *pentamerous* (parts in five's) flowers, and by the floral elements being so crowded on the short axis that they no longer are in spirals but in whorls or cycles (cyclic arrangement). This specialized condition, shown in the reduction from numerous parts, to a few definite in number, is regarded as showing a higher state of evolution. It is often accompanied by the loss of certain parts in some flowers, which leads to two different kinds of flowers, on the same plant or on different plants, shown in the ray-flowered composites; also in the difference in length of the same essential organs in different flowers (dichogamy) or in a difference in time of maturity (proterandry, proterogeny). In the more primitive flowers the parts are all separate, and the flowers are *actinomorphic* or radiate in the arrangement of the parts (radial symmetry). As the flower has become more specialized, a change in form to bilateral symmetry has taken place in many groups, as in the labiates (in mints, many legumes, many orchids; etc.), which provides better facilities for insuring cross pollination by insects. *The fusion of parts of the flower* of different sets follows as in *epigynous*, *perigynous* or *epipetalous* flowers. Then parts of the same kind are united by coalescence as in *sympetalous* (petals united) and *synsepalous* (sepals united) flowers, while *syncarpous* fruits (carpels united forming a compound pistil) represent the highest condition of the development of the carpels. *The massing of flowers* is also another evidence of progression. The highest expression of this arrangement is seen in the composite flowers where numerous small flowers unite to form " heads." In many of these, the outer circle of flowers is conspicuous by the lateral elongation of the corolla tube, which is bright colored and serves to attract insects to the head where there are many proterandrous flowers insuring cross pollination. It is to be noted also that the composites have reached the highest stage of the union of parts, and they are recognized as the highest expression of the development of the flower.

Fifth. **The closed seed case.**—The formation of a closed capsule or case (ovary) containing the ovule, which is an advance over the open seed carpel in the Gymnosperms.

540. The parts of the flower are modified leaves.—The sepals and petals are leaf-like in form. They are leaves which have become modified in their development to serve certain definite useful purposes for the plant, as protecting envelopes while the essential parts of the flower are forming, and the petals often serve to attract insects which aid in cross pollination. In some flowers the sepals are green in color, or the same form as the leaves and arranged in the same way on the stem, as in the wake robin (*Trillium*). In this same plant the petals sometimes take on a green color, and thus more clearly show that as members of the plant body they are leaves (floral leaves). This transformation of the sepals and petals to leaves also occurs now and then in many other plants. The stamens and pistils (carpels rather) are also modified leaves. Their leaf nature is sometimes manifest, under peculiar conditions, when the stamens and pistils expand into green leaves showing also some intermediate stages with partly developed anther sacs or ovules on them.

541. The stamen is a microsporophyll.—The function of the stamen is the production of pollen. Each pollen grain is a spore, and four are formed from a mother cell in the anther sac just as the spores of the ferns, mosses and liverworts are formed. When the pollen grain germinates it produces the pollen tube and two sperm cells. It is therefore the male gametophyte. The pollen spore is the *microspore*, the anther sac is the *microsporangium*, and the stamen is the *microsporophyll*.

542. The pistil, or carpel, is a macrosporophyll (=megasporophyll).—The simple pistil is a carpel, while a compound pistil is formed of several carpels united. The pistil is composed of the *ovary*, the *style* (which may be wanting) and the *stigma*. The function of the ovary is the production of ovules with the contained embryo sac and egg. The egg it will be remembered in the Gymnosperms is developed by the gametophyte. The embryo sac with the egg is the female gametophyte of the Angiosperms. It represents the macrospore, just as the female prothallium in Selaginella enclosed by the spore wall is the macrospore (or megaspore).

The ovule then which produces the macrospore is the macrosporangium, and the carpel is the macrosporophyll.

543. The sexual organs of Angiosperms.—The stamens and pistils are often spoken of as the sexual organs of the flower. This is not strictly correct, for the sexual organs are borne on the gametophyte and are a part of it, while the stamen and pistil are parts of the sporophyte. While it is not strictly correct then to say that the stamen is a sexual organ, or male organ, it is a *male member* of the flower for it is a flower member. We should then distinguish between its functions as organ and member. It is an organ when we consider pollen production, but it is not a sexual organ, for the pollen sac is not a sperm case (antheridium), it is a spore case. The spore case is a part of the sporophyll (stamen). But when we consider fertilization, the sperms are formed in the sperm case (antheridium) which is here much reduced, consisting of the tube cell and generative cell (central cell), i.e., the mature pollen grain. The stamen is a member of the flower when we are considering the principal parts of the flower structure or form. It possesses certain characters of form, size, structure, etc., which are correlated with its functions of spore production, and since the spore on germination produces the male sexual organs, these characters possessed by the stamen are qualities of maleness. From this point of view the stamen is a male member of the flower. In a similar way the pistil is not the female sexual organ. It is the female member of the flower and is the organ for the production of the macrospore (or female prothallium) which in turn gives rise to the sexual organ, here reduced to the egg, the wall of its case wanting.

The following table will serve to indicate these relations.

Stamen = spore-bearing leaf = male member of flower.
Anther locule = sporangium.
Pollen grain = small spore = reduced male prothallium and sexual organ, sterile part of prothallium not formed.
Pistil, or carpel = spore-bearing leaf = female member of flower.
Ovule = sporangium.
Embryo sac = large spore = female prothallium containing the egg.
The egg = a reduced archegonium = the female sexual organ.

544. Life history of the Angiosperms.—Since a thorough study has been made of the sporophyte of the Angiosperms in Part I, this account will treat briefly of the gametophytes and the early stage of the embryo, in order to form a basis for comparison with the lower plants.

545. The male gametophyte.—The male gametophyte begins with the pollen grain, or microspore, four of which are formed from a mother cell in the anther sac. When the pollen grain is ripe it usually consists of two cells, one the tube cell with a prominent nucleus, the other a smaller cell with no cell wall, which floats in the tube cell but at first is separated by a thin arched cell wall (fig. 375). This is the *generative* cell or *body* cell, and was formed on germination of the young microspore by the division of the single nucleus of the microspore before the pollen grain was ripe. After the pollen grain has reached the stigma of the pistil (see Pollination, Chapter XVIII) it germinates, producing a tube which travels down the style (or in the stylar canal in some plants), enters the ovary, and passing through the micropyle * bores its way through the nucellus until it reaches the embryo sac. The tube nucleus has followed along with the advance of the tube. Soon after the pollen grain germinates the generative cell divides into two cells, the *sperm cells*, and these move into the tube, if the generative cell was not already there before division. The stigma of the pistil is covered by a moist somewhat viscous secretion which holds the pollen grains. The moisture and certain saccharine or other secretions favor or stimulate the germination of the pollen grain.


Fig. 375.
Nearly mature pollen grain of trillium. The smaller cell is the generative cell.

546. The female gametophyte.—The female gametophyte is developed from a special cell in the nucellus of the ovule. The ovule is an outgrowth usually from some part of the ovary and enclosed by it (the main part of the carpel or macrosporophyll which in development folds in such a way as to form a case). It is the macrosporangium (or megasporangium). It consists of the nucellus surrounded by two coats which do not quite cover up the nucellus at one end, thus leaving a minute opening (the *micropyle*). In the lily a subepidermal cell in the nucellus, near the micropyle, becomes larger than its neighbors, with a large nu-


Fig. 376.
Germinating spores (pollen grains) of peltandra; generative nucleus in one undivided, in other divided to form the two sperm nuclei; vegetative nucleus in each near the pollen grain.

---

* In a few plants, as in some of the ament-bearing plants, the pollen tube enters the ovule at the chalaza end.

cleus and abundant protoplasm. This cell continues to enlarge until it forms a large usually elongated sac, the *embryo sac*. During its enlargement the nucleus divides by three successive divisions into eight nuclei which have a definite arrangement in the embryo sac. At first there are four nuclei at the outer end (next the micropyle, called the micropylar end of embryo sac), and four at the base (called the antipodal end). But soon one nucleus from each pole (called polar nuclei) of the embryo sac moves to the center, where they fuse to form the *primary endosperm* nucleus of the endosperm. This leaves three nuclei in each end of the embryo sac. The three at the base are called antipodals. They usually soon degenerate. The three at the micropylar end are called together the *egg apparatus*. The two nearest the micropylar end are called the *synergids*, which means *helpers* or *coworkers*, because it was once thought they assisted the pollen

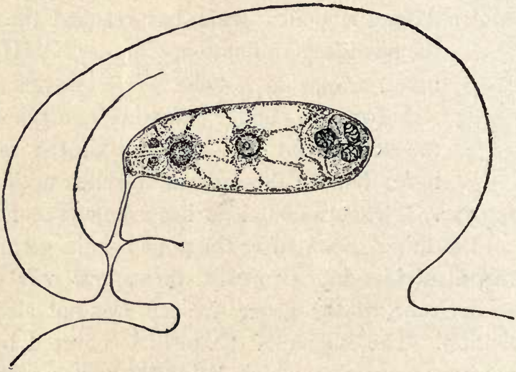


Fig. 377.

Podophyllum peltatum, ovule containing mature embryo sac; two synergids, and eggs at left, endosperm nucleus in center, three antipodal cells at right.

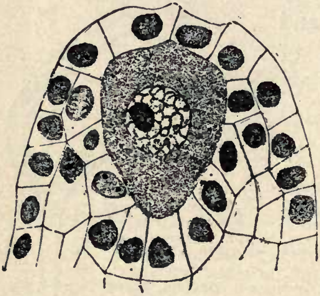


Fig. 378.

Macrospore (one-celled stage) of Lilium.

tube in bringing the sperm cell to the egg. The third nucleus of the egg apparatus is that of the egg cell.

547. Fertilization.—When the pollen tube has reached the embryo sac it opens at the end, and the sperm cells with some of the protoplasm are emptied. One of the sperm nuclei unites with the egg nucleus bringing about fertilization. The second sperm, in a number of plants, has been found to join the two polar nuclei in the center of the embryo sac, the three nuclei fusing to form the *primary endosperm* nucleus. This is called *double fertilization.*

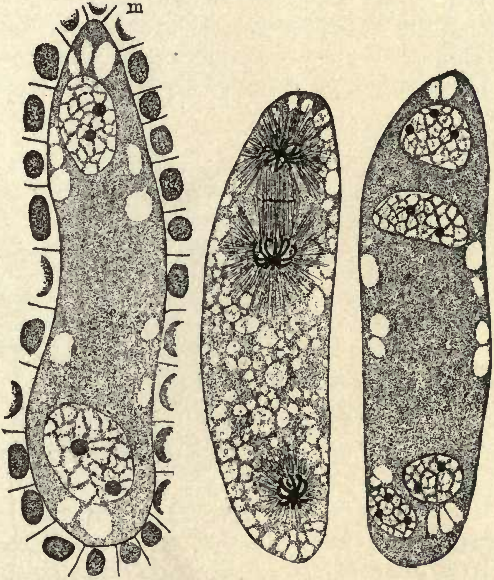


Fig. 379.

Two- and four-celled stage of embryo sac of Lilium. The middle one shows division of nuclei to form the four-celled stage. (Easter lily.)

548. The endosperm of the Angiosperms.—The primary endosperm nucleus, formed by the fusion of the two polar nuclei (and sometimes by triple fusion with the second sperm nucleus), develops the endosperm. The nucleus divides successively into a large number of free nuclei arranged in the protoplasm, which form a peripheral layer in the embryo sac and are later separated by cell walls, thus forming the cellular endosperm. This serves as food for the embryo just as in the case of the Gymnosperms, but its origin is different. In the formation of the endosperm the tissue of the nucellus (inner portion of the macrosporangium) is usually all consumed, leaving only a thin, dead outer portion surrounded by the ovule coats, or *integuments*. In a few plants, however (water lily family, pepper family, etc.), much of the nucellus remains in the seed as a nutritive tissue

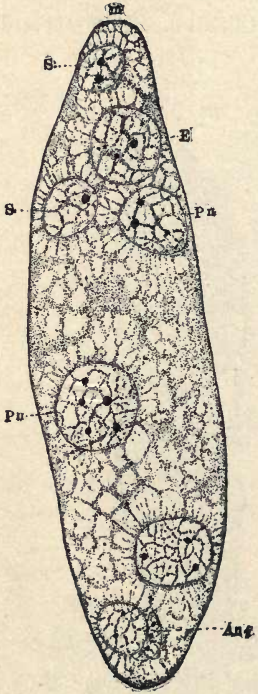


Fig. 380.

Mature embryo sac (young prothallium) of Lilium. *m*, micropylar end; *S*, synergids; *E*, egg; *Pn*, polar nuclei; *Ant*, antipodals. (Easter lily.)

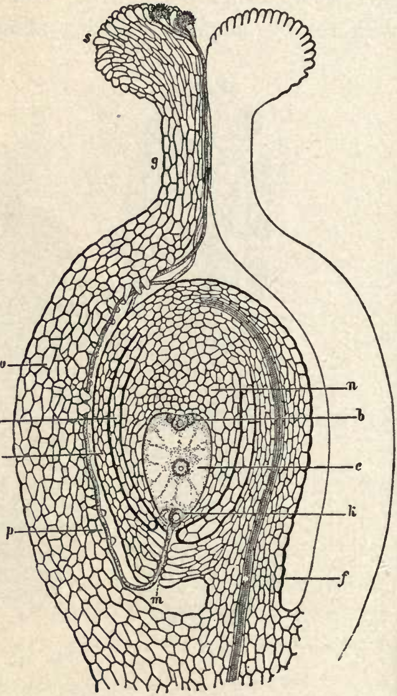


Fig. 381.

Diagrammatic section of ovary and ovule at time of fertilization in angiosperm. *f*, funicle of ovule; *n*, nucellus; *m*, micropyle; *b*, antipodal cells of embryo sac; *e*, endosperm nucleus; *k*, egg cell and synergids; *ai*, outer integument of ovule; *ii*, inner integument. The track of the pollen tube is shown down through the style, walls of the ovary to the micropylar end of the embryo sac.

for the seedling at time of germination. This is called the *perisperm.* The endosperm of the Angiosperms is not developed unless fertilization takes place, even in those cases where double fertilization may not occur.

549. In case of crosses between different varieties of plants, the effect of the cross usually is not apparent in the seed because the qualities of the two parents are united in the embryo and would not be shown until the embryo develops into a plant, or in a following generation. Sometimes, however, the effect of the cross is seen in the seed formed following fertilization, as for example in corn, where there is a change in color of the seed when different colored varieties are crossed. This phenomenon is called *xenia* and is perhaps the result of double fertilization, the fusion of the second sperm nucleus with the two polar nuclei to form the primary endosperm nucleus which forms a hybrid endosperm.

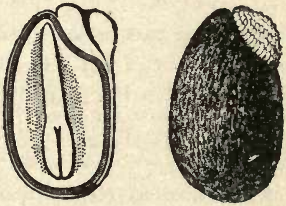


Fig. 382.

Seed of violet, external view, and section. The section shows the embryo lying in the endosperm.

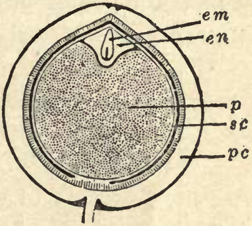


Fig. 383.

Section of fruit of pepper (Piper nigrum), showing small embryo lying in a small quantity of whitish endosperm at one end, the perisperm occupying the larger part of the interior, surrounded by pericarp.

550. The embryo and seed.—The fertilized egg cell which is near the micropylar end of the embryo sac, now by a series of divisions, and by growth, forms the embryo. At first it forms a simple cell mass with a suspensor at one end, which pushes the growing point down into the mass of endosperm. Soon the parts of the embryo (root, stem and leaf bud) are organized and the seed ripens. In some plants only a small part of the endosperm is used by the embryo before the seed ripens, as in the corn, cereals, etc. (albuminous seeds); in others the endosperm is all consumed by the forming embryo, and is stored in the cotyledons, as in the bean, pea, oak (exalbuminous seeds), and the remnant of the endosperm forms a thin papery membrane around the embryo. All of these changes take place within the ovule while it is still attached to the ovary and nourished by the sporophyte. The seed at maturity then consists of the embryo, surrounded by the endosperm or its remnants, and the seed coats which are formed from the coats, or integuments, of the ovule. In some seeds there is in addition the *perisperm* (see paragraph 548).

551. Synopsis of the seed.—The following table will show those parts composing the seed.

The seed.
- Ripened ovule.
  - Aril, rarely present.*
  - Ovular coats (one or two usually present), the testa.
  - Funicle (stalk of ovule), raphe (portion of funicle when bent on to the side of ovule), micropyle, hilum (scar where seed was attached to ovary).
  - Remnant of the nucellus (central part of ovule); sometimes nucellus remains as Perisperm in some albuminous seeds.
- Endosperm, present in albuminous seeds.
- Embryo within surrounded by endosperm when this is present, or by the remnant of nucellus, and by the ovular coats which make the testa In many seeds (example, bean) the endosperm is transferred to the cotyledons which become fleshy (exalbuminous seeds).

COMPARATIVE REVIEW OF THE ANGIOSPERMS.

552. Origin of the Angiosperms.—Botanists are not agreed as to the origin of the Angiosperms, nor as to whether the monocotyledons or dicotyledons were the lowest group. Some have suggested that the Angiosperms were derived from a Gymnosperm-like ancestor similar to *Ginkgo*, while others believe they were perhaps derived from early plants similar to some of the

---

* The aril is present in ginkgo and the yew, as a collar at the base of the ovule which in the yew grows to form the red fleshy covering of the berry. In the milkweed and willow there is a hairy aril.

higher fern plants (related to *Selaginella*, etc.). The two classes of seed plants, the Gymnosperms and Angiosperms, probably represent divergent lines of development from the same or related stock belonging to the Pteridophytes of geologic times, that is of a very early past, for there are fossil remains of both at a very early period. Some of the characters possessed by the Angiosperms which mark an advance over those of the fern plants are possessed by the Gymnosperms also. Taking the Angiosperms alone (see paragraph 536 for advances in the Gymnosperms) the principal advances may be enumerated as follows:

First. The more highly developed tissue systems in the parts of the plant body, root, stem and leaf, with a more efficient conducting system with true vessels.

Second. The development of the parts from a growing point, or meristem, consisting of a group of cells, instead of from a single apical cell.

Third. The collateral arrangement of the tissues in the vascular bundles; in the dicotyledons the cyclic arrangement of open bundles which permits of indefinite growth of the stem resulting in massive trunks (also a character of many of the Gymnosperms). In the monocotyledons the bundles are scattered in the fundamental tissue of the stem, which soon pass over into permanent tissue and the development of massive tree trunks is limited.

Fourth. The great variety of vegetative forms, trees, shrubs and herbs, with their adaptation to an aquatic as well as a land habit, and, especially in the latter, the adaptation to a great variety of climate and soil fits them for growing in climates from the tropic to the subtropic regions, in swamps, deserts, plains and steppes, as well as in regions more temperate as regards climate and moisture content of the soil. Many are adapted also to grow as shade plants or climbers. With this great variety of habit and character the Angiosperms are especially fitted to compete successfully with climate, soil, and with other groups of plants.

Fifth. The absolute prevalence of heterospory which insures cross fertilization as far as the gametophytes are concerned, but is not necessarily cross fertilization so far as the plants (sporophytes) are concerned.

Sixth. In the retention of the macrospore in the ovule (macrosporangium), and the development of an embryo plant, while still attached to and nourished by the old sporophyte, the *seed* is produced with its protecting coats and stored food, which more certainly provides for the distribution and perpetuation of the species under a great variety of adverse conditions.

Seventh. The increasing importance and greater complexity of the sporophyte in the liverworts, mosses, fern plants and Gymnosperms have been accompanied by a gradual diminution and degeneration of the gametophyte, and in the Angiosperms this degeneration of the gametophyte phase has gone still farther, which is another evidence of the higher evolution of the Angiosperms. The male gametophyte * consists of two cells, a tube cell with a cell wall enclosing a central cell or generative cell (pollen grain or microspore) which lacks a cell wall and floats in the protoplasm of the cell, and forms two sperm cells on division, the tube cell growing as a parasite through the stigma and stye to the ovule. In some of the Gymnosperms the male gametophyte is just as simple (the yew, *Taxus*, for example). The female gametophyte shows a greater degeneration even than in the Gymnosperms, being in the Angiosperms reduced to a few nuclei in cytoplasm not separated by cell walls (the embryo sac), and the archegonium is reduced to the egg cell. Sometimes the female gametophyte is developed from what may be considered a true spore, and in other plants from the mother cell direct, thus still farther cutting short the development of the gametophyte generation.

Eighth. The development of the flower, which marks the

---

* The male gametophyte probably represents solely a reduced antheridium, or sexual organ. The tube cell may be the wall of the antheridium here reduced to a single cell, for in *Selaginella* and *Isoëtes* the antheridium is formed from the larger part of the microspore, though wall cells completely surround the central cell which forms the sperms. However, in some of the heterosporous ferns (the water fern *Salvinia*) the antheridium does not have a complete wall of cells surrounding the central cell.

climax in the evolution of the known plants and was foreshadowed in the massing of the sporophylls of the higher Pteridophytes.

The most striking advances shown in the flower are as follows:

1. The evolution of floral envelopes for protection and for attracting insects to aid in cross pollination.

2. The change from radial symmetry to bilateral symmetry in certain flowers.

3. The progression from indefinite and numerous flower parts to a definite and limited number.

4. The change from free parts of hypogynous flowers to union of parts as shown in perigynous, epigynous, epipetalous, sympetalous and synsepalous flowers, reaching the climax in the composites.

5. Dimorphism or flowers and flower parts shown in monœcism, diœcism, dichogamy, requiring cross fertilization.

6. Proterandry and proterogyny, also requiring cross fertilization.

Ninth. The development of the ovule case, or seed case, which when young is a small and open carpel with exposed ovules, but later infolds, thus enclosing the ovules which become seeds.

Tenth. The seed, consisting of the ovule with its coats which become the seed coats containing the embryo, and food substances.

553. Formula for life history of the Angiosperms.*—This would be similar to that of the Gymnosperms and may be written as follows:

$$\text{Sporophyte}\left\langle\begin{array}{l}\underset{\textit{(pollen grain)}}{\text{Microspore}}\text{ — }\underset{\textit{(pollen tube and contents)}}{\text{Male Gametophyte}}\text{ — sperm}\\ \underset{\textit{(embryo sac)}}{\text{Macrospore}}\text{ — }\underset{\textit{(embryo sac and contents)}}{\text{Female Gametophyte}}\text{ — egg}\end{array}\right\rangle\text{- -}$$

Fertilized egg — Sporophyte, etc. In abbreviated form this becomes $\text{S}\left\langle\begin{array}{l}\text{mi sp — MG — s}\\ \text{ma sp — FG — e}\end{array}\right\rangle\text{FE}$ — S., etc. Starting with the

---

* For reference only.

gametophyte or first generation, and reducing the two kinds of prothallia to one, the formula becomes $\mathrm{G} \left\langle \begin{matrix} \mathrm{s} \\ \mathrm{e} \end{matrix} \right\rangle \mathrm{FE} - \mathrm{S} - \mathrm{asp} - \mathrm{G}$., etc., which represents the alternation of generations, and compared with that of the ferns and mosses is seen to be identical.

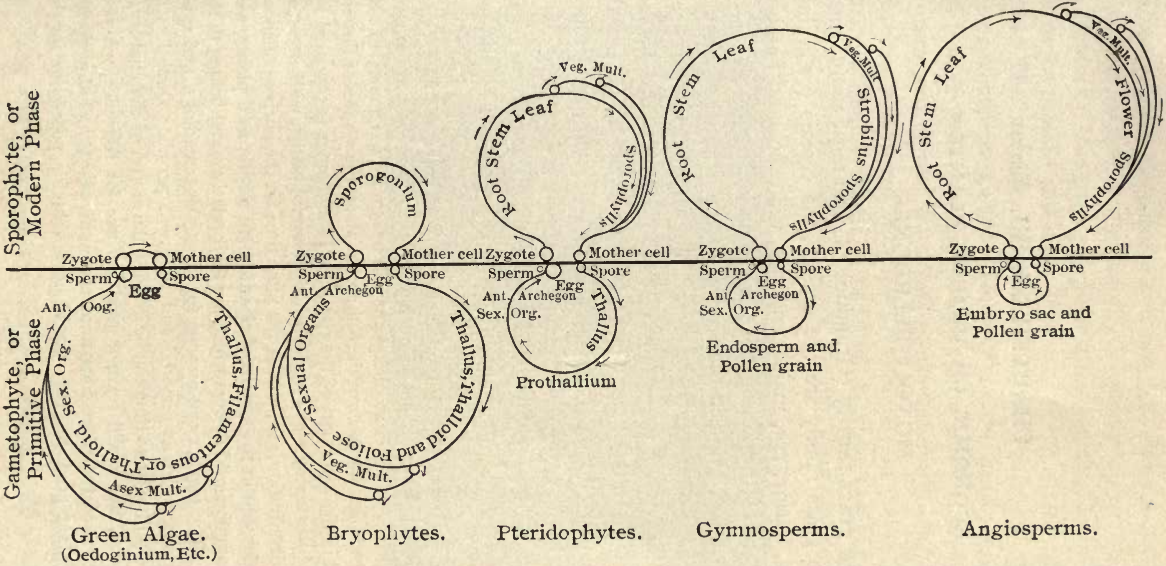


Diagram No. VII. Illustrating the life cycle of the great groups of green plants. Course of development follows the direction indicated by arrows. The base line represents the division between the gametophyte and sporophyte stages. Note the gradual increase in size and importance of the sporophyte which becomes the dominant type of vegetation in modern times. The gradual decrease in size and importance of the gametophyte shows the dominance and importance of the gametophyte as the primitive phase of plant life. Note the transference of asexual, or vegetative, multiplication from the gametophyte, the primitive phase, to the sporophyte in the modern phase.

CHAPTER XXXVI.

ECONOMIC OR USEFUL PLANTS.*

MONOCOTYLEDONES.

554. The grass family (Gramineæ). The most useful members of the grass family are the grasses, the cereals (or grains), wheat, oats, barley, rye, maize, and rice, the canes and bamboo. The members of the family have a very wide distribution over the earth, some growing in the wild state while most of the useful ones are kept under cultivation. While they display a great variety in individual appearance, the flower structure is very similar in all, and is very simple (see Chapter XVII for the flower of maize and oats). The true grasses, i.e., the members of the grass family, which are popularly called grasses, include a considerable variety of cultivated forms, which are often grown for special purposes because of their fitness for special conditions,

---

* To the Teacher. Only the larger and more important families are intended for study. The others are included simply to round out the topic as a whole. Many of the economic plants will be studied in connection with the study of seedlings, the parts of the full-grown plant, the studies of flowers, fruit and seed in the early part of the course. This chapter is prepared for the purpose of discussing some of the principal useful plants, with notes on their history, distribution, etc., and at the same time for the purpose of showing their relationship in the system of classification among seed plants, and some of our common wild flowers which are their relatives and belong to the same family. The teacher can arrange for discussions, readings, and exhibitions of various topics as material and time will permit. Doubtless in many cases very little or no time can be given to the matter of the chapter in the regular work, but it will serve a good purpose for reference. A permanent collection of the more important economic plants including fruits, nuts, woods, plant products, etc., would be a valuable possession for the schools.

as lawn grasses, for pasture and for hay. The red top is often grown for pasture, while timothy is widely grown for hay, and the Kentucky blue grass or June grass is valuable for lawns as well as for pasture and hay.

555. The cereals, or grains.—The cereals, or grains, are grasses which are cultivated chiefly for the food present in the seed fruit or grain, though the straw often makes excellent fodder for stock and is used for a variety of other purposes. The chief cereals are wheat, rye, oats, barley, rice, corn or maize.

556. Wheat.—Wheat is believed to have originated from a species (*Triticum ovatum*) native to the Mediterranean region.

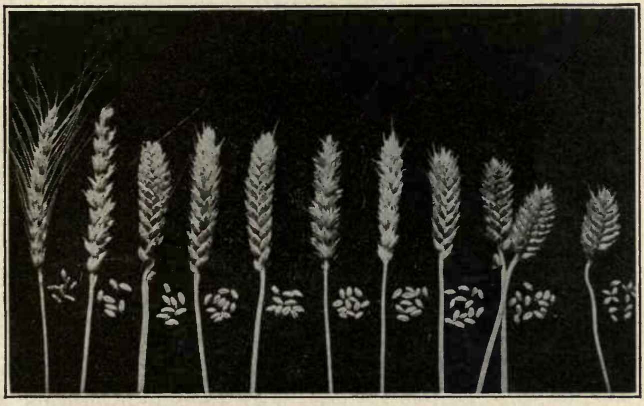


Fig. 384.

Bearded and bald wheat heads (common varieties of wheats grown at Pullman, Washington). From Bureau of Plant Industry.

It is one of the staple crops of the north temperate regions, since wheat requires cool weather for the early stages of growth to cause it to stool and become stocky and vigorous. A great many different varieties of wheat are propagated for the different grades of flour, because of their relation to different kinds of soil or climate. The grains vary as to color and hardness. The heads vary as to bearded or bald varieties, the awns on the palets being very long and barbed in the bearded wheat. All of these kinds are usually classed under two heads, as winter wheat and spring wheat. Winter wheat is sown in late summer or early autumn. The cool weather of autumn checks the rapid growth and causes it to "stool," i.e., to throw out numerous branches or "suckers," while the stalks do not become tall. It is very hardy in the young stages and withstands the cold winter, though open winters with alternate thawing and freezing often cause it to "heave," so that it dies because the roots are lifted out of the ground. The spring wheats are sown in early spring, but they do well only in the extreme northern latitudes of the temperate region. When grown in the middle temperate regions spring wheat is an uncertain crop, and it is necessary to obtain seed from wheat grown in northern latitudes to obtain the best results. For example, much of the seed spring wheat for the Northern States is grown in Canada. When spring wheat can be sown early and the spring season is cold, an opportunity is given for the plants to stool and make a vigorous and stocky growth. While wheat is grown successfully throughout the Northern States and Canada, the great wheat section is in some of the Northwestern States and in Manitoba, though as high yields per acre are obtained in New York as in the great wheat-growing sections. The annual production in the United States amounts to from $300,000,000 to $500,000,000.

The "hard" wheats, i.e., those with a hard grain, have a greater nitrogen content than the "soft" or starchy wheats, and thus are more nutritious. The hard wheats are better for making bread, rolls, etc., because the "dough" rises better than that made from the soft wheats. The soft wheats are better for cakes and for pastry. Millers, however, often mix soft wheat with the hard because the latter is more expensive. The spring wheats grown in Canada, Minnesota, Dakota, and other places in the northwest, where there is a low rainfall and consequently drier climate, are chiefly hard wheats, and yield the best flour. In some sections winter wheat is not grown, or is grown to a much less extent because of the severe winters with little snow and high wind. Some winter wheats are, however, hard wheats;

examples, those grown in Kansas and the southwest. These however are not quite equal to the spring wheat of the northwest; because of the somewhat more extended period of growth, there is a larger proportion of starch.

557. Rye.—(*Secale cereale*, believed to be native in the region between the Black and Caspian Seas).—This cereal resembles wheat, but the heads are longer and more slender, the grains being more slender, and the straw is stiff and long. It is very extensively cultivated in northern Europe, and is there more commonly used for bread than in this country where the crop is small. Russia is the greatest rye-growing country in the world. Winter varieties are most generally used, and are sown in the autumn. Rye does well on much poorer soil than wheat, and the crop is sometimes used for green soiling by plowing it under to enrich the soil. Besides its use for food rye is used in making some of the grades of whisky.

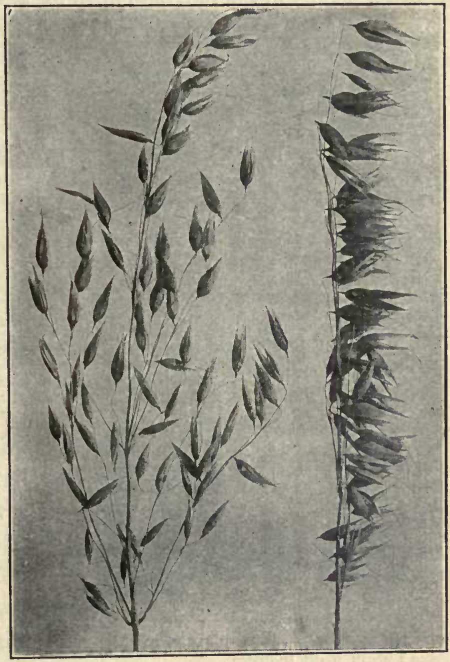


Fig. 385.
Oat heads, showing the common branching one and a side head variety (flag oats). From Bureau Plant Industry.

558. Oats.—The flowers of oats (*Avena sativa*) are in loose panicles and the grains are permanently covered by the palets, not shelling out as in wheat. In northern climates they are sown early in the spring to secure the stocky growth. In southern latitudes they are often sown in the autumn, since tne winters are rarely severe enough to kill the young plants. Oats are grown chiefly for stock feeding, but oatmeal for household use is obtained by special processes for removing the closely adhering palets.

559. Barley.—Barley resembles wheat in the form of the fruiting heads, but is like oats in the grain being permanently and closely covered by the palets. It is grown from arctic to tropical regions, being acclimated over a greater region than other cereals. Barley is chiefly used for making malt in breweries, though both the grain and straw are used as food for stock. It is also used for making certain of the fine grades of whisky, as Scotch whisky. Spring or summer barley is a four-rowed species (*Hordeum vulgare*), while winter barley (*H. hexastichon*) is six-rowed and earlier introduced into cultivation.

Fig. 386.
Barley heads (grown at Pullman, Wash.). From Bureau Plant Industry.

560. Rice. — This cereal (*Oryza sativa*) is grown chiefly in China, Japan, India, and the East Indies, which is said to have been its home. It is extensively cultivated in this country in South Carolina, which produces the best rice in the world, and in Louisiana. The industry is being developed in other South Atlantic Gulf States. It requires a rich moist soil, which can be flooded at certain seasons, though varieties are being developed which grow under drier conditions. Rice is a nutritious food, and the water in which it is cooked is said to contain a great part of the nutriment. Rice is the principal cereal food for a large part of the human race. It contains about seventy-five per cent starch, but a low per cent of proteid matter, which is more fattening. Rice is therefore a good food in hot climates. Most of the rice in this country is polished by machinery with leather rollers before it is put on the market. This pernicious practice removes the outer layer, which is colored (a golden yellow in the Carolina rice, and sometimes called the "bloom"), and also removes the most nutritious part containing the proteids, as well as the flavor.*

561. Indian corn, or maize.—This is a very important crop in the United States. Maize (*Zea Mays*) was cultivated by the Indian tribes in America from early times and is supposed to be of American origin. It is now cultivated in Europe and other countries (for botanical characters see Chapter XVII). Many varieties are now known which are grouped in certain well-marked types, as dent corn with a prominent indentation at the free end of the grain, flint corn with smooth and very hard kernels, pop corn noted for the sudden expansion of its grains into a large, light, palatable mass under the influence of heat, and sweet corn with its wrinkled grains containing sugar instead of starch as in the other varieties. The United States produces four-fifths of the Indian corn grown in the world. While it is grown over quite a wide latitudinal range, it does not do well in the colder temperate regions because of the short cool summers. It does best in rich bottom or muck soil along river bottoms in warmer climates, attaining a height of fifteen to twenty feet along the Mississippi River and in the Southern States, or up to thirty feet in the West Indies, while dwarf varieties with the flint grain succeed better in the extreme northern latitudes of its range. Besides the use of the grain as food for stock and man, it is the source of much of the whisky in the United States and most of the starch. Sixty per cent of the commercial starch is obtained from the grains of corn. The grains of maize contain also about five per cent of oil, and some attention is given to its extraction for food and for commercial purposes. The blades make excellent fodder, and the husks, pith and cobs are used in the

* See the *National Geographic Magazine* for April, 1906.

manufacture of various articles (see paragraph 442 for smut of corn).

562. Sugar cane, sorghum, broom corn, etc.—The sugar of commerce is largely obtained from sugar cane (*Saccharum officinarum*), though the sugar beet is also the source of a great quantity. The sugar cane is a tropical and subtropical member of the grass family. Louisiana is the greatest sugar-producing state in the Union. The plant is ten to twenty feet high and has a widely spreading panicle of flowers at the top. It does not produce seed in the United States but is grown on large plantations from cuttings. The canes, after being stripped of the leaves, are crushed to obtain the sap, which is boiled down to obtain the sugar and various syrups and molasses. Some of the great sugar-growing regions are Cuba, Java, the Hawaiian

Fig. 387.

Cutting sugar-cane in Louisiana. From Louisiana Agricultural Experiment Station.

Islands, and Louisiana. Sorghum is a somewhat similar cane grown in more northern latitudes, where it seeds. It is used for making certain grades of molasses. Broom corn (*Sorghum vulgare*), an allied plant, is grown for the stiff, spreading divisions of the panicle which are used for making brooms, brushes, etc.

563. Bamboo.—The bamboo canes grow in tropical and subtropical countries, where they attain the height of small trees and a diameter of several inches to a foot. The stems are hard, light and strong. They are used for building purposes and for making various useful articles. There are several species used, but the most common and widely distributed one is *Bambusa vulgaris*. A related plant (*Arundinaria macrosperma*), the giant cane, forms the well-known "cane brakes" along river bottoms in the Southern States, and is used for making fishing rods, while split bamboo is also used for the same purpose.

564. The palm family (Palmaceæ).—The members of this family are tropical and subtropical plants, and, because of their beauty and grace of form, many are grown in northern latitudes indoors for ornamental purposes. A common example in the Southern States is the palmetto, a fan palm, which is the emblem of South Carolina. The Washington palm of Arizona and southern California is tree-like, having a tall trunk, with spreading leaves at the top forming a dense mass. It grows in desert regions. The finest palms grow in the tropics and are the most striking and characteristic feature of the landscape, with a great variety of form and size. Some of the most useful palms are as follows. The *cocoanut palm* (*Cocos nucifera*) always occurs near the sea, and is widely distributed in all tropical countries. It is planted to some extent in the interior. In the cocoanut the outer layer of the fruit, or exocarp, is fibrous, and is usually removed in the preparation of the fruits for commerce. The fibrous material is used for coarse articles, as mats, brushes, cordage, etc. The inner layer of the wall (endocarp) is stony, and at one end are seen the three scars indicating the compound nature of the fruit, since it is composed of three carpels. The *date palm* (*Phœnix dactylifera*) is a native of Arabia, is cultivated in northern Africa, and is being introduced in the desert and alkaline regions of California and Arizona, where it promises to succeed.* This work is being done by the Department of Seed and Plant Introduction of the United States Department of Agriculture, which is already producing very important results for agriculture and horticulture in this country, especially in the arid and semi-arid regions. Because it is adapted to grow in hot dry regions, it becomes a valuable crop for these regions. It has a short stout trunk covered with the old leaf bases, while at the top are long feathery leaves. Single trees sometimes produce three hundred to five hundred pounds of dates in a season. The flowers are in dense branched panicles, and the weight of the numerous dates later bends the flower stalk downward, forming a graceful cluster. In some countries, especially along the Nile in Egypt, the trees are all numbered by the Government, and

Fig. 388.

Fruiting date palms at Old Biskra, Algeria, with fig trees growing underneath. From Bureau Plant Industry.

---

* See "Our Plant Immigrants," in *National Geographic Magazine* for April, 1906.

taxed. The *sago palm* * (*Metroxylon lævis* and *M. rumphii*) produces starch which is sold in the form of sago. It is cultivated in the East Indies, where it is native. The starch is formed in the large pith of the trunk and several hundred pounds (500 to 800) are obtained from a single large tree. These species produce the best sago, but sago starch is obtained from a number of other palms. Panama hats are made from the leaves of *Corludovica palmata*, the value of exports from Ecuador alone in 1905 amounting to more than $600,000.

565. The pineapple family (Bromeliaceæ).—The *pineapple* (*Ananas sativus*) is native to tropical America. It is a low plant with hard, stiff, narrow, pointed leaves with a radiate arrangement. The fruit is borne around a short axis above the leaves. It is cultivated in Florida, which furnishes part of the supply for our markets, a large part coming also from the West Indies and the Bahama Islands. The whole flower cluster becomes a fleshy mass forming the part which is eaten. The hanging moss (*Tillandsia usneoides*) belongs to the same family.

566. The Lily Family (Liliaceæ).—This is one of the most characteristic families of the monocotyledons, since the flower parts are normal and well developed, not having undergone the modification shown in most of the other orders, There is a well-developed perianth of six parts which makes the most showy part of the flower. The members of the family are nearly all herbs growing on the ground. Many are noted for the production of bulbs or root stocks containing stored food providing for the rapid and early growth of the flower stalk in the early part of the season. The Easter lily and some related species are grown in immense quantities in tropical countries (Bermuda, Japan, etc.) and the bulbs are shipped to cooler climates to plant in greenhouses. Other cultivated forms are tulips, hyacinths, etc. The most important vegetable products for food in this family

---

* The *Cycas revoluta* is sometimes incorrectly called sago palm. But Japanese sago, a coarse starchy material, is obtained from the stems of cycads, and a sago starch is also obtained from *Zamia* in Jamaica and Florida.

are the onion and asparagus. Fibers are obtained from the New Zealand flax, a member of this family, and from the century plant. Among the native wild species may be mentioned dog-tooth violet or adder's tongue, the wild lilies, etc.

Fig. 389.

Cannabis sativa. Cutting hemp with ordinary mowing machine. A horizontal bar attached to an upright from the tongue of the machine bends the hemp forward in the same direction that the machine moves. In China and Formosa, where ramie is grown commercially, one stalk is cut at a time, leaving the younger stalks to continue their growth. Immediately after cutting the stalk the bark, including the fiber, is stripped off and the fiber is then cleaned by hand. From Fiber Investigations, U. S. Department of Agriculture.

567. The banana (*Musa paradisiaca*) should be mentioned among other useful food plants of the monocotyledons. The banana is a native of tropical countries and is cultivated for its long pod-like fruits which are seedless in the commercial variety. The flowers are somewhat related to the orchids, and are produced in a long terminal spike, the large fruits hanging in dense heavy clusters. The plant is like a small tree in size, with broad and long strap-shaped leaves. One of these "plants," or aerial shoots, bears but once. It dies down and a new shoot is rapidly developed from a short stout root-stock. The banana is grown in greenhouses for ornament, and the commercial variety often fruits here. It is cultivated to some extent outdoors in the extreme southern parts of the United States, but our chief supply comes from the West Indies and Central America. Other varieties for ornament are grown from the seed. Manila hemp (*Musa textilis*) is cultivated in the Philippines for the fiber.

DICOTYLEDONES.

568. The ament-bearing plants.—These include three orders which resemble each other in that the flowers, at least the staminate ones, are in aments or catkins. The flowers are either monœcious or diœcious and very much reduced, the floral envelopes being reduced to mere scales. They are as follows: The *willow order* (Salicales), including the willows, poplars (Lombardy and trembling poplars), and the cottonwoods, has both kinds of flowers in catkins. Certain willows are cultivated for making baskets. The *walnut order* (Juglandales) includes the walnut, butternut, and hickory trees. The staminate flowers only are borne in catkins. The *beech order* (Fagales) includes the beech, birch, hazelnut, alder, oaks, chestnut, etc. The staminate flowers here are also in catkins, and the fruits as acorns in the oaks, burs in the chestnut, etc., are well known. These three orders include many valuable trees for lumber, the most valuable being the walnut, hickory, oaks, beech, birch, and

Fig. 390.

Cannabis sativa. Breaking hemp on hand brakes in Kentucky. The dark stripes across the field show where the hemp has been spread for retting. After lying on the ground from 8 to 12 weeks it is set up in shocks to dry, and is then broken and the fiber cleaned by whipping it across the brake. One man with a hand brake will average about 75 pounds of cleaned fiber per day. From Fiber Investigations, U. S. Department of Agriculture.

cottonwoods, and form a large part of the deciduous forest. Aside from the amentiferous trees for timber, shade, and ornament, many of the members of these bear nuts which form an important article of food and are the source also of certain kinds of oil. Most of these nuts are well known, as walnuts, butternuts, pecans, hickory nuts, hazelnuts, filberts, chestnuts, and beechnuts.

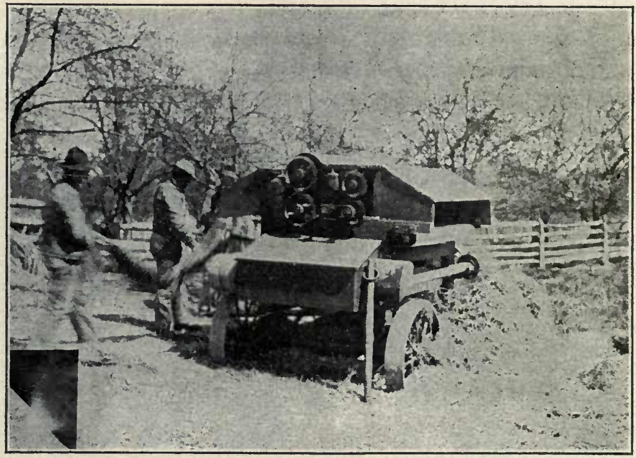


Fig. 391.

Cannabis sativa. Hemp brake in operation at Hanover, Penn. With this machine, which breaks the hurds or woody portion of the stalk and separates it from the fiber, four men can clean from 800 to 1200 pounds of hemp fiber in a day. From Fiber Investigations, U. S. Department of Agriculture.

569. The nettle family (Urticaceæ).— *Hemp.* The hemp is cultivated for the fiber and derived from a species (*Cannabis sativa*) native to central Asia. It has long been cultivated in Europe, and has become naturalized in many countries. The fibers are the fibro-vascular bundles, the other tissues being removed by special processes. It is grown to some extent in the United States for fiber. The hemp is cut with an ordinary mowing machine, as shown in fig. 389; an elevated horizontal bar bends the stalks forward as they are cut. The hemp is spread on the ground for "retting." Here the soft tissues are disorganized, so that the tough elongated fibers are easily freed. After lying on the ground for eight to twelve weeks it is set up in shocks to dry (fig. 390). It is broken and cleaned by hand, or by machine (figs. 390, 391). *Ramie*, also called China grass, silk grass, ramie-hemp, etc., is the fiber from a shrub (*Bœhmeria nivea*) native in China and the Malay Islands, where it has long been cultivated for its fiber, which is used for making fish nets, cloth, etc., while in China and Japan some beautiful textile fabrics are made from it. It is cultivated to some extent in the southeastern United States. The name hemp is also applied to fiber used for similar purposes and obtained from plants belonging to a number of different families. Manila hemp comes from a species of banana (*Musa textilis*) and is extensively cultivated in the Philippine Islands. "Sisal," or "sisal hemp," is obtained from the henequen plant, a species of *Agave*, especially *Agave elongata*. It is grown in the tropics, a large quantity being grown in Yucatan. More than nine-tenths of the "sisal" used in making binder twine is made from the henequen plant.

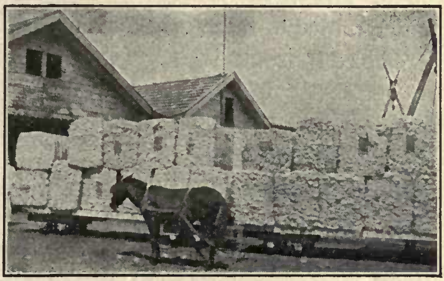


Fig. 392.

Agave elongata. Sisal from the henequen plant on the dock, ready for shipment from Progreso, Yucatan. The henequen plant, cultivated in Yucatan, produces more than nine-tenths of the fiber called "sisal" used in the manufacture of binder twine. It can be grown successfully only in the Tropics. More than $33,000,000 worth (Mexican silver) of this fiber are exported from Progreso every year, and about $15,000,000 worth, gold, are imported into the United States to be used chiefly in the manufacture of binder twine. From Fiber Investigations, U. S. Department of Agriculture.

570. The elm family (Ulmaceæ) includes a number of trees. Our most prominent one is the American elm (*Ulmus americana*), a large tree valuable for lumber. It is much planted for shade and as an ornamental tree. It is one of the most rapidly growing trees.

571. The mulberry family (Moraceæ) includes the mulberry tree, which is grown for its fruit and as a shade tree. The paper mulberries furnish from their bark the fiber for making the beautiful Japanese paper.

572. The fig (*Ficus carica*) is another fruit in this family. The fig is cultivated extensively in southern Europe and Asia, and to a slight extent in some of the Southern States, but in California it bids fair to become an important addition to the great fruit industry of that State (paragraph 297). Our chief supply comes from the Mediterranean region.

573. The bread fruit (*Artocarpus incisa*) is a member of this family, native to the south Pacific Islands. Recently it has been introduced in tropical parts of America. The tree bears a roundish fruit four to eight inches in diameter. When baked it much resembles bread, and is one of the chief sources of food for the natives of these islands.

574. The rose family (Rosaceæ).—These plants are cultivated in a vast number of varieties chiefly for their beautiful flowers. Among the fruits may be mentioned the following. *Strawberries* (see paragraph 327). Like all of our common fruits there are many cultivated varieties of strawberries. They originated from the species native in Chili about two hundred years ago, and being hardy are widely distributed from tropical to arctic regions. They are propagated by runners, new plants for transplanting being obtained from the young ones formed where the runners strike root. Our native wild species is edible, but has not been successfully cultivated, nor does it occur in sufficient quantity for market, while in parts of Europe wild strawberries are abundant and are found in the markets during the entire summer season. They are much prized, though much smaller than the cultivated ones. *Raspberries* and *blackberries* (aggregate fruits, see paragraph 324) are shrubs, and are also extensively cultivated in many varieties, though certain wild species produce abundant and luscious fruit in some sections. They are propagated by cuttings and by layers, since certain species propagate naturally by striking root where the tips touch the ground.

575. The apple family (Pomaceæ).—This family includes the apples, pears, and quinces. These are called *pome* fruits (from the Latin word *pomum*, a fruit or apple). They are all remarkable for the beautiful flowers in early spring as well as for the fruit (see paragraph 328 for structure of the fruit). *Apples* were derived from wild species of *Pirus*, occurring in Europe and southwestern Asia, by improvement in cultivation. From one of these species came the many varieties of our common apples, and from the other came the varieties of crab apples. North America now leads the world in the production of apples. It is our most valuable fruit because of the great number of varieties ripening from June to October, with a great variety in flavor and keeping qualities, some varieties keeping nearly a year after maturity, when properly stored. They are now more extensively used than any other fruit both in the fresh condition and as evaporated fruits, though formerly they were chiefly prized for the making of cider and vinegar. Apples are generally grown over the country, but the most favorable regions are the States east and southeast of Lake Michigan as far as Nova Scotia and Virginia, the region about Arkansas, and the foothills of the Pacific coast. *Pears* are also chiefly derived from a native European species of *Pirus*. The trees are not so hardy as the apple tree, the flowers, twigs, and branches being more subject to blight, a bacterial disease, which kills and blackens the affected parts, though the apple tree is sometimes seriously affected. In some sections of the country, especially in the Middle West, the disease is more serious than in others, and successful pear culture is more limited than that of apples. *Quinces* are chiefly used as preserves and to flavor other fruits, as the flavor is too rich and strong for relish when eaten raw. They are extensively grown in western New York, and are subject to a serious disease, the leaf and fruit spot (*Entomosporium maculatum*).

576. The plum family (Drupaceæ).—These include the drupes or stone fruits (paragraph 323). The principal "stone fruits" cultivated in this country are peaches, plums, apricots and cherries. *Peaches* have been cultivated from time immemorial in China where they were native, but they came to New York by way of Persia. The species name (*Prunus persica*) refers to their introduction from that country. The fruit is downy (except certain smooth varieties known as *nectarines*) and the stone is corrugated. The flowers of many varieties are conspicuous and beautiful, though many of the recent valuable varieties have rather inconspicuous flowers because of the small size of the petals. The flower buds and flowers are very sensitive to frost and extreme cold weather, and they are easily killed during a severe freeze after the buds have begun to swell. Warm seasons during mid-winter, followed by very low temperature, sometimes kill the flower buds before they open, and late severe frosts in the spring also kill the pistil of very young fruit just before or after the flowers have opened. This limits the successful culture of peaches to certain sections where natural conditions modify the severity of the cold, as near large bodies of water or in protected localities. The best peach-growing sections in the United States are along the eastern and southern shores of Lake Erie and Ontario, and the eastern shore of Lake Michigan, along Long Island Sound, the Atlantic Coast and Chesapeake Bay, in New Jersey, Delaware and Maryland, in the milder climates of northern Georgia, Alabama, southern Illinois to Kansas and Missouri, and along the Pacific Coast. *Plums* have a smooth skin and stone and there are a great many cultivated varieties. They are hardier than the peach and thus are cultivated over a much wider area. *Prunes* are varieties of plums which are sweet, and are dried with the stone. California is the greatest prune-growing section in this country. *Apricots* resemble a smooth peach and have a smooth stone like a plum, and in external appearance resemble both a plum and a peach. They were native of China or Japan, are similar to the peach in sensitiveness to cold and are not extensively cultivated in this country except in California and in parts of New York. The *almond* is closely related to the peach and originated from a species (*Prunus amygdalinus*) probably native to southern Europe. It is chiefly cultivated in the Mediterranean region, and of late years with some success in California. The flowers are like those of the peach. The fruit when young resembles a peach but the exocarp is thin, and when ripe, cracks open, freeing the nuts. In its native country it is often found on the markets green. It is eaten in this condition by cutting open the flesh to secure the green nut. The cultivated *cherries* are derived from two species native to Europe, one of these producing the varieties of sour cherries which are extensively grown in the eastern United States. In western New York they are largely grown for canning. The sweet cherries form a large and tall tree, are also grown in the eastern United States, but most extensively in California. The native species in this country have small fruits and have not yet shown adaptability to improvement in cultivation. One, the wild black cherry (*Prunus serotina*), is very valuable for lumber.

577. The pea family (Papilionaceæ).—This is a large and important family. The name refers to the supposed resemblance of pea flowers to a butterfly (*Papilio*). The flower and fruit are described in paragraphs 249–251 and 320. The name of the family is sometimes given as *Leguminosæ*, the name being taken from the characteristic fruit which is a *legume* or *pod*. Many of the members of the family have showy flowers and are grown for orna-

Fig. 393.

Peanuts in the field, showing how the earth is drawn up to cover the young forming pods; in front a few plants pulled, showing the peanuts. From Bureau Plant Industry.

ment, as the wistaria, sweet pea, etc. The sensitive plants (*Mimosa*) also belong here. Peas and beans are important garden and field crops, there being many varieties. The peas originated from southern Europe and Asia. The lima bean was originally a native of South America, as well as the kidney bean, from which the common bean originated. The peanut (also called " ground nut " and " goober ") is also a native of South America, probably Brazil. It is extensively cultivated in the Carolinas, Georgia and Tennessee. After the flowers fall the pod turns downward and pushes into the loose soil where the peanut matures. The *clovers* (*Trifolium*) are important forage plants, the red clover being the most important. The clovers, especially the white clover, are visited by bees for honey, and white clover honey is one of the most prized kinds. *Alfalfa* is related to the clovers and is also an important forage crop, especially in arid regions where the land is irrigated. The clover and alfalfa, as well as peas, are often used for " green soiling," and all of the leguminous plants are valuable for enriching the soil in nitrogen because of the presence of the nitrogen fixing organisms which cause the tubercles or knots on the roots (paragraph 203). There are some valuable trees in the order, especially the common locust (*Robinia*) valuable for timber because of its great durability. The honey locust (*Gleditsia*) is noted for its thorns and is cultivated for ornament. The red bud (*Cercis*) is grown for ornament, and is remarkable for the numerous dark red flower buds which open before the leaves appear.

578. Flax.—The flax (*Linum usitatissimum*) is a member of the *flax family* (Linaceæ) and is an important fiber plant. The fiber is separated from the stem and is used to make linen thread and cloth, while linseed oil is obtained by pressure from the seed. This flax is native in the Mediterranean region and has been cultivated from very early times. It has been long cultivated in the United States for oil, and recently for fiber in a number of the northwestern states. Russia leads the world in the amount of flax grown, while Belgium produces the finest fiber. Several species of wild flax are native to the United States.

579. Citrous fruits.—The citrous fruits belong to the *family Rutaceæ*, which includes also our native prickly ash (*Xanthoxylum*). They belong to the genus *Citrus*, shrubs or small trees native in tropical and subtropical Asia. Three types of the citrous fruits are cultivated in the United States. The culture of the citrous fruits is often attended with considerable risk because of hard frosts which sometimes nearly or quite destroy the crop, or even kill the trees. Experiments are now in progress by the United States Department of Agriculture which have for their object the development of more hardy varieties. The sweet orange has been crossed with *Citrus trifoliata* (which has an unedible fruit), and the result is a hardier tree which can be cultivated about two hundred miles farther north than the present limit of orange culture. A number of varieties have been obtained and a few are promising. The fruit is called *citrange.* Two varieties give promise of being used as substitutes for lemons.

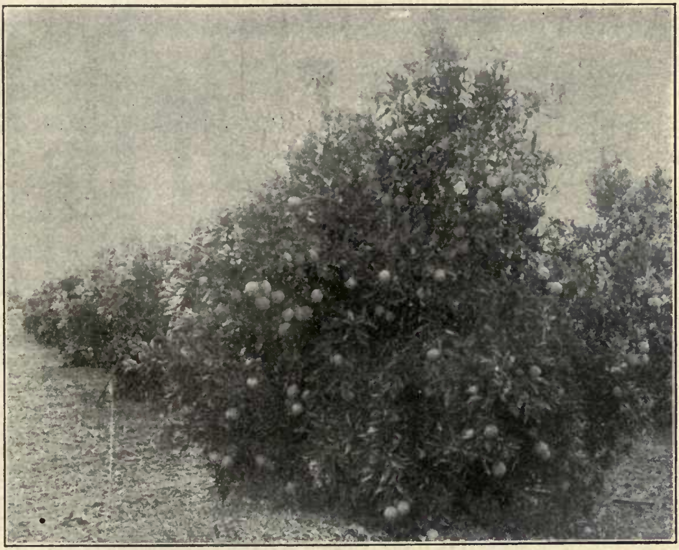


Fig. 394.
Naval orange tree, ten years old. From Bureau Plant Industry.

Another new fruit, *tangero*, is a cross between the tangerine and grape fruit, in which the qualities of the two fruits are blended.

580. Oranges.—The varieties of oranges originated from one species (*Citrus aurantium*), the principal forms found in the market being sweet, while some forms are bitter. In the United States they are cultivated in central and southern Florida, in California and in the delta region of the Mississippi. The seedless naval oranges grown in California were introduced in 1870 from Brazil where they originated as a seedling variety. The *mandarins* or "kid glove oranges" belong to a closely related species (*Citrus nobilis*). Some are small and of a light orange color, while others called *tangerines* are dark orange or red and are preferred in the market to the others.

581. Grape fruits.—The grape fruits were derived from a species (*Citrus decumana*) native in the Malayan and Polynesian Islands. Many of the varieties have originated in Florida. The fruit is rounded in form, and was earlier known as *pomelo*, and sometimes called *shaddock*, while the real shaddock is a different variety, pear-shaped and little used. Grape fruit is extensively cultivated in India, Florida and California.

582. Lemons.—The lemons (*Citrus medica*) are cultivated to some extent in Florida and California, but they are more easily injured by cold, and our chief supply comes from southeastern Europe (Italy, Spain and Portugal). The lime is a variety of the lemon, with acid, bitter fruit from which lime juice is obtained.

583. The maple family (Aceraceæ) has inconspicuous flowers and the fruit is called a key fruit or samara. Several of the maples are valuable timber trees. The hard or rock maple (*Acer saccharum*) is also known as sugar maple, its sap yielding the maple sugar of commerce. When the wood is full of little knots, the grain of the lumber is very beautiful because of numerous concentric rings. It is then known as "bird's-eye" maple, and is much prized for cabinet work. The black sugar maple is *A. nigrum*. The soft maple (*A. saccharinum*) yields smaller quantities of sap. These and several other maples, as the red maple, the silver maple, box elder, etc., are planted for ornament and shade.

584. The linden family (Tiliaceæ).—Our well-known representative is the bass-wood or linden. The American linden (*Tilia americana*) is a forest tree producing a soft white wood occurring from New Brunswick to Georgia and Manitoba. The white bass-wood, or "linn" tree as it is called in the South, is a forest tree from New York to Florida and west to Tennessee. It is sometimes called "bee-tree" and is noted for the fine grade of honey made from the nectar in the flowers. The bast (paragraph 98) of the bass-wood trees forms long and stout fibers. The bast, or Russian bast as it is sometimes called in certain trees, is used for making coarse mats. "Jute" is the bast from certain tropical linden plants (*Corchorus olitarius*).

585. The mallow family (Malvaceæ) includes the hollyhocks, mallows, rose of sharon (*Hibiscus*), cotton, etc. The cotton plant is cultivated for the fiber on the seed. Cotton (*Gossypium*) is the most important fiber plant known. The

Fig. 395.
Picking cotton. From Bureau Plant Industry.

cultivated varieties were derived from tropical species. One of the best varieties is the Sea Island cotton (*Gossypium barbadense* from the West Indies) which has very long fibers. The best quality of this variety is cultivated along the coast of South Carolina, Georgia and Florida. Upland cotton (*Gossypium herbaceum*, probably from southern Asia) is grown back from the coast over a wide area and there are many varieties. The Sea Island cotton is what is called a long-staple cotton, because of the long fibers. Upland cotton is a short-staple cotton, the fiber being much shorter than that of the Sea Island. The long-staple cotton is necessary for some purposes and the Sea Island cotton in consequence is worth nearly twice as much as the upland, but since it can be cultivated over such a small area as compared with the total cotton-growing area the proportion of long-staple cotton is small. Efforts have been made to cross the long and short staple in order to get a variety of cotton with a longer staple than the upland which can be grown in the upland area. A variety has been developed which is improved in these respects. Texas, Louisiana, Georgia, Alabama, Mississippi and South Carolina are the greatest cotton-producing states, but it is also grown in Florida, North Carolina, Kentucky, Tennessee, Missouri and Arkansas. India, Egypt, and the warmer parts of South America and Russia are great cotton-producing countries. The compound pistil forms the capsule or " boll " as it is called. The fibers are attached to the seed. When ripe the boll bursts open and the fluffy white mass of fiber is easily " picked." The fiber is removed from the seed by passing it through a machine, the " cotton gin." A fine grade of oil, resembling olive oil, is obtained from the seed by pressure, and the meal left is used as food for cattle, and for fertilizer.

586. Chocolate.—Chocolate or cacao is obtained from the seeds of the cacao tree (*Theobroma cacao*), a native species of Mexico and related to the previous order. It was introduced into Europe by the Spaniards and is cultivated in all tropical countries. The cacao is expressed from the seed, heated and moulded into cakes. An aromatic substance in cacao, known as coca-butter, is used in medicine, and when removed from the chocolate leaves *coco*, which for some persons makes a more digestible beverage than chocolate.

587. The tea family (Theaceæ) is represented by the loblolly bay, or tan bay (*Gordonia lasianthus*), a tree with coriaceous evergreen leaves, and large, white, solitary flowers often clustered at the ends of branches. The tree grows from West Virginia to Florida in low woods, and flowers from May to July. Franklin's tree (*G. pubescens = Franklinia altamaha*), a native of Georgia, is cultivated as an ornamental tree as far north as Massachusetts. The most important economic plant in the family is the tea plant (*Thea*). Tea is a native shrub of subtropical Asia. The dried leaves are used for making the well-known beverage. It has long been cultivated in China and Japan, and was introduced in cultivation more than a century ago in Java, India and Ceylon. Attempts have been made to cultivate it in South Carolina.

588. The heath family (Ericaceæ).—Examples are Labrador tea (*Ledum*), in bogs and swamps in northern North America. The azaleas, with several species widely distributed, are beautiful flowering shrubs, and many varieties are cultivated. The rhododendrons are larger, with larger flower-clusters, and are also beautiful flowering shrubs. *R. maximum* occurs in the Alleghany Mountains and vicinity, from Nova Scotia to Ohio and Georgia. *R. catawbiense*, usually at somewhat higher elevations, occurs in Virginia and Georgia. The mountain laurel (*Kalmia latifolia*) and other species rival the rhododendrons and azaleas in beauty. The trailing arbutus (*Epigæa repens*), in sandy or rocky woods, is a well-known small trailing shrub in eastern North America. The sourwood (*Oxydendrum arboreum*) is a tree with white racemes of flowers in August and scarlet leaves in autumn. The spring or creeping wintergreen (*Gaultheria procumbens*) is a small shrub with aromatic leaves, and bright red, spicy berries.

589. The huckleberry family (Vacciniaceæ) includes the huckleberries or whortleberries (example, *Gaylussacia resinosa*, the black or high-bush huckleberry, eastern United States); the mountain cranberry (*Vaccinium vitisidæa* = *Vitis-Idæa vitisidæa*) in the northern hemisphere; the bilberries and blueberries (*Vaccinium*); and the cranberries, the large American cranberry (*Vaccinium macrocarpon* = *Oxycoccus macrocarpus*) in the cold bogs of North America, and the small or European cranberry (*Vaccinium oxycoccus* = *Oxycoccus oxycoccus*) in northern North America, Europe and Asia.

590. The olive family (Oleaceæ) includes the common lilac (*Syringa*), the ash trees (*Fraxinus*), some of which afford valuable lumber, the privet (*Ligustrum*, used for hedges) and the olive tree. *The olive tree* (*Olea europæa*) is a native of the Old World and has been cultivated in the subtropical regions of Europe and Asia from early times. The fruits, which resemble stone fruits, are used for pickles and for extracting olive oil. The olive is cultivated successfully in parts of California, especially in the San Joaquin and Sacramento valleys of the Coast Range and in the warm belt of the Sierra Nevada.

591. The potato family (Solanaceæ).—This family is also known as the *nightshade family* because of the number of plants called "nightshade." Many of the nightshades have an evil smelling foliage, and the leaves and fruits of some are poisonous. Examples are ground-cherry, belladonna, henbane, petunia, jimson-weed or thorn-apple, matrimony vine, etc. This family also includes several important cultivated plants, as potato, tomato, tobacco, etc. The potato (*Solanum tuberosum*) was derived from a wild species native to the mountain regions of the Western Continent from Colorado to Chili. It was cultivated by the native Indians before the discovery of America. From here it was introduced into Europe and has been so extensively cultivated in Ireland, where it is one of the most important foods, that it is often called even in this country "Irish potato." The subterranean tubers filled with starch are the parts of the plant used. The *tomato* (*Lycopersicum esculentum*) originated in South America, where it was native in the region of the Andes Mountains. Many varieties are now known which are extensively cultivated in this country and Europe, though the greatest production is in the United States, where it is used raw as a salad, or cooked in various ways. Large quantities are canned, about 300,000 acres annually being cultivated to supply the canning industry. It is the fruit which is used. Not many years ago it was supposed to be inedible, was grown for ornament, and called "love apple." Peppers and egg plants are related species. *Tobacco* (*Nicotiana tabacum*) belongs to the same family. At the time of the discovery of America, tobacco was found in culti-

Fig. 396.

Tobacco field in Virginia at harvest time. At the right, showing several rows cut and lying on the ground to wilt before hauling to the curing barn. From Tobacco Investigations, Bureau Plant Industry.

Fig. 397.

Showing sun and air process of curing tobacco in Virginia. Part of the tobacco hung in the curing barn. From Tobacco Investigations, Bureau Plant Industry.

vation by the Indians. From here it was introduced into Europe, and now is extensively cultivated in the warmer parts of the world. The best grades are grown in Cuba, but fine tobacco is also grown in the other West Indies, in Florida, the Philippines, Borneo, Ceylon, etc. In the United States it is extensively cultivated in Florida, Connecticut, Pennsylvania, Wisconsin, Kentucky, Virginia, North Carolina, Maryland, Ohio, Indiana, Missouri, and some other states. The leaves of the tobacco are used, being cured by drying.

592. Order Rubiales, the madders.—There are three families in this order. The *madder family* (Rubiaceæ) includes the bluets (*Houstonia*, paragraph 292), the button bush (*Cephalanthus*), the partridge berry (*Mitchella*), the bed straws (*Galium*), etc., in this country; and several important cultivated plants in tropical countries. The *coffee* plant (*Coffeia ărabica*), as its technical name suggests, is a native of Arabia, but is now cultivated in many other tropical countries where there is a high temperature throughout the year. Brazil now leads all other countries in its production. Other countries where it is extensively grown are Mexico, Central America, Java, Sumatra, India, Ceylon, Arabia, Hawaiian Islands, West Indies, etc. It has been in use in Arabia for over 500 years. The " beans " which are used for making the beverage are seeds. It is said that nearly half the coffee produced is consumed in the United States. Quinine is obtained from the bark (Peruvian bark) of trees in the genus *Cinchonia*, which grow in South America chiefly along the eastern slopes of the western range of mountains. The trees are cultivated extensively in Java, British India, Ceylon, Japan and Jamaica.

593. The honeysuckle family (Caprifoliaceæ) includes the elder (Sambucus), the arrowwoods and cranberry trees (*Viburnum*), the honeysuckles (*Lonicera*), etc.

594. Order Valerianales with two families includes the *teasel family* (Dipsacaceæ). Example, Fuller's teasel (*Dipsacus*).

595. Order Campanulales, the gourds and composites.—There are several families in this order. The most important one from an economic standpoint is the *gourd family* (Cucurbitaceæ), which contains the watermelons, cucumbers, muskmelons, pumpkins, etc. The floral and fruit structures of this family are well represented by the squash. The *muskmelons* have been derived from a species (*Cucumis melo*) native in southern Asia but is now cultivated the world over. Large crops are grown in New Jersey, Michigan and Colorado. The two principal types of muskmelons are the *cantaloupes*, which are elongated and have a furrowed or ribbed rind, and the *nutmeg melons*, which have rinds with a netted sculpture. *Watermelons* were derived from a species native in tropical Africa, and have been cultivated from time immemorial, but now the United States leads the world in their production. They are grown over a large part of the United States, but the larger markets are chiefly supplied from the southeastern states (Georgia especially). *Cucumbers* (*Cucumis sativus*) are native to southern Asia, and now are grown in different parts of the world. They are chiefly used for pickles and are extensively grown in the United States. *Pumpkins* (*Cucurbita pepo*) were native to the Western Continent, probably originating in tropical America. Squashes have originated from several different species, some from the same species as the pumpkin in America, and others from species native to southern Asia.

596. The chicory family (Cichoriaceæ) includes the chicory or succory (*Cichorium intybus*, known also as blue-sailors), the oyster-plant or salsify (*Tragopogon porrifolius*), the dandelion (*Taraxacum densleonis* = *Taraxacum taraxacum*), the lettuce (*Lactuca*), the hawkweed (*Hieraceum*), and others. Lettuce (*Lactuca sativa*) is cultivated for salad, and is generally supposed to be derived from one of the compass plants (*Lactuca scariola*, see paragraph 132), a species native to Asia. Chicory is extensively cultivated in Europe and Asia. The fleshy root is dried, roasted and ground, when it is used as a substitute for coffee or to adulterate it. The leaves, after being bleached, are also used for salad.

597. The thistle family (Compositæ) includes the thistle (*Carduus*), asters (*Aster*), goldenrods (*Solidago*), sunflowers

(*Helianthus*), eupatoriums or joepye-weeds, thoroughworts (*Eupatorium*); coneflowers or black-eyed Susans (*Rudbeckia*), tickseed (*Coreopsis*), burmarigold or beggar-ticks or devil's-bootjack (*Bidens*), chrysanthemums, etc. One of the food plants is the Jerusalem artichoke (*Helianthus tuberosus*), a native of Canada and the upper valley of the Mississippi, cultivated for the fleshy tubers or root-stocks, which are sweet and mealy. It was formerly grown by the Indians. In the globe artichoke (*Cynara scolymus*), extensively cultivated in Europe, the fleshy bracts of the flower head and the young portion of the receptacle and flowers are used for food.

CHAPTER XXXVII.

RELATION OF PLANTS TO ENVIRONMENT OR ECOLOGY.*

598. Influence of environment on the life processes of plants.—By environment is meant all those conditions or factors outside of the plant which in any way influence its growth, form, nutrition, reproduction, distribution, etc. The relation which some of these conditions, or factors, bear to the plant has been quite fully studied in some of the former chapters. For example in Chapter XVIII it has been shown how the pollination of plants is largely (in most cases wholly) dependent upon factors or agencies outside of the plant, as in cross pollination by the wind and insects.

I. FACTORS INFLUENCING VEGETATIVE TYPES.

599. These conditions of environment acting on the plants are *factors* which have an important determining influence on the existence, habitat, habit, and form of the plant. These factors are sometimes spoken of as *ecological factors*, and the study of plants in this relation is sometimes spoken of as *ecology*,† which means a study of plants in their home or a study of the household relations of plants. These factors are of three sorts: first, physical factors; second, climatic factors; third, biotic, or life, factors.

---

* To the Teacher. Chapters XXXVII–XXXIX are intended to outline the subject of the relation of plants to environment, or ecology, and to serve as the basis for informal talks at the discretion of the teacher, or parts may be assigned for reading in connection with some of the studies in the earlier chapters in the book. When possible, excursions should be arranged to the fields or parks where many of the principles discussed in these chapters can be illustrated. Talks by the teacher, illustrated by lantern views, can also be given.

† *οἶκος* = house, and *λόγος* = discourse.

600. Physical factors.—Some of these factors are water, light, heat, wind, chemical or physical condition of the soil, etc. Water is a very important factor for all plants. Even those growing on land contain a large percentage of water, which we have seen is rapidly lost by transpiration, and unless water is available for root absorption the plant soon suffers, and aquatic plants are injured very quickly by drying when taken from the water. Excess of soil water is injurious to some plants. *Light* is important in photosynthesis, in determining direction of growth as well as in determining the formation of suitable leaves in most plants, and has an influence on the structure of the leaf according as the light may be strong, weak, etc. *Heat* has great influence on plant growth and on the distribution of plants. The growth period for most vegetation begins at 6° C. (= 43° F.), or in the tropics at 10° to 12° C., but a much higher temperature is usually necessary for reproduction. Some arctic algæ, however, fruit at 1.8° C. The upper limit of temperature favorable for plants in general is 45° to 50° C., while the optimum is below this. Very high temperatures are injurious, and fatal to most plants, but some algæ grow in hot springs where the temperature reaches 80° to 90° C. Some desert plants are able to endure a temperature of 70° C., while some flowering plants of other regions are killed at 45° C. Some plants are specifically susceptible to cold, but most plants which are injured by freezing suffer because the freezing is a drying process extracting water from the protoplasm (see paragraph 83). *Wind* may serve a useful purpose in pollination and in aeration, but severe winds injure plants by causing too rapid transpiration, by felling trees, by breaking plant parts, by deforming trees and shrubs, and by mechanical injuries from "sand-blast." *Ground covers* protect plants in several ways. Snow during the winter checks radiation of heat from the ground so that it does not freeze to so great a depth, and this is very important for many trees and shrubs. It also prevents alternate freezing and thawing of the ground, which "heaves" some plants from the soil. Leaves and other plant-remains mulch the soil and check evaporation of water. The influence of the *chemical* *condition* of the soil is very marked in alkaline areas where the concentration of salt in the soil permits a very limited range of species. So the physical and mechanical conditions of the soil influence plants because the moisture content of the ground is so closely dependent on its physical condition. Rocky and gravelly soil, other things being equal, is dry. Clay is more retentive of moisture than sand, and moisture also varies according to the per cent of humus mixed with sand, the humus increasing the percentage of moisture retained.

Fig. 398.
Main trunk straight, branches all bent and fixed to one side by wind from one direction (Rocky Mountains).

601. Effects of cold and frost.—Intense cold prevents root absorption, and has a drying effect on vegetation, so that vegetation protects itself in several ways through the severe winter in temperate and arctic climates. The deciduous habit of trees and shrubs, the underground stem of perennial herbs, the rosette habit of perennials, the bud-scales on winter shoots, and the low stature of arctic and alpine plants are modifications in response to the harmful effects of extreme cold.

602. Effects of freezing.—In freezing weather plants are injured in three ways: First. The chilling effect of cold is sufficient to kill some plants which are very sensitive to low temperatures. Second. Others are killed even by comparatively light frosts, or freezes (examples: potatoes, tomatoes, corn, many herbs, young leaves and shoots of many plants). In these cases the injury is chiefly caused by the loss of water from the protoplasm in the cells. As freezing takes place in the tissues the ice crystals are usually not formed within the cells. But some of the water, under the influence of the extreme cold, is gradually withdrawn from the cells into the intercellular spaces where the ice crystals are gradually formed. This is in reality a protection to the protoplasm, since it becomes " drier " and thus more resistant to cold. When the plants " thaw " out, if the protoplasm has not been killed by the cold, this water may be absorbed by the protoplasm again, and the plant is not injured. Freezing, then, to a certain extent has the same effect on the protoplasm as the loss of too much water by transpiration. The bud-scales thus prevent the loss of too much water from the cells of the delicate tissues of the growing point of shoots in winter, although in many cases freezing in these tissues takes place. Third. In other cases plants are killed by the actual freezing of the protoplasm, though there are some plants which are not killed by freezing of the water in the protoplasm.

603. Climatic factors.—These factors are operative over very wide areas. There are two climatic factors: rainfall or atmospheric moisture, and temperature. A very low annual rainfall in warm or tropical countries causes a desert; an abundance of rain permits the growth of forests; extreme cold prevents the growth of forests and gives us the low vegetation of arctic and alpine regions.

604. Biotic, or life, factors.*—These are animals which act favorably in pollination, seed distribution, or unfavorably in destroying or injuring plants, and man himself is one of the great agencies in checking the growth of some plants while favoring the growth of others. Plants also react on themselves in a multitude of ways for good or evil. Some are parasites on others; some in symbiosis (see paragraph 206) are aided in obtaining food; shade plants are protected by those which overtop them; mushrooms

---

* These biotic factors (plants and animals) in many cases do not exert a *personal* or direct influence themselves on the vegetation concerned. They often merely introduce physical factors, as shade, etc. But in some of the more intimate relations of plants in symbiosis, parasitism (one form of symbiosis), etc., the living organism as a factor is more evident, but it should be understood that this factor is not in the nature of vitalism in the sense of the old vitalistic theory.

and other fungi disintegrate dead plants to make humus and finally plant food; certain bacteria prepare nitrates for the higher plants (see paragraph 200).

II. VEGETATION TYPES AND STRUCTURES.

605. Responsive type of vegetation.—In studying plants in relation to environment we treat rather of the form of the plants, which fits them to exist under the local conditions, than of the classification of plants according to natural relationships. Plants may have the same vegetation * type, grow side by side, and still belong to very different floristic † types. For example, the cactus, yucca, three-leaved sumac, the sage-brush, etc., have all the same general vegetation type and thrive in desert regions. The red oaks, the elms, many goldenrods, trillium, etc., have the same general vegetation type, but represent very different floristic types since they belong to different families and orders. The latter plants grow in regions with abundant rainfall throughout the year, where the growing season is not very short and temperature conditions are moderate. Some goldenrods grow in very sandy soil which dries out quickly. These have fleshy or succulent leaves for storing water, and while they are of the same floristic type as goldenrods growing in other places, the vegetation

Fig. 399.
Bank of ferns. (After MacMillan.)

---

* i.e., the stems, leaves, etc., are of a kind suitable for existence under the same conditions.

† Flower-structure type.

type is very different. The types of vegetation, which fit plants for growing in special regions or under special conditions, they have taken on in response to the influence of the conditions of their environment. While we find all gradations between the different types of vegetation, looking at the vegetation in a broad way, several types are recognized which were proposed by Warming as follows:

606. Mesophytes.*—These are represented by land plants under temperate or moderate climatic and soil conditions. The normal land vegetation of our temperate region is composed of mesophytes, that is, the plants have mesophytic † structures during the growing season. The deciduous forests or thickets of trees and shrubs with their undergrowth, the meadows, pastures, prairies, weeds, etc., are examples. In those portions of the tropics where rainfall is great the vegetation is mesophytic the year round.

Fig. 400.
Tropical vegetation, ferns and other plants growing around and upon a column of lava, Hawaii.

607. Xerophytes.‡—These are plants which are provided with structures which enable them to live under severe conditions of dryness, where the air and soil are very dry, as in deserts or

---

* *μεσος* = middle, *φυτον* = plant.

† Intermediate between the structures of desert and water plants.

‡ *ξερος* = dry, *φυτον* = plant.

semideserts, or where the soil is very dry or not retentive of moisture, as in very sandy soil which is above ground water, or in rocky areas. Since the plants cannot obtain much water from the soil they must be provided with structures which will enable them to retain the small amount they can absorb from the soil and give it off slowly. Otherwise they would dry out by evaporation and die. Some of the structures which enable xerophytic plants to withstand the conditions of dry climate and soil are lessened leaf surface, increase in thickness of leaf, increase in thickness of cuticle, deeply sunken stomates, compact growth, also succulent leaves and stems, and in some cases loss of the leaf. Evergreens of the north temperate and the arctic regions are xerophytes.*

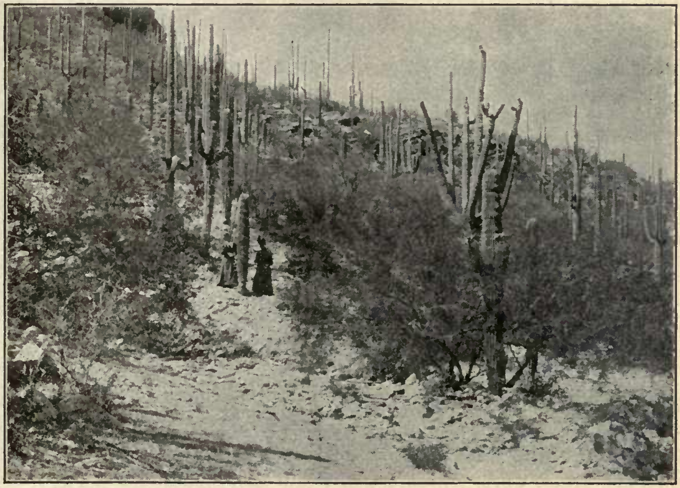


Fig. 401.
Desert society, chiefly cactus, Arizona. (Photograph by Tuomey.)

---

* The xerophytic condition of the conifers is probably brought about as a result of imperfect vascular system of the stems. There not being true vessels the water supply to the leaves is scanty and slow. The leaves are consequently narrow, thickened, hard, and with a thick cuticle. This offers an excellent example of correlation (paragraph 656).

608. Hydrophytes.*—These are plants which grow in fresh water or in very damp situations. The leaves of aerial hydrophytes are very thin, have a thin cuticle, and lose water easily, so that if the air becomes quite dry they are in danger of drying up even though the roots may be supplied with an abundance of water. The aquatic plants which are entirely submerged have often thin leaves, or very finely divided or slender leaves, since these are less liable to be torn by currents of water. The stems are slender and especially lack strengthening tissue, since the water buoys them up. Removed from the water they droop of their own weight, and soon dry up. The stems and leaves have large intercellular spaces filled with air which aids in aeration and in the diffusion of gases. Some use the term *hygrophytes*.

Fig. 402.
Pond lilies, Harlem Lake, Central Park, N. Y. City. (After Murrill.)

609. Halophytes.†—These are salt-enduring plants. They grow in salt water, or in salt marshes where the water is brackish, or in soil which contains a high per cent of certain salts, for example the alkaline soils of the West, especially in the so-called

* *ὑδορ* = water, *φυτον* = plant.
† *ἀλος* = salt, *φυτον* = plant.

"Bad Lands" of Dakota and Nebraska, and in alkaline soils of the Southwest and California. These plants are able to withstand a stronger concentration of salts in the water or soil moisture than other plants. They are also found in soil about salt springs.

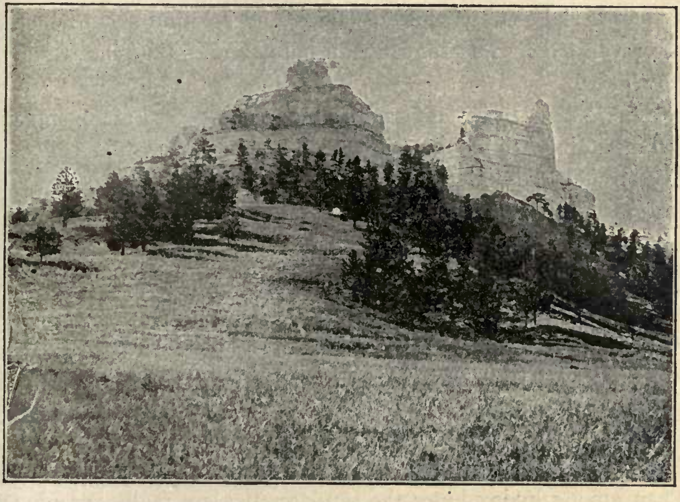


Fig. 403.

Bad Lands. Pinus ponderosa scopularum on the talus of buttes on the borders of Sowbelly Canyon, Pine Ridge, Nebraska. Bouteloua oligostachya (grama grass) formation in foreground (Dept. Geol., iv. Nebr.).

610. Tropophytes.*—Tropophytes are plants which can live as mesophytes during the growing season, and then turn to a xerophyte habit in the resting season. Deciduous trees and shrubs, and perennial herbs of our temperate regions, are in this sense tropophytes, while many are at the same time mesophytes if they exist in the portions of the temperate region where rainfall is abundant. In the spring and summer they have broad and comparatively thin leaves, transpiration goes on rapidly, but there is an abundance of moisture in the soil, so that root absorption quickly replaces the loss and the plant does not suffer. In

---

* Term used by Schimper, *τροπος*, from *τρεπειν* = to turn, *φυτον*=plant.

the autumn the trees shed their leaves, and in this condition with the bare twigs they are able to stand the drying effect of the cold and winds of the winter because transpiration is now at a minimum, while root absorption is at a minimum because of the cold condition of the soil. Perennial herbs like trillium, dentaria, the goldenrods, etc., turn to xerophytic habit by the death of their aerial shoots, while the thick underground shoot which is also protected by its subterranean habit carries the plant through the winter.

611. While these different vegetation types are generally dominant in certain climatic regions or under certain soil conditions, they are not the exclusive vegetation types of the regions. For example, in desert and semidesert regions the dominant vegetation type is made up of xerophytes. But there is a mesophytic flora even in deserts, which appears during the rainy season where temperature conditions are favorable for growth. This is sometimes spoken of as the rainy-season flora. The plants are annuals and by formation of seed can tide over the dry season. So in the region where mesophytes grow there are xerophytes, examples being the evergreens like the pines, spruces, rhododendrons; or succulent plants like the stonecrop, the purslane, etc. Then among hydrophytes the semiaquatics are really xerophytes. The roots are in water, and absorption is slow because there are no root hairs, or but few, and the aerial parts of the plant are xerophytic.

CHAPTER XXXVIII.

MIGRATION AND DISTRIBUTION OF PLANTS.

612. The migration of plants is the movement of plants over the earth, not only into new territory, but also movement from place to place within the territory already occupied by a given species. The word distribution is sometimes used in place of the word migration, and is also used to indicate the area already occupied by a species.

613. One very important principle in plant migration is that of the *pressures*, as they are called, which are behind many of the plant movements. Plants produce great quantities of seeds or other reproductive bodies, the larger number of which fail to make new plants. These seeds are scattered yearly from their centers of production so that whenever a chance comes for growth the seed is there to start it. In the area occupied by the species in question some of them grow to new plants to take the place of those which perish. Other seeds are carried beyond this area into new territory. If this territory is suitable for the growth of the species in question it may gain a foothold and thus extend the " range " of the species. If the seeds are carried into a climate unfavorable for this species, they die. This great fertility of species therefore constitutes a pressure which is ever forcing the species onward and outward, in many cases into territory where it cannot possibly obtain a footing. Great changes in climate also produce pressures which result in the migration of plants. Some of the principles of plant migration may be considered under the following heads: First, methods and causes of plant migration; second, barriers to plant migration.

I. METHODS AND CAUSES OF PLANT MIGRATION.

614. Advantages of plant migration.—The advantages accruing to plants, through their power or tendency to migrate, is that individuals of a species are increased by extending their area of occupation. Whether the plant concerned occupies any given area to the exclusion of other species or not, an extension of the area provides for an increase in individuals, and the perpetuation of species is thus more surely safeguarded. It increases the factor of safety for existence: First. By the larger number of individuals possible over a larger area. Second. The safety of some is assured in case of disaster to others in a certain region. Disaster may come by sharp competition of other species, or by the destructive effect of physical changes in the topography of certain areas. For example, in time of flood, areas being covered by sand, gravel, or other rock débris; or by changes in the climate, etc. Third. The species often gains in vigor by coming under new conditions, better soil conditions, more favorable climate conditions, etc.

615. Structural characters favoring plant migration.—Many of these characters are discussed more fully in the chapter on "Seed Dispersal," and others in the chapter on "Stems," etc. The mere enumeration of some of these characters is given here.

1. *Seeds.*—First. The buoyancy of seeds produced by the development of so-called "wings" on the elm, maple, etc., the pappus of the composites and other hairy or wooly outgrowths form part of the seed or fruit which enable it to catch the wind. Small size and lightness of many seeds also give them a certain amount of buoyancy. Second. The development of structures for grasping hold upon other objects; for example, barbs and hooks on seeds or fruits for clinging to animals. Third. The use of seeds as food by animals. Fourth. Seeds which are capable of floating on the water.

2. *Fruit.*—There are many fruits which are used for food by animals and the seeds of which often pass through the body

uninjured, and thus often gain wide distribution, especially in the case of migrating birds. Cedars are often seen growing along fences where perching birds have dropped the seeds. Some plants, like those of the mistletoe, are distributed by birds. Exploding fruits also bring about the dispersal of seed, as in the vetches, the touch-me-not, the fruit of the witch-hazel; or of spores, as in the sporangia of ferns, or of some of the fungi.

3. *Tumble-weeds.*—Several kinds of tumble-weeds are known, some of which are popularly spoken of as "resurrection-plants," especially certain species of club-mosses (*Lycopodium*). These, as is well known, in dry weather curl their stems into a more or less round, compact ball, and in so doing the roots are frequently torn from their attachment to the soil, and the ball is rolled along by the wind over plains to considerable distances. During the rainy season these plants, which have retained their life in the dry condition, expand and the roots take hold of the soil again. Parts of plants, as the seed-bearing portion of certain grasses, are often broken during heavy winds, and are blown or rolled for a considerable distance over the ground, thus providing for the distribution of seed.

4. *Floating of broken branches.*—In the case of certain trees or shrubs growing next to water the branches are often broken by the wind and, floating to new places, sometimes aid in the distribution of the species.

5. *Prostrate creeping plants* or plants with a more rampant habit migrate through a system of natural layering. In prostrate or creeping plants, like the strawberry, or trailing roses, the stems take root here and there, and thus slowly and surely extend the area of occupation by the species. Plants of more rampant habit, like the blackberries, or certain roses, take root at the tips of their branches, where they come in contact with the ground, and new shoots develop at this point. This habit is sometimes spoken of as walking. Example, the "walking-fern" (fig. 302).

6. *Underground creeping stems or roots.*—Of this type there are a large number of well-known examples (the underground

shoots of many grasses for example, of ferns like the sensitive fern, or bracken fern). Among those which extend their distribution through roots, a striking example is that of certain species of sumac. In New York state several species of sumac by their seeds gain foothold in abandoned fields or in pastures. The roots of these species spread many feet just underneath the surface of the soil, and each year from the roots new shoots are developed. The sumac often spreads from five to ten feet per year in this way.

616. Causes of plant migration.—The plant has no choice in the matter of migration such as man has. In the vast majority of cases, and in all those where any great distance is covered, the migration of the plant is a matter of accident so far as the plant is concerned. The plants are moved from one place to another almost wholly by physical agencies, by changes in climate, or by the agency of man and other animals.

The work of man in plant migration is carried out in two different ways: by *design* and by *accident*. The history of agriculture and horticulture abounds in accounts of the search for useful plants, and their introduction and improvement. Many cultivated species have thus a much wider range and grow in far greater numbers under the protection of man than could ever have been possible had they been left entirely to natural causes. In a number of cases the plants imported for cultivation "escape" and establish themselves as "wild" plants, and thus become an element in the flora of the region. A number of plants, especially weeds, are introduced from one country to another by accident, through commerce. Weed seeds may be accidentally present with grains or other seeds of cultivated plants, or in the straw used for packing. In other cases seeds are fraudulently adulterated by designing tradesmen; so that it has become necessary for the government to establish a seed testing laboratory to examine seeds and expose these fraudulent methods.

617. Causes of plant migration initiated by plants themselves are found in: First: *Fertility of species* by which seed results. Plants which have the power to develop large numbers of fertile seeds with the best means for seed distribution not only gain distribution through the seed, but by the crowding of certain areas bring about pressures. Second. The centrifugal habit of self-propagation by runners, by layerings, or by the propagation of stems from separate roots. Third. The factor of adaptation to environment, or acclimatization. Other causes are found in *physical and climatic factors*. Some of these have already been mentioned under the head of structural characters favoring plant migration. 1st: There are certain physical factors, as wind and water, which float seeds of various plants to great distances. Then the increase of depth of water or the lowering of depth of bodies of water forces to a limited extent migration of plants along other shores. 2nd: Tensions in fruits; for example, exploding fruits.

618. Changes in climate cause migrations of plants.—Movements of plants are caused by changes in the climate which extend over long periods of time. The most noted of these influences upon plant distribution occurred in what is known as glacial times. During this epoch of the earth's history a great ice-sheet formed in Canada and British America, flowed down across the border and over a great portion of the northern United States. This great change in the climate, the intense cold for so many ages gradually extending southward, forced the plants of northern North America southward. Those which were not able to migrate in advance of the glacier perished. As the ice-sheet reached into the temperate regions it forced in advance of it the species from the temperate regions southward. Then as the glacier retreated northward the plants which were able to survive by southward migration again migrated northward. Geological evidence goes to show that there were a number of movements back and forth of the ice-sheet. This great climatic pressure, therefore, fluctuated for long periods, forcing the plants southward, then again yielding and allowing the plants to take up their former positions, when again they would be forced southward, and so on.

619. Evidences of plant migration in glacial times.—In studies of the distribution of the plants of North America, Europe and Asia, there are at present evidences of this migration of plants southward. Many arctic plants which at that time moved southward are now left on the higher mountain peaks, or in the cool sphagnum moors formed among some of the terminal moraines. With the proximity of the continents in the arctic circle there is reason to believe that in former times plants migrated readily between the continents of North America, Europe and Asia. During glacial times these were forced southward, in Europe, North America and Japan. Evidence of this is shown in the close relationship of the flora of northern Europe, North America and Japan. Many species and genera of plants found in these countries are the same. Under the present conditions of the climatology of the earth it would be impossible for the plants to communicate to such an extent as to explain the presence in these different continents of such a large number of the same species. While in the seed plants there are many similarities in the flora, and many species and genera are identical, in the lower forms, among the algæ, fungi, liverworts and mosses, there is an even greater similarity. This leads us to believe that even microscopic plants like the fungi and algæ migrated under these conditions along with the seed plants. The parasitic fungi moved along with their hosts, and saprophytic fungi, like the mushrooms, followed the movements of forest trees, growing on dying or dead trunks, upon the leaves, and leaf-mold in the forest. The aquatic fungi and the fresh-water algæ likewise moved southward with the aquatic flowering plants. The fact that so many of the fresh-water forms of the fungi and algæ, as well as of the flowering plants, are identical with many of those in northern Europe suggests that in former times the continents in the arctic circle were very near together, if not actually connected, that the climate was milder, and that there was a migration of these fresh-water plants between the continents. This might be brought about by a possible continuity of land and fresh-water areas; or through the migration of water-fowl the spores of algæ and fungi clinging to their feet could be transported across land areas or channels of salt water, when these were not too wide, and lodged in the fresh-water pools, or lakes, or streams of another near-by continent.

620. Present climatic pressures.—Other climatic pressures also existed and continue to the present time. In the humid tropics large numbers of individuals of different species are propagated, which produce a pressure northward and southward from this point, but those moving southward on the northern hemisphere come in contact with those moving northward, and here a lateral pressure is exerted which crowds the plants to the west and east. Pressures also exist in the borders of arid regions. The fertility of aggressive species wherever they occur tends to produce pressures in all directions.

II. BARRIERS TO PLANT MIGRATION.

621. There are a number of barriers which plants meet in their migration over the surface of the earth. In general terms we might speak of four when looking at the world as a whole. First. *Kinds of climate.* Regions of great heat or cold, of dryness or moisture, etc. All these regions oppose obstacles to the entrance and passage of plants which are accustomed to live in different climates. Second. *Kinds of soil.* For example, the alkaline deserts and the great salt steppes present effectual barriers to the passage of plants not provided with adaptations which would enable them to live under such extreme conditions. Third. *Discontinuity of land.* Here bodies of water present a barrier to the passage of plants from one continent to another, or from one island to another, which are separated by broad lakes or seas. A good illustration of this is shown in the relation of the continents of the southern hemisphere as compared with those of the northern hemisphere already pointed out. Fourth. *Mountain chains.* High mountain chains, because of the great cold, often form impassable barriers for plants. Good illustrations of this are shown in a comparison of the number of species of plants in Europe and North America and their distribution. Under the high climatic pressures which existed, for example, in glacial times, the plants of North America met with no barrier in their southward movement; probably a large percentage of them survived. In North America the mountain chains were parallel with the migratory movement and permitted the southward flow and return of the species. On the contrary, on the continent of Europe, during the same period, in their southward movement the plants met with an impassable barrier in the Alps and Pyrenees mountains, which extend east and west across southern Europe. Many of the species thus perished and were not left to join in the return movement in populating the continent after the disappearance of the ice-sheet. Likewise the Alps and Pyrenees presented a barrier to the northern movement of the plants of southern Europe. The Rocky Mountains afford a barrier between the flora of the Pacific Coast and the country to the east.

622. Conflict of species in migration.—This is one of the most noticeable features in plant migration. With the means for movement with which plants are provided, together with the pressures exerted, forcing them to move, they are constantly reaching out for new territory and struggling to hold that which they already occupy. The competition becomes severe because of the large number of species which are adapted to live under similar conditions. Some have compared the struggles of plants to occupy new territory, or to maintain their hold upon their own, to the competition which exists among human societies. Every plant must be able to propagate itself and to hold territory in competition not only with climatic conditions, but also with other plants entering the same region. It must either hold its territory or cede it to its more successful rivals. Thus plants which are adapted to live under the conditions of a given territory are those which survive, while the weaker ones are driven out, or exterminated, or occupy a very subordinate place in the society.

CHAPTER XXXIX.

PLANT SOCIETIES.

623. Plant societies are associations of the plants of an area, over which the conditions are similar. Every plant society has one or several dominant species, the individuals of which, because of their number and size, give it its peculiar character. The society may be so nearly pure that it appears to consist of the individuals of a single species. But even in those cases there are small and inconspicuous plants of other species which occupy spaces between the dominant ones. Usually there are several or more kinds in the same society. The larger individuals come into competition for first place in regard to ground and light. The smaller ones come into competition for the intervening spaces for shade, and so on down in the scale of size and shade tolerance. Then climbing plants (lianas) and epiphytes (lichens, algæ, mosses, ferns, tree orchids, etc.) gain access to light and support by growing on other larger and stouter members of the society.

Parasites (dodder, mistletoes, rusts, smuts, mildews, bacteria, etc.) are present, either actually or potentially, in all societies, and in their methods of obtaining food sap the life and health of their hosts. Then come the scavenger members, whose work it is to clean house, as it were, the great army of saprophytic fungi (molds, mushrooms, etc.), and bacteria, ready to lay hold on dead and dying leaves, branches, trunks, roots, etc., disintegrate them, and reduce them to humus, where other fungi change them into a form in which the larger members of the plant society can utilize them as plant food, and thus continue the cycle of matter through life, death, decay, and into life again. Mycorhizas (see paragraph 205) or other forms of mutualistic symbiosis occur, which make atmospheric nitrogen available for food, or shorten the path from humus to available food, or the humus plants feed on the humus directly. Nor should we leave out of account the myriads of nitrite and nitrate bacteria (see paragraph 200) which make certain substances in the soil available to the higher members of the society. Most plant societies are also benefited or profoundly influenced in other ways by animals, as the flower-visiting insects, birds which feed on injurious insects, the worms which mellow up the soil * and cover dead organic matter so that it may more thoroughly decay. In short, every plant society is a great collection or gathering of multitudinous forms, where processes, influences, evolutions, degenerations, and regenerations are at work.

FOREST SOCIETIES.

624. Different kinds of forests.—We know that the members of a plant community vary. Not only is there variation in different years or periods, but also in different regions. Regions which are so widely separated as to show great climatic differences show great differences in the character of plant societies. The same is true of the forest. Each different climatic belt or region has its characteristic forest. For example, the northernmost forests are chiefly firs and balsams with here and there colonies of birches and aspens. Next to these come extensive forests of the white pine in North America, and also hemlock. These forests of firs and balsams and pines extend southward on the higher mountains because it is an extension of the same climatic belt. Next to this great belt of conifers is a great belt of the hardwoods, including the oaks, hickory, beech, maples, etc. The forests of the Rocky Mountains are different from those of the Alleghanies, because of the great barrier of the plains between them which has prevented the migration of species. Tropical forests are different from those of the temperate regions. The character of these forests depends largely on climatic factors. The character of the forest varies, however, even in

---

* See Darwin, Vegetable Mould and Earth-worms.

the same climatic area, dependent on soil conditions, or success in seeding and ground-graining of the different species in competition, etc.

Fig. 404.

Mature forest of redwood (Sequoia sempervirens). Bureau of Forestry, U. S. Dept. Agr., Bull. 38.

625. General structure of the forest.—Structurally the forest possesses three subdivisions: the *floor*, the *canopy* and the *interior*. The floor is the surface soil, which holds the rootage of the trees, with its covering of leaf-mold and carpet of leaves, mosses, or other low, more or less compact vegetation. The canopy is formed by the spreading foliage of the tree-crowns, which, in a forest of an even and regular stand, meet and form a continuous mass of foliage through which some light filters down into the interior. Where the forest is uneven there are open places in the canopy which admit more light, in which case the undergrowth may be different. The interior of the forest lies between the canopy and the floor. It provides for aeration of the floor and interior occupants, and also room for the boles or tree trunks (called by foresters the *wood mass* of the forest) which support the canopy and provide the channels for communication and food exchange between the floor and canopy. The canopy manufactures the carbohydrate food and assimilates the mineral and proteid substances absorbed by the roots in the soil; and also gets rid of the surplus water needed for conveying food materials from the floor to the place where they are elaborated. It is the seat where energy is created for work; and also the place for seed production.

626. Longevity of the forest.—The forest is capable of self perpetuation, and except in case of unusual disaster or the action of man, it should live indefinitely. As the old trees die they are gradually replaced by younger ones. So while trees may come and trees may go, the forest goes on forever.

627. Age of trees.—Many trees live for several centuries. A few trees are known which have lived several thousand years. It is said there is in Kent, England, a tree of the genus Taxus, 3000 years old; also that there are now living on the slopes of Mount Etna chestnut trees from which Homer might have gathered nuts; in southern Mexico there is an old cypress tree (*Taxodium*) believed to be about 6000 years old, and in the Cape Verde Islands an *Adansonia* of similar age. Another account states that this old cypress in Mexico is about 2500 years old. It is difficult to get accurate data concerning trees of such age, but in the case of the big trees of California (*Sequoia washingtoniana*) data have been obtained by counting the annual rings of a number of trees, which shows their age to range up to 4000 years.

628. Forests do not materially increase rainfall of a region.—In a study of the climatic vegetation regions it is clear that the forest is dependent on rainfall, and below a certain minimum annual precipitation, not very definitely determined, forests will not develop, and of course the rainfall must be rather evenly distributed throughout the year, or at least through the growing season. But that the rainfall of a region is influenced by the forest to any great extent, as is often supposed, is not so evident. Long-continued droughts during the growing season which occur now and then, and the great accompanying forest fires, show the inability of the forest to produce rainfall *per se.*

629. Importance of the forest in the disposal of rainfall.—The importance of the forest in disposing of the rainfall is very great. The great accumulation of humus on the forest floor holds back the water both by absorption and by checking its flow so that it does not immediately flow quickly off the slopes into the drainage system of the valley. It percolates into the soil. Much of it is held in the humus and soil. What is not retained thus filters slowly through the soil and is doled out more gradually into the valley streams and mountain tributaries, so that the flood period is extended, and its injury lessened or entirely prevented, because the body of water moving at any one time is not dangerously high. The winter snow is shaded and in the spring melts slowly, and the spring freshets are thus lessened. The action of the leaves and humus in retarding the flow of the water prevents the washing away of the soil; the roots of trees bind the soil also and assist in holding it.

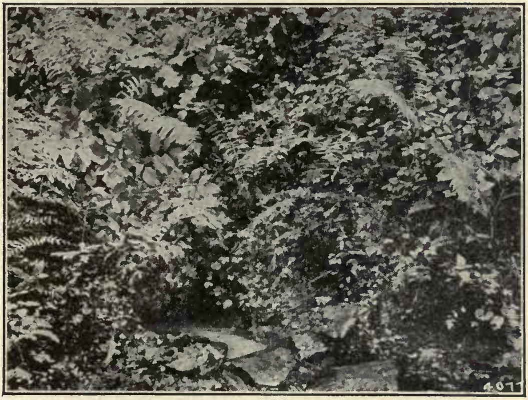


Fig. 405.

Mountain spring in forest, fed by the water held back by the abundant humus and dense undergrowth. From Bureau of Forestry.

630. Absence of forest encourages serious floods.—The great floods of the Mississippi and its tributaries are due to the rapidity with which heavy rainfall flows from the rolling prairies of the West and from the deforested areas west of the Alleghany system. The serious floods in recent years in some of the South Atlantic States are in part due to the increasing area of deforestation in the Blue Ridge and southern Alleghany system. The aggregate damage from floods along the southern Appalachian streams in the year 1901–1902, reached the sum of $18,000,000. A movement is on foot, and Congress has been urged, to establish a southern Appalachian Forest Preserve, and it is to be hoped that this will be accomplished (see Message of President Roosevelt to Congress concerning this, Washington, 1902).

Fig. 406.

Stone Mountain near Atlanta, Ga., the ax and fire having removed the forest, and the heavy rains have removed the soil which once covered the larger part of this rocky nob. From President's Message in relation to the forests, rivers, and mountains of the Appalachian region, 1902.

631. Regeneration of forests.—If the forest is to be perpetuated there must be regeneration, or in time all trees will die and the forest thus become extinct. *Natural regeneration* takes place in two ways: first, through the seed; and second, by the growth of sprouts from the stump when the tree is cut, or from the roots. These sprouts are called *coppice*. Trees which are shade-endurers are apt to have the advantage in the natural regeneration of the forest. The hemlock spruce, for example, is a shade-endurer, and thus the seedlings and young trees in the forest stand a good chance of coming to maturity. The redwood (*Sequoia sempervirens*) is a light-demander, and so natural regeneration by seed is difficult except in open places. The redwood, however, develops abundant *coppice*, and the great amount of nutriment in the roots of the large trees supplies it with an abundance of food, so that it grows rapidly, the stems often becoming quite tall, and the young trees remaining white except for a small crown of green leafage at the top. The big tree (*Sequoia washingtoniana*) regenerates by seed, and while not a great shade-endurer, enough seedlings survive to provide a succession of different ages where lumbering is not practiced.

Fig. 407.

Coppice from redwood, showing sprouts 6 to 8 years old. (From Bull. 38, Bureau of Forestry.)

Very few of the other conifers can develop effective coppice. They are dependent on the seed for natural regeneration. On the other hand, broad-leaved trees develop abundant coppice, and in this respect have the advantage over conifers, which are not shade-endurers or do not develop coppice. Broad-leaved trees are limited, however, in their competition with conifers on thin, sandy soil, and in cold regions, because many species of the latter can grow with a low sum total of heat.

632. Protection of forests.—The fact that forests have an important influence in regulating the movement and disposal of rainfall has led the National Government and several State Governments to adopt forest policies and to set apart certain forest areas as reservations, especially in mountainous districts, where lumbering is prohibited by law and efforts made to regenerate the forests where necessary and protect them from fire. The value of these forest reservations is, first, the protection of game and other wild animals; second, holding in reserve water-storage for power, as well as for city supplies; third, the protection of the valleys and lowlands from destructive floods; fourth, the providing healthful resorts where people find rest from the busy and exacting professional and business lives. When the principles of forestry are better understood by the people the reservations will probably be cropped and regenerated according to some suitable system which will not lessen their value for the purposes for which they were first set apart, and at the same time will yield the state a revenue sufficient to more than pay for the cost of management, and also will tend to keep within reasonable bounds the prices of building materials.

OTHER PLANT SOCIETIES.

633. The prairie and plains societies.—These are to be found in the grassland region. In the prairies, " meadows " are formed in the lower ground near river courses where there is greater moisture in soil. The grasses here are principally " sod-formers " which have creeping underground stems which mat together, forming a dense sod. On the higher and drier ground the "bunch" grasses, like buffalo grass, beard-grass, or broom-sedge, etc., are dominant, and in the drier regions as one approaches desert conditions the vegetation gradually takes on more the character of the desert, so that in the plains, sage-brush, the prickly-pear cactus, etc., occur. Besides the dominant vegetation of the society there are subordinate species, and the societies are especially marked by a spring and autumn flora of conspicuous flowering plants which are mixed with the grasses.

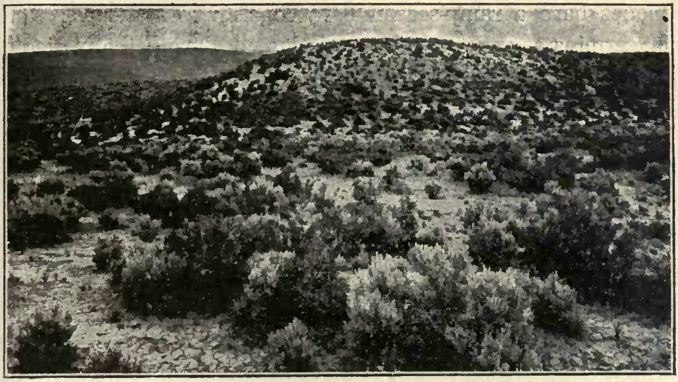


Fig. 408.

Winter range in northwestern Nevada, showing open formations; white sage (Eurotia lanata) in foreground, salt-bush (Atriplex confertifolia) and bud-sage (Artemisia spinescens) at base of hill, red sage (Kochia americana) on the higher slope. (After Griffiths, Bull. 38, Bureau Plant Ind., U. S. Dept. Agr.)

634. Desert societies.—These are composed of plants which possess a form or structure enabling them to exist in a very dry climate where the air is very dry and the soil contains but little moisture. The true desert plants are perennial. The growth and flowering period occurs during the rainy season, or those portions of the rainy season when the temperature is favorable, and the plants rest during the very dry season and cold. Characteristic desert plants are the cacti with thick succulent green stems or massive trunks, the leaves being absent or reduced to mere spines which no longer function in photosynthesis; yuccas with thick, narrow and long leaves with a firm and thick cuticle; small shrubs or herbs with compact rounded habit and small thick gray leaves. All of these structures conserve moisture. The mesquite tree is one of the common trees in portions of the Sonora Nevada desert. Besides the true desert plants, desert societies have a rainy-season flora consisting of annuals, which can germinate, vegetate, flower and seed during the period of rain and before the ground moisture has largely disappeared, and then pass the resting period in seed.

635. Conditions with which desert plants contend.—The conditions of the desert are very austere, so that plant life comes in sharp competition with the climate. The principal factors are:

First, the very low rainfall, varying from 8 to 10 inches; in some deserts, to 4 inches, or even less than 1 inch in some areas.

Second, the great amount of evaporation during the long, dry, hot season.

Some of the minor factors which might be mentioned are as follows:

First, the strong light (solar radiation), especially during the warm season. This is due to the absence of clouds which form a blanket over the earth, not only cutting off direct solar radiation during the day, but which also check radiation of moisture from the soil both during the day and night.

Second, high winds, which often sweep over desert areas, increasing the drying effect of the air on vegetation.

Third, the physical or chemical character of the soil often is such as to enforce a xerophytic habit for vegetation even if rainfall were greater; for example, salty or alkaline condition of the soil, calcareous soils in some desert or semidesert areas, the loose and crumbling condition of soil in some regions which permits the rapid filtering away of storm- and ground-water; the topography of the region also, when very rolling or hilly, permits rapid run-off of storm-water.

636. How desert plants meet these conditions.—This they do by provision for: First, reduction of transpiration; second, provision for water-storage; and third, increased surface for root-absorption.

1. *Reduction of transpiration.*—This is brought about in several ways: first, by reduction in size so that the leaves are smaller and thicker; second, by hairy coverings; third, the stomates are sunk deeply in the surface; fourth, the cuticle is thickened; fifth, the leaves are entirely dispensed with and the stems are green and function as leaves; sixth, the stems are shorter, with a thick cuticle and often hairy or waxy coverings.

2. *Provisions for water-storage.*—This is provided for by thick and often fleshy leaves, by fleshy stems as in the cacti, and often by a thick root system. Some of the cacti have large, rounded, globose stems. Some other plants have large, swollen bases to their stems, and in others the roots are also much enlarged. These types with enlarged roots are rather rare in the Sonora Nevada desert in the southwestern part of the United States, but are more common in southwestern Africa and in western South America.

3. *Increased surface for root-absorption.*—This is provided for by the great length of the root system and the profuse branching. In many desert plants the roots extend to great depths in the soil, where they obtain ground-water which is not so available nearer the surface.

637. Arctic-alpine societies.—The most striking of the arctic plant societies are the "polar tundra," extensive mats of vegetation largely made up of mosses, lichens, etc., only partially decayed because of the great cold of the subsoil, and perhaps also because of humus acid in the partially decayed vegetation. These tundras are brightened by numerous flowering plants which are characterized by short stems, a rosette of leaves near the ground, and by large bright-colored flowers. Heaths, saxifrages, and dwarf willows abound. Alpine-plant societies are similar to the arctic, although some of the conditions are more severe than in the arctic region. This is principally due to the fact that during the summer while the plants are growing they are subject to a high temperature during the day and a very low temperature at night, whereas during the summer in arctic regions while the plants are growing there is continuous warmth for growth and continuous light for photosynthesis. Five types of alpine plants are recognized by some. First. *Elfin tree.* This type has short, gnarled, often horizontal stems, as seen in pines, birches, and other trees growing in alpine heights. Second. *The alpine shrubs.* In the highest alpine belts they are dwarfed and creeping, richly branched and spreading close to the ground, while at lower belts they are more like lowland shrubs. Third. *The cushion type.* The branching is very profuse and the branches are short and touch each other on all sides, forming compact masses (examples: saxifrages, androsace, mosses, etc.). Fourth. *Rosette plants.* These are perennial, with short stems and very strong roots, and play an important part in the alpine meadows. Fifth. *Alpine grasses.* These usually have much shorter leaves than grasses of the lowlands and consequently form a low sward.

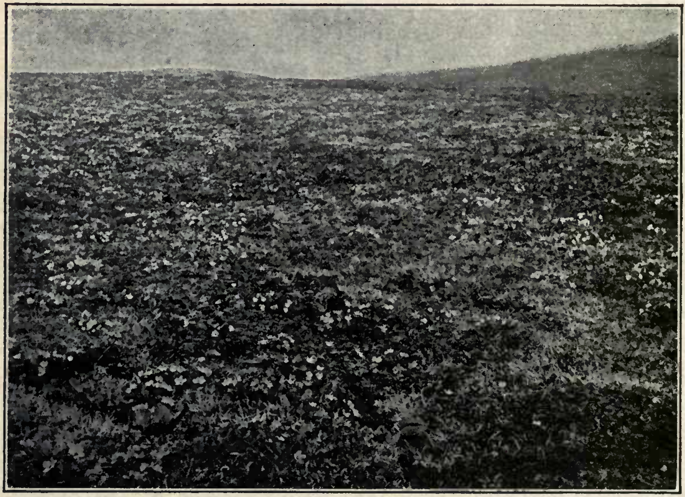


Fig. 409.
Polar tundra with scattered flowers, Alaska. (Copyright by E. H. Harriman.)

638. Edaphic plant societies.—These are societies the plants of which are chiefly controlled by the peculiar conditions of the soil. There are a number of different kinds of edaphic plant societies determined by the character of the physiographic areas. First. *Sphagnum moors.* These are formed in shallow basins originally with more or less water. The growth of the sphagnum moss along with other vegetation and its partial decay in the water builds up ground rapidly so that in course of time the pond may be completely filled in. This filling in proceeds from the shore toward the center, and in the early stages of course there would be a pond in the center. The partial decay of vegetation creates an excess of humus acid which retards absorption by the roots. The conditions are such, then, as require aerial structures for retarding the loss of water, and plants growing in such moors are usually xerophytes. Some of the plants are identical with those growing in the arctic tundra. Second. *Sand strand or beach.** The quantity of sand with very little or no admixture of humus or plant food makes it difficult for plants to obtain a sufficient amount of water even where rainfall is abundant. The same may be said of the sand dunes farther back from the shore. The plants of these areas are then usually

Fig. 410.

Perennial rosette plant from alpine flora of the Andes, showing short stem, rosette of leaves, and large flower. (After Schimper.)

---

* See Chapter LIV of the author's College Text-book of Botany.

xerophytes. Some of the plants accustomed to growing in such localities are American sea-rocket, seaside spurge, bug-seed, sea-blite, sea-purslane, the sand-cherry, dwarf willow, marram-grass, certain species of beard-grass, etc. Third. *Rocky shores or areas.* Here lichens and mosses first grow, later to be followed by herbs, grasses, shrubs and trees, as decayed plant-remains accumulate in the rock crevices. Fourth. *Shores of ponds, or swamp moors.* Here the vegetation often takes on a zonal arrangement (zonation) if the ground gradually slopes to the shore and out into the pond. In fig. 412 is shown zonal distribution of plants. The different kinds of plants are drawn into these zones by the varying amount of ground-water in the soil, or the varying depth of the water on the margin of the pond as one proceeds from the land towards the deeper water. On the border lines or tension lines between the different zones, the plants are struggling to occupy here ground which is suitable for each adjacent individual formation. Other edaphic societies are those of marl ponds, alkaline areas, oases in deserts, warm oases

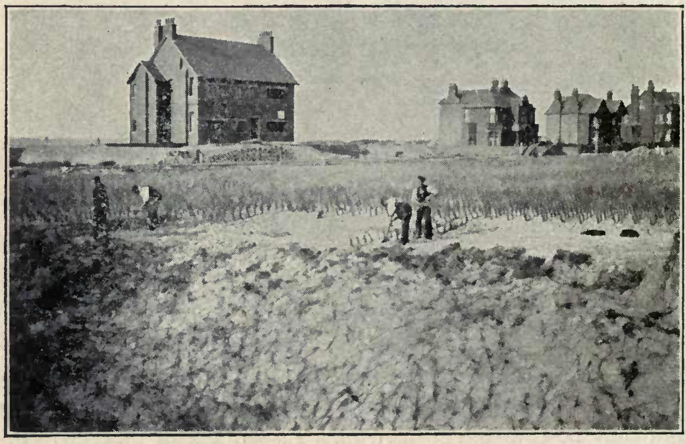


Fig. 411.

Planting grasses on wind-swept sandy coasts to prevent movement of dunes into the city, Southport, England. (Photograph by the author.)

Fig. 412.
Zonal distribution of plants, south shore of Cayuga Lake. See text. (Photograph by the author.)

in arctic lands, the forested areas along river bottoms in prairie or plains regions, etc.

639. Aquatic plant societies. — In general we might distinguish three kinds. First. *Fresh-water plant societies*, with floating algæ like spirogyra, œdogonium, etc., the floating duckmeats, riccias; the plants of the lily type with roots and stems attached to the bottom and leaves floating on the surface, like the water-lily and certain pondweeds, and finally the completely submerged ones like certain pondweeds, the bassweed (*Chara*), etc. Second. *Marine plant societies*, which are made up mostly of the red and brown algæ or "seaweeds," though some green algæ and flowering plants also occur. Third. The *salt marshes* where the water is brackish and there is usually a luxuriant growth of marsh-grasses. (See Chapter LV of the author's College Text-book of Botany.)

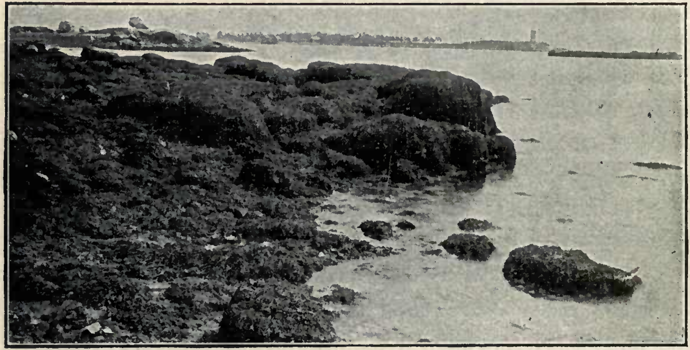


Fig. 413.

Macrophytes in the upper zone of the photic region. Ascophyllum and Fucus at low tide, Hunter's Island, New York City. (Photograph by M. A. Howe.)

CHAPTER XL.

SOME PRINCIPLES OF PLANT EVOLUTION.

640. Evolution means development and progress according to natural laws.—It is growth and progress from very simple conditions or things, to a more or less high, complex and perfect condition,* by more or less gradual changes which take place in a natural way. Looking at the whole period of development we can see different steps in the progress which has taken place.

641. If we look at the progress made by man from the savage state up to the present high state of civilization, we can see that there has been a gradual change, a progression in his relations to his neighbors, in the relations and dealings of communities, tribes and nations with each other. In the various arts, trades, and manufactures there were very crude beginnings, with gradual change and progressive improvements to the present time, as shown by the many inventions and the high state of efficiency in the trades and manufactures at the present time. All this has come about by evolution. It is evolution of social man, of communities, of tribes, of nations; evolution of trade, evolution of arts and manufactures. It would have been impossible for savage man or for the early civilized men to invent and build at once the many highly useful and efficient appliances, the means for transportation and communication, etc., which exist to-day. Very crude utensils, appliances and build-

To the Teacher. This chapter is intended chiefly for reading and reference. It can serve as the basis for informal talks by the teacher, or portions can be assigned for reading at his discretion. There should not be any attempt to commit it to memory. The teacher can select such portions as he wishes for special assignment.

---

* There are also evolutions downwards, degeneration or retrogression.

ings were first invented by early man. These formed the basis for improvement and further invention, so that there has been a gradual and natural growth up to the present highly efficient state of things. This is evolution, i.e., it is the evolution of man and his work from the savage state to the present time. History teaches us this. But in parts of the earth man still exists in the savage state. So there are half-civilized tribes where crude and very inefficient appliances are still used. So among the civilized nations there are shown various degrees of progress toward the condition which has been reached in the most highly civilized nations. The present savages, semi-civilized tribes and less civilized nations have lagged behind in this evolution. Some made little progress, while others progressed for a time and then stood still. Thus we have, in different parts of the world at the present time, living examples, which represent some of the steps in this evolution of man from the savage state.

642. Evolution of an individual.—In the development of an individual it begins as a single cell. By growth and differentiation of its parts it finally reaches maturity, completing its life cycle, when single cells are formed which start another life cycle. As an example let us take the fern plant. The asexual spore from the spore case on the fern plant germinates and produces a short thread, the *protonema*, or first thread, which resembles some of the thread-like green algæ. The end of this thread soon begins to expand by growth and cell division. It now forms a thin, flattened mass of cells, somewhat heart-shaped in form, the *prothallium*. This resembles certain thin membranous cell masses, or cell plates in the green algæ, or the thallus of the liverworts. The sexual organs are next formed, and then the egg is fertilized. The fertilized egg now divides, and in its early stages recalls the very young embryo of the liverworts, but it soon departs widely from the course of development shown by the liverworts and mosses. Stem, roots and leaves are developed. The prothallium which lived an independent existence dies, and the fern plant becomes an independent plant able to carry on its nutrition and growth of mass, finally producing spores again which complete its entire life cycle. This is evolution of the individual.* There is change and progression, in a natural way, i.e., according to natural laws.

643. There are, however, different steps in the individual evolution of the fern, some of which are quite clearly marked, so that we can recognize them. We can also recognize that they have a resemblance to lower forms of plant life. The asexual spore recalls the single-celled plants, the protonema recalls the thread-like algæ, and the prothallium recalls green tissue plates or membranous masses of cells. So it is with sexual organs and the very early stages of the embryo. We see then that there are plants living to-day which in their mature condition represent or picture, as it were, some of the different stages in the individual evolution of the fern plant. Some of them have made little progress or change from very simple one-celled plants. Others progressed for a time and then stood still, or only further differentiation took place. They have lagged behind, and thus never reached the high state of development shown in the fern plant. The seed plants show a still further progress and a higher state of development.

644. The evolution, or life history, of the individuals in the different groups of plants, if read aright, teaches us that the higher groups have been built on the experience in the evolutions or life histories of some of the lower groups. There has been change and progression according to natural laws from the low unicellular plants, upward, resulting in the seed plants, the dominant vegetation on the earth at the present time. This is the evolution † of higher groups from the lower groups along lines which often can be traced, as regards the more general features. So it is with the animal kingdom; the higher forms have been developed from the lower forms, as a study of the life histories or evolu-

---

* Usually called *Ontogenetic* evolution (ὤν, ὄντος = being; γένεσις = generation or development).

† The tracing of lines of evolution from lower groups to higher groups is called *Phylogeny*.

tions * of the individuals have taught us, together with the study of fossil forms of animals and plants in the successive geologic strata of the earth, as well as the method of distribution of plants and animals over the earth's surface. In everything where change and progress takes place, evolution is manifest.

645. The influence of Darwin in establishing the theory of evolution.—To Charles Darwin, probably more than to any other one man, we owe the evidence which has led to the general belief in the theory of evolution as against the theory of the special creation of species. This theory has been accepted, because it appeals to the mind of man as being more reasonable that species should be created according to natural laws rather than by an arbitrary and special creation.

Charles Darwin was born in Shrewsbury, England, Feb. 12, 1809, and died in 1882. At an early age he showed an interest in natural science, at the age of eight years becoming interested in insects. In his sixteenth year his father sent him to college to study medicine, but becoming satisfied that his bent was in other directions, in 1828, sent him to Cambridge University with the idea of his eventually becoming a clergyman. His interest in natural history, making collections and studies, was continued. By the encouragement and advice of some of his science friends in the faculty, and others, he was led to devote more attention to the subjects of geology and natural history. As a result of this, at the age of twenty-two, he was recommended to the captain of the ship *Beadle*, who wanted a young naturalist to accompany him on a scientific exploration in different parts of the southern hemisphere. This was the real beginning of his life work. His collections and observations on this voyage led him to serious reflection on the origin of species.

From this time on his whole life was devoted to careful observation and study of the habits of plants and animals, their vari-

---

* The evolution of man from lower animals does not mean that man was developed from the monkey, but that man was developed from some being in the remote past which was probably also the remote ancestor of the anthropoid apes.

ation under different conditions, as well as the causes of these variations, and the natural methods by which certain ones survived while others perished. To him we owe the elaboration of the theory of "Natural Selection" as one of the important natural laws in the origin and differentiation of species, though several men half a century before had expressed their belief in the natural origin of species.

Darwin's most important work was the "Origin of Species," first published in 1859. This work was the result of twenty years of careful study and observation on the variations of plants and animals, both wild and domesticated, and the causes which led to improvement under the control of man, as well as in a state of nature. His great work here consisted in the vast amount of evidence which he presented in favor of the natural origin of species, that species vary, and where these variations are beneficial, natural selection preserves the forms which possess them while it destroys the others.

646. Mendelism, or mendelian hybrids.—Gregor Mendel, born in Brün, Austria, in 1822, discovered the law governing this kind of hybrids. He was a monk, and afterward became the Abbot of Brün. He discovered this law during his experiments on plant hybridization, and published an account of this in the Natural History paper of his town. This work did not become widely known at the time, and the paper was only recently rediscovered and published, so that it became accessible to all workers in plant breeding.* It was a very interesting discovery as well as being of great importance to the plant breeder. Mendel worked chiefly with peas. Two examples will be given here to serve as illustrations of the principle.

He selected two varieties of peas which differed in one being tall and the other a dwarf. These were cross pollinated. The seed from the cross was sown the following year, and all the progeny resembled the tall parent, i.e., all of the first generation of hybrids were talls, and no sign of the dwarf character could

---

* See Bateson, Mendel's Principles of Heredity; also Punnet, R. C., Mendelism.

be seen. But in the second generation of hybrids (from seed of the first) talls and dwarfs were both present, and in the proportion of twelve talls to four dwarfs.* The talls of the first hybrid generation, then, contained the dwarf character as well as the tall character, but the tall is the dominant character and prevented the dwarf from expressing itself. The dwarf character was latent.

On planting seeds of this second hybrid generation, dwarfs and talls being kept separate, the dwarfs were shown to be pure dwarfs, and in all the succeeding generations produced nothing but dwarfs. This showed that out of every sixteen of the second generation, four dwarfs were "extracted." The dwarf character is the *recessive* character. A study of the talls of the second hybrid generation showed also that for every sixteen of the second generation there were four talls extracted, which thereafter always produced talls. The other eight talls of the second generation had both the tall and dwarf character, but in the third generation split up so that for every sixteen there were twelve talls and four dwarfs, and so on. This can be shown by the following diagram.

	1st Hybrid Generation	2nd Hybrid Generation	3rd Hybrid Generation	4th Hybrid Generation
		25% pure talls	= 100% pure talls	= 100% pure talls
			25% pure talls	= 100% pure talls
Tall plant				25% pure talls
	100% mixed talls	50% mixed talls	50% mixed talls	50% mixed talls
Dwarf plant				25% pure dwarfs
			25% pure dwarfs	= 100% pure dwarfs
		25% pure dwarfs	= 100% pure dwarfs	= 100% pure dwarfs

---

* They do not always come out in such exact mathematical proportions, but when the number of plants grown is large, the proportion is very close to this.

Characters which behave in this way are called *unit* characters. Mendel studied the relation of other unit characters of the pea, and found that smooth seeds are dominant to wrinkled seeds, colored are dominant to white, yellow color dominant to green, etc. Where two unit characters in each parent are contrasted the result is still more interesting because it results in the production of two new forms. For example, he crossed tall yellow peas with dwarf green peas. The result was that in the first hybrid generation all were tall yellows. But in the second hybrid generation they split up with the following result. For every sixteen plants there were nine tall yellows, three *dwarf yellows*, three *tall greens*, and one dwarf green. It will be seen that the dwarf yellows and tall greens are new forms, and successive generations show that these can be extracted and grown as pure forms. This is a very important discovery for it enables the plant breeder, after he has determined by experiment what the unit characters of his plants are, to combine certain desirable characters in a single form (paragraph 663).

647. Mutation.—Mutation is the term applied to those sudden variations, not due to cross fertilization, in which the new form is so unlike its parent that it is regarded as a new species, often termed an elementary species. The new forms arising in this way by a leap or bound as it were are called *mutants*. The phenomenon is sometimes spoken of as *discontinuous variation* in contrast with fluctuating variation. Mutations were first thoroughly studied by De Vries in one of the evening primroses (*Œnothera lamarckiana*), which may be taken to illustrate this type of variation. This is a large flowering evening primrose. It is supposed to have been native to North America since specimens occur in several herbaria collected in some of the southern states. It was introduced into Europe where it is grown in gardens, and as an escaped plant it also grows wild there in a number of places. De Vries observed it growing wild near Amsterdam in Holland. Growing with Lamarck's evening primrose (*Œnothera lamarckiana*) were several other primroses which could be recognized as different because of the form of the rosettes. These were different from any known species of evening primrose. One form (*O. lævifolia*) with smooth leaves was found growing in a group a little distance from the main body of *O. lamarckiana*, where it was reproducing itself. The different forms found growing wild were transplanted to the garden. Seeds from *O. lamarckiana* were sown in the garden in large numbers. Some of these seeds developed forms exactly like those new ones found in the field. After several years of study and experimentation several distinct mutants of *O. lamarckiana* were obtained in pure culture in the garden, which were new forms or elementary species as they are called.

Fig. 414.

Large plant, Lamarck's primrose (Œnothera lamarckiana); small plant at the right, dwarf primrose (Œnothera nanella), a mutant from Lamarck's primrose. (After MacDougall.)

When close pollinated these forms bred true, except that some of them threw off mutants also; the forms thrown off by the primary mutants, however, were not new forms. Some of them were the original parent, while others were one or more of the sister species. This suggests that the parent form possesses more characters than it can give expression to in one individual. Some of them are "hidden" or latent, and when some of these latent ones express themselves they do so at the expense of others which in turn become latent or hidden.

CHAPTER XLI.

SOME PRINCIPLES OF PLANT BREEDING.

648. Object of plant breeding.—Plant breeding has for its object the improvement of cultivated varieties of plants, the selection and improvement of promising wild plants, and the production of new and better varieties. Its success is dependent to some extent on a knowledge of the laws and factors of evolution, as well as on an intelligent analysis and handling of the materials. The factors are the same as those operating in nature on wild plants, but in many points artificial methods are introduced to replace the natural methods operating in the world at large. In this way progress is more rapid because favorable conditions can be provided, a better food supply can be furnished, competition can be removed, variation can be amplified, and an intelligent selection can fix upon those characters of greatest value for the purpose in view, and quickly eliminate the undesirable forms. Two principal lines of plant breeding might be mentioned here.

First, the improvement of existing species or varieties in one or several directions, in order to obtain the highest percentage in content of certain desirable substances, as starch content, sugar content, oil content, protein content, etc. This results in the production of what are called *races*. Such races can only be maintained by continued selection in breeding, otherwise they rapidly deteriorate.

Second, the production of entirely new forms of plants, in the nature of varieties, subvarieties, subspecies, or physiological species, forms which are different from the parent by the possession of certain characters not shown by the parent.

I. THE IMPROVEMENT OF EXISTING VARIETIES.

649. Cultivated races of plants.—Until recent years plant breeders have given their attention chiefly to the production of varieties which differed from each other in regard to form, color, productivity, etc. In recent years increasing attention has been given to improving existing varieties in the direction of increasing the percentage of certain constituent substances in the commercial plant product. For example, increase in the percentage of sugar in the sugar beet and sugar cane; increase in the percentage of protein in corn and wheat, of oil in corn, etc. Since these cannot well be distinguished as varieties, there is a tendency to apply the term *race* to highly developed and selected variations of this kind. There are great variations in the percentages of these constituent substances in plant products. By selecting the seed (or cuttings, grafts, etc., from those propagated by asexual methods) from individuals of a good variety which yield the highest percentage in the desired constituent (of course having regard to the proper physical conformation of the plant), planting this and selecting again from the individuals among the offspring of the selected ones, and repeating this for several years, a high standard of excellence can be attained. With these races the process of selection and good cultivation must continue year after year, otherwise deterioration results. The percentage of the desired constituent is determined either by chemical or physical analysis.

Seed corn (Indian corn or maize) can be selected by a physical analysis. The proportion of starch in the grain is inverse to the proportion of gluten or the size of the embryo. A section of the grain (paragraph 11 and fig. 14) will show to the eye the proportion of these constituents to each other. When the white starchy portion in the center is limited, the hard outer gluten-bearing portion will be greater. If one is selecting for protein content, grains are chosen which have a small starch content, since the horny layer containing gluten (a protein substance) and the embryo (containing protein) are both inverse in bulk to that of the starch. Corn, therefore, can be selected so as to develop two races, one for protein and oil, and one for starch. In Illinois, where a great deal of attention is given to breeding corn, the oil content has been raised from between 4–5 per cent to 7 per cent, and in other races has been reduced to 2 per cent. The grains of corn on a single ear all have nearly the same percentage of a given constituent. A few kernels then can be examined on different ears, and from the ear giving the highest percentage of the desired constituent the remaining kernels can be planted. The product from this seed can be subjected to a similar selection, and so on each year until the high standard of excellence or the desired hereditary percentage is reached. The kernels from each ear are sown in separate rows or patches so that the crop from the different ears can be compared. Thereafter the process must be continued for the purpose of growing seed in order to keep the race up to the high standard. This is true in all selection as has been pointed out above. At this point seedsmen can continue the selection and furnish seed to the growers, or the grower can each year raise his own seed.

A race of corn with high starch content is better for feeding hogs, since a firmer and better quality of bacon is produced than from corn with a high oil content. Glucose is manufactured from the starch, but manufacturers of glucose from corn prefer a corn having a high percentage of protein and oil, since in the process of separating the starch from the kernels, the by-products, protein and oil (from the horny layer and embryo) are cheaply obtained and sold for a good price. Therefore they would be glad to pay a higher price for a race of corn containing a high percentage of oil and protein even though the percentage of starch were reduced. A company which manufactures glucose could afford to pay five cents more per bushel for corn containing one pound more of oil. For the 50,000,000 bushels which this company use annually this would mean $2,500,000 more than for the same amount of a common race of corn.

650. In connection with breeding for these constituents corn should be bred for physical perfection, which includes length and circumference of ear, shape of ear and cob, number of kernels in a row and number of rows, size and shape of kernels, weight and color of grain and cob. White corn meal is preferred by some for domestic use and is almost exclusively used in the south; some in the north and northwest prefer the yellow meal. This preference in some cases is probably due to custom. Attention should also be given to developing in harmony with this an all round good plant, and to yield per acre. In every field of common corn there are stalks which do not bear ripe ears, i.e., are "barren." These often produce more pollen than fertile plants and exercise a great influence in pollinating the fertile ears. In selection all such stalks should be removed before the pollen matures in order that this character may not be carried over into the seed. Races are bred which produce a single large ear on a stalk. These are more valuable when corn is husked by hand. When it is husked by machinery to feed to cattle, races with several small ears to each stalk are preferred. Races and varieties are also bred which are more suitable to soil or climatic conditions, and varieties have been developed which range from the tropics to the Lake Superior region.

651. In Minnesota wheats have been bred to increase the number of bushels per acre, the famous "Minnesota No. 169" producing three to five bushels more per acre than the ordinary wheats. When grown largely over the state it showed an average yield of 18 per cent over the common wheats. The gradual development of these improved races of different cultivated plants and their general cultivation in place of the common sorts will add many millions of dollars to the value of our crops with no additional cost in the production.

II. THE PRODUCTION OF NEW VARIETIES.

652. Variation increased by cultivation, by better food supply and by crossing.—It is well known that cultivation and an increased food supply make plants more variable than they are in the wild state. The plant breeder seizes upon this and then selects the most promising forms. By crossing different varieties with the promising ones, or by crossing closely related species the offspring is made more variable, which gives a wider range to select from and makes possible, by this wider range of variation, forms which are more productive and of better quality and of a hardier nature. The crossing is brought about by artificial pollination since the parents can be selected for definite purposes, one parent possessing one desirable quality and the other parent another desirable quality, with the result that these two qualities can often be combined. This improved form can then be crossed with another possessing another desirable quality. The hybrid or " cross " is often crossed again with one of its parents, which often induces greater variability and also often gives greater fertility. This furnishes a greater number of variations to select from.

653. Artificial pollination.—The artificial pollination is accomplished in the following way. Before the flower is open the stamens are removed from one parent, and if the stigma of the pistil is not ready for the reception of the pollen the flowers are covered with paper bags to exclude insects which might introduce pollen from an undesirable parent. One must be sure that the stamens are removed before they begin shedding their pollen. The pollen is sometimes shed before the flower is open. A little examination of a few flowers will show when the operation of *emasculation*, as the removal of the stamens is called, should be performed. Some open the flower and with forceps or a hook pull off the stamens, but a better method practiced by some is to cut away the calyx, corolla and stamens near the receptacle with a small pair of scissors. The emasculated flower is then covered with a paper bag which is gathered and tied closely to the branch at the neck in order to shut out insects, until the stigma reaches the receptive stage, or until the pollen is ready. When the pollen is ripe it is gathered in a small receptacle. If one wishes to be very careful to have the pollen free from that of other individuals or variety, as is necessary in careful experimental work, the male flower should be covered with a paper bag before it opens. The pollen is applied in various ways according to the necessities of the case. In large operations it is often applied by the fingers. In other cases with a camel's-hair brush, but this is objectionable in smaller operations and where one is pollinating several different varieties, for there is danger of pollen adhering to the brush when the next variety is taken up. Some use a pointed scalpel made by inserting the head of a pin in a small stick and pounding the pointed end into a thin blade. After the pollen is applied to the stigma the flower is again covered with the paper bag, until the receptive stage of the stigma is passed. In some cases bags of gauze are used which exclude the insects, and in case the fruit or seed is large enough it is caught and saved, in case, at maturity, the fruit or seed should fall before being harvested by hand. In some cases thousands of these seeds are obtained and planted in order to have as wide a range of variation as possible to select from.

654. Selection in plant breeding.—Artificial selection, that is selection by man, here merely replaces natural selection. Plant breeding by artificial selection has long been practiced by man, so long that we do not even know the origin of some of our most important domesticated plants to say nothing of the early history of their development and improvement. The practice began with man in his savage state. It is only during recent years that civilized man has kept any record of the origin of new forms, and many of these have so far departed from any feral species at present known that we cannot now trace the history, nor in some cases determine what species might have been the parent of the form now in cultivation. The origin of some is known while that of others is a matter of conjecture. The origin of many of the more recent introductions is comparatively well known, and the pedigree of some has been quite accurately kept. As soon as savage man began to apply the principle of selection and cultivation even on a crude scale, the fruits, grains and vegetables which formerly he collected from feral plants became more productive, larger and of better quality. Experience and a growing insight into the laws of evolution brought vastly improved methods, until now wonderful results are obtained. The science of plant breeding is still much of it in an experimental stage, but in some directions definite ends can be planned and worked for with more or less certainty of success, though in a majority of cases the length of time needed to attain the desired result and the degree of success remains, and will probably always remain, an unknown quantity. Studies of experimental evolution will make the way more and more clear in the future, just as the increased knowledge of the laws of variation, adaptation, heredity, etc., gives plant breeders to-day greater success than was ever attained before.

655. Severity in selection.—From the many thousands a few, the most promising, are selected. This weeding-out process of the undesirable forms, or "rogues" as they are termed, is often called "rogueing." The thousands of plants which some plant breeders discard, in order to select only the very few of the highest quality, sometimes seems like ruthless destruction, but it is this rigorous system of selection which brings the highest success. One might paraphrase the old adage of "spare the rod and spoil the child" by saying, "*spare the rogue and spoil the breed.*" The flowers from the offspring of these selected hybrids are protected from cross pollination, and seeds are again planted until the desired quality in fruit (color, flavor, size, period of maturity, shipping quality, vigor, hardiness, etc.) is obtained. In the case of plants which require several years of growth from the seed before fruit and seed is obtained (as in the case of apples, pears, peaches, plums, etc.), the time of the experiment can be shortened by grafting the seedling shoot on a mature stock. If the fruit is not satisfactory in all respects the process must be continued. When the desired results are obtained it is then necessary to fix the variety. When the variety can only be propagated by seed this must be done by continued selection. Some varieties will remain quite constant from the seed from the first, and it is then only necessary to continue good cultivation and selection of seed from the most productive plants which have the other desirable qualities. The cereals for example must be propagated from the seed.

656. Selection and fixing of varieties for special purposes.—Varieties are selected and propagated for various purposes, as for color of flour, high percentage of gluten, or oil, or starch, etc. Sugar beets are selected for productivity and high percentage of sugar. It is noteworthy that in all cases when a variety has been bred to a high state of excellence, continued selection of seed from the best must be followed up continuously, otherwise the variety will deteriorate, since even with the best and most highly bred varieties variation continues. The variety is not fixed by selection so that it cannot change. By selection man can intensify the desired character and increase the frequency with which it occurs. He can do no more. If selection were not continued, the varieties would gradually deteriorate since in the case of those where cross pollination took place the variety would gradually sink to the level of the average. This average would give varieties still lower than the lowest of the highly bred variety which would tend to a still lower average level. The same result would also finally be reached in the case of those varieties which were self-pollinated if selection were not continued. Selection should also be made in the light of *correlated variation.* For example, the selection of the largest ears of corn which could be found in a field would not necessarily give the best results. The largest ears borne on the best stalks, and in some cases on stalks where there is more than one ear, give better results; also ears with the highest percentage of grain in proportion to cob. But recent experiments show that the best method is selection from an area which gives the highest yield per acre. In the case of plants which can be propagated asexually, variation in the desired variety can be lessened and the character more permanently fixed by asexual methods of propagation,* as by grafting in the case of apples, pears, etc., by

---

* This is sometimes called *asexual multiplication of extremes.* When a variety from which it is desired to select has reached a high state of fluctuating variation, it is the extremes of variation which are selected, and usually

budding as in the peach, by layering as in the case of raspberries and blackberries, by offsets as in the case of strawberries, etc., or by root stocks, tubers, bulbs, etc., in the case of many other plants.

657. Difficulty sometimes encountered in fixing desirable varieties.—It sometimes happens as a result of crossing that the resulting hybrids and their progeny are so variable and continue to be so that no desirable type or variety can be fixed. It runs out or changes in each succeeding generation. This is especially the case in certain crosses of squashes, as Bailey has shown. In a cross between a summer yellow crook-neck and a white bush scallop, a squash of great excellence was obtained which combined the merits of summer and winter squashes, attractive in form, habit, size and color. It was a most promising type. The seeds of the finest squash in this plant were saved and planted. Only two or three plants from this seed were almost like the parent, the rest being very different, altogether there being one hundred and ten different kinds " distinct enough to be named and recognized." The flowers of one of these plants were infertile to their own pollen, and as the plants were slightly different, cross pollination was resorted to. A few fruits were developed and the seeds of these were planted the following year. " Not one seed produced a squash like the parent."

658. Objects in developing new varieties.—There are many useful ends toward which the plant breeder works. Some of these have already been mentioned as greater productivity, increase of the desired product as percentage of flour, gluten, oil, starch, etc.; in fruits, improvement of flavor, color, texture, varieties for home consumption, for keeping or shipping qualities, etc.; in fibers, length, strength, fineness or coarseness. So there is the development of varieties suited to different climates.

the best extreme, since that possesses the highest standard of the desired quality. Sometimes, however, there may be an undesirable quality which must be gotten rid of or decreased. Selection proceeds then to develop a high standard of extremes in desirable qualities and a low standard of extremes in the undesirable qualities if they cannot be entirely gotten rid of.

Indian corn is a good example of this. Originally a subtropical plant it is now cultivated over a wide range of the north temperate zone, with varieties of low stature which mature in six to eight weeks in the northern latitudes. A very important object in plant breeding, and one which should not be overlooked, is the harmonious development of all parts, the general form and constitution of the plant, in order that these auxiliary characters which contribute to the well being of the plant as a whole, which bring the greatest returns in proportion to the cost of production, as ease of cultivation and handling, conformity to soil and climatic conditions, resistance to disease, etc., may be present. Breeding for varieties which are resistant to disease is one of the most recent efforts of the plant breeder. Its success is based on the same natural laws which make possible the improvement of varieties in many other directions, viz., variation and selection. Plants vary in their disease-resisting qualities just as animals do. It is rare that one finds all of the plants in a given locality equally subject to a fungus disease. The resistant individuals are selected to propagate from, either by seed or by asexual means according to the case in hand. This process of selection is continued for several years, weeding out those which are susceptible to attack until resistant varieties are obtained. Some success has already been obtained in this direction in the case of rust-resisting varieties of wheat, and in varieties of cotton, clover, etc., which are resistant to certain of the diseases common to them. It is not to be expected that complete resistance to disease in plants will be attained by plant breeding of disease-resistant varieties, because variation cannot be eliminated. Some individuals will be more susceptible than others and will now and then become diseased, the percentage varying with the variations in external and cultural conditions as well as with the persistence and intelligence with which the selection is continued. Disease-resistant varieties, like other varieties, depend on continued selection for the maintenance of a high standard of excellence.

659. " Breaking the type " in plant breeding.—When the plant breeder undertakes to improve a variety, or develop new ones, if it does not already present great variation among the individuals it is necessary to bring it into a variable state. The plant may vary only with reference to percentages of a desirable quality of product. In this case continued selection would only maintain a high degree of excellence in this respect. It may be desirable to develop a different variety which may possess this same quality in a higher state of excellence or to work for new qualities. If the variety to be experimented on is a comparatively stable type it is first necessary to get it out of this state of stability, otherwise no satisfactory improvement could be made. It is necessary to "break the type," as plant breeders say. This may be done in one of several ways according to conditions. Methods much employed are: first, by cross pollination of closely related varieties; second, by cross pollination of a variety with its species; third, by cross pollination of closely related species. The hybrids from these crosses are likely to show greater variation than either of the parent forms. The type may often be still farther broken, or greater variation may often be induced, fourth, by crossing the hybrid with one or both of its parents. Variation is resorted to because the greater the range of variation the greater chance there is of obtaining the desired qualities among the individuals. Variation can also be induced in other ways. It is well known that when feral plants are taken into cultivation and given better food, and competition is largely removed, the plants tend to vary, and often this variation extends over a wide range. So when plants are introduced in new localities where the conditions are different, variation often is the result. This fact is often taken advantage of and leads to a fifth principle according to which the type can be broken, namely, by securing seed from a different locality. This seed from a distant locality when planted side by side with seed of plants which in their own locality are quite stable and show little variation, often produces plants which are very variable and thus affords a wide range for the selection of varieties which can be still farther improved by selection. This is often combined with a sixth method, that of crossing individuals of the same variety which come from widely different localities. For example, seed of a given variety obtained from a distant locality is planted in a given locality where the same variety is stable. The breeder cross-pollinates these with the individuals of the same variety in his own locality, which is apt to induce still greater variation.

660. A definite purpose in crossing.—The plant breeder usually works for a definite purpose in view. Sometimes it is possible to predict results, i.e., to form an idea, or a picture, several years in advance, of the shape and quality of the plant product desired. For example, seedsmen have on several occasions described to plant breeders the character and quality of a wholly new variety of beans which they believed would possess especial commercial merit. The plant breeder was asked how long it would take to breed this variety, and being told that it could be produced in about three years, the seedsman advertised the seed in advance of the existence of the variety. It is rare, however, that the breeder can work with such precision as to determine the time at which the desired result can be obtained except in dealing with varieties whose variations in different directions are already known to him, and by knowing the variations and plasticity of his material he can select during several years for this one result.

661. Work for one thing at a time.—The experience of most breeders leads them to work for one thing at a time, since if the breeder selects his plants for several qualities, progress towards excellence in one direction is impeded and often defeated because of some antagonism in the strain he is working on between some of the qualities he is striving to develop. When the desired excellence is reached in regard to one quality, plants possessing this quality are then bred for another quality. If certain of the desired qualities cannot be obtained from this variety by selection, it is then crossed with some closely related variety possessing this character and selection is again resorted to until the plant and productivity as a whole has been brought to the highest state of excellence, or the state of excellence desired. Selection may be carried too far in certain directions, when it will be necessary to breed back to the best state, as was the case with a variety of walnuts bred by Burbank. He was breeding for a nut with a thin shell. He succeeded so far as to produce a nut with a shell so thin that the birds could break through it and eat the meat. It was then necessary to breed back a thicker shell, at the same time retaining the other good qualities of the nut and the general vigor of the tree.

662. Crossing different species for the production of new varieties.—Where species not too distantly related possess certain characters which it is desired to bring into one variety, they are often crossed for this purpose with excellent results, but some plant breeders advise against the crossing of species as a rule. Some of the reasons for not crossing species are that the hybrids of species are apt to be sterile or at least to possess a high percentage of sterility. The more distantly related the species crossed, the greater, in general, will be the percentage of sterility. Thus little or no seed is obtained which makes the propagation of the new variety unprofitable if it is to be propagated from the seed. If a valuable variety is obtained in this way which has a low percentage of fertility, the percentage of fertility can often be improved by crossing the hybrid with one of its parents. On the other hand hybrids of varieties are apt to possess a high percentage of fertility. Crossing of species, if they are not closely related, is apt to be more or less guess work, and in the large number of cases does not lead to success. Now and then, however, very valuable varieties are obtained in this way.

663. Relation of Mendel's law to plant breeding.*—Because of the approximate precision with which the hybrids, which follow Mendel's law, come out with dominant and recessive characters, it has been thought by some it would be possible to predict the nature of varieties or hybrids which one could obtain by the crossing of closely related species or varieties. In crossing varieties differing in respect only to one character, which

* For special assignment.

hybridize according to Mendel's law, nothing would be gained because only two forms are obtained, which are exactly like the parents (paragraph 646). These are called *monohybrids*. In crossing varieties which differ in respect to two characters which behave according to Mendel's law, *dihybrids* are produced and four combinations are possible, resulting in successive generations in four different varieties which breed true, two of them like the parents and two new varieties. For example, in crossing the blue-flowered thorn apple, or jimson weed, with the white-flowered smooth one, besides the two parent forms, two new ones are obtained, a blue-flowered smooth one and a white-flowered thorny one. So in the case of three different unit characters in the parents eight combinations are possible, two of them like the parent and six new ones. In these cases it is possible to predict in advance the new forms which can be obtained and selection can be made from them.

Very important results have in fact been obtained recently by Biffen of Cambridge University in England. The wheat commonly grown in England is a soft wheat, i.e., with a high percentage of starch and low protein content, but it also produces a large yield. He worked to develop a variety of wheat having a high protein content, with the high productivity of the English wheat, and also which would be free from the disease known as rust. He found by experimental work that these and some other characters behaved as unit characters in Mendelian fashion (paragraph 646), as follows:

Having cropping quality dominant to poor cropping quality.
Glutinous wheat (high per cent protein) dominant to starchy wheat.
Rusty plants dominant to resistant plants.
Early wheat dominant to late.
Red grain dominant to white.
Rough chaff dominant to smooth.
Bearded wheat dominant to bald.
Stiff stems dominant to weak.

By crossing in various combinations he was able to produce a variety of wheat possessing the heavy cropping qualities and good straw of the English wheat, the high protein content of a foreign wheat, and resistance to the rust.*

664. Varieties are continually changing.—It is a matter of common observation on the part of horticulturists and others that many of the new varieties put upon the market in a few years are so greatly changed, that they no longer resemble the variety as it was originally known and described. In fact several different new varieties may arise from it in different sections of the country without any effort on the part of the cultivators to develop them, and still they may all go by the name of the original new variety. This is due to several causes. First, the variety, although in general breeding true, is variable. Second, when cultivated in different localities where climatic, soil and food conditions are different, variations are introduced in different directions. Third, the growers, while not attempting to breed new varieties, unconsciously pursue a method which would lead to the production of new varieties. In the selection of seed it is taken from the best plants or from the best fruit. Naturally the ideals of different persons would be different and so their selection would lead in the direction of forming new variations in a few years.

665. Records.—It is very important that one engaged in plant breeding should keep a careful and accurate record of their work so that the pedigree of the races and varieties may be well known. For methods of keeping records reference should be made to some work on plant breeding (see Bailey's Plant Breeding, 4th edition, 1906).

NOTE.— The plant breeding by the United States Department of Agriculture is concerned with the improvement of the cotton staple, citrous fruits, apples, pineapples, oats, tobacco, etc.

---

* See Punnet, R. C., Applied Heredity, *Harper's Monthly,* December, 1908.

INDEX