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OUTLINES OF BOTANY

FOR THE

HIGH SCHOOL LABORATORY AND CLASSROOM

(BASED ON GRAY'S LESSONS IN BOTANY)

BY

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*Prepared at the request of the Botanical Department of
Harvard University*

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OUTLINES OF BOTANY

W. P. 14

PREFACE

THE present text-book has been prepared to meet a specific demand. There are many schools which, having outgrown certain now antiquated methods of teaching botany, find the best of the more recent text-books too difficult and comprehensive for practical use in an elementary course. The large number of subjects included in the modern high school course necessarily confines within narrow time limits the attention which can be devoted to any one branch. Thus, more than ever before, a careful selection and judicious arrangement as well as great simplicity and definiteness in presentation are all requisite to the practical success of any one course of study. This book offers (1) a series of laboratory exercises in the morphology and physiology of phanerogams, (2) directions for a practicable study of typical cryptogams, representing the chief groups from the lowest to the highest, and (3) a substantial body of information regarding the forms, activities, and relationships of plants and supplementing the laboratory studies.

The practical exercises and experiments have been so chosen that schools with compound microscopes and expensive laboratory apparatus may have ample opportunity to employ to advantage their superior equipment. On the other hand, the needs of less fortunate schools, which possess as yet only simple microscopes and very limited apparatus, have been constantly borne in mind. Even when the cryptogams and certain anatomical features of the phanerogams are to be dealt with, much may be accomplished with the hand lens, and, where applicable at all, it is in an elementary course usually a better aid to clear comprehension of objects examined than the compound microscope. Furthermore, the experiments covering the fundamental principles of plant physiology have been so far as possible arranged in such a manner as to require only simple appliances.

In arranging a scientific text-book it has been a common practice to interpolate directions for observation and experiment in the body of the text. In teaching, however, the writer has found this arrangement highly objectionable. Both laboratory work and class-room exercises suffer from it. Accordingly, in this book instructions for laboratory study are placed in divisions by themselves, preceding the related chapters of descriptive text. The pupil with his book open before him in the laboratory will, therefore, not here be confronted by pictures and statements constituting keys to the work which he should carry out independently. Although it is not intended that each laboratory chapter should of necessity be finished before the following chapter of text is taken up, the examination of the plants themselves should naturally be kept somewhat in advance of the recitations which summarize and complement the information gained from that study.

The descriptive text follows in the main the sequence of topics of Gray's "Lessons in Botany," and certain parts of that book have been retained, as occasional paragraphs will show. In view of the relation of the present book to the "Lessons" as indicated on the title-page, the writer has felt free to adopt the phraseology of Dr. Gray wherever desired, without quotation marks. A considerable number of descriptive terms and definitions applied to the leaf and the flower have been taken from the "Lessons," being now placed apart, for the use of the classes making a somewhat detailed study of phanerogams in a systematic way. But the greater part of the descriptive text throughout is new, the chapters on cryptogams and on physiology being entirely so.

In an endeavor to combine the best features of newer methods with the lucidity and definiteness which have given Dr. Gray's textbooks their extraordinary merit, the present book departs from its predecessor in paying more attention to the life of plants, as contrasted with mere form. The writer has aimed to give due prominence to function which underlies form, that is to physiology and the relations of plants to their surroundings. Yet while seeking properly to emphasize the ecological aspects of plant life, he believes that ecology should not be made the basis of elementary botany. It seems to him that a course should be built primarily upon a careful study of form, leading to some power of intelligent discrimination in morphology and of accurate description in the technical language of the science. Equally essential are certain perfectly definite principles of vegetable physiology. The core of any rational elementary course is thus believed to be concrete, embodied in precise and more or less technical language, and measurably endowed with a quality which some would with disfavor characterize as formalism. The writer believes that the body of concrete instruction is not likely soon to be displaced by the less definite and as yet more tentative generalizations of the latest Ecology.

The Appendix is an essential part of the book, but is primarily addressed to the teacher. It contains suggestions in regard to equipment, books, materials, experiments, and additional exercises, as well as pedagogical methods.

The writer appreciates, and here takes occasion to acknowledge, the care with which Mr. C. E. Faxon and Mr. F. Schuyler Mathews have made many new drawings for this book. Thanks are due to the staff of the Gray Herbarium for aid in proof reading, especially to Miss M. A. Day, Librarian. The writer is deeply indebted for advice and criticism to Mr. William Orr, Principal of the High School, Springfield, Massachusetts. Above all, the writer would acknowledge his great obligation to Dr. B. L. Robinson, Asa Gray Professor of Systematic Botany in Harvard University.

R. G. LEAVITT,

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OUTLINES OF BOTANY

I. LABORATORY STUDIES OF SEEDS AND SEEDLINGS

A seed comes to the ground, lodges in a crevice of the earth, is warmed by the sun and wet by the rain, and after a time a new plant, the seedling, appears.

- a.* To what extent is the new plant already formed within the seed before germination begins?
- b.* What provision is made in the seed, in the way of food, for the growth of the seedling and its establishment as an independent individual?
- c.* What internal processes at the time of germination may be detected by suitable experiments?
- d.* By what steps does the nascent plant (*embryo*) develop and attain to a life of self-support?

These are the general questions which the student is asked to answer for himself in the studies outlined in this chapter. The first exercises deal with the seed before germination, and the later ones with the seedling, that is, with the germination of the embryo and subsequent events.

THE SEED

EXERCISE I. THE EMBRYO: ITS FORM AND CONDITION PREVIOUS TO GERMINATION

Castor Bean. — Beginning at the smaller end of the seed, cut away the hard outer coat, or *integument*, without injuring the contents, or *kernel*. Run the point of a knife around the edge of the kernel, then split the halves apart.

Carefully remove for study the structures discovered within. Examine them with the lens. Describe all parts of the kernel with included embryo.

The substance surrounding the embryo is the *albumen*; the leaves are the *cotyledons*; the axis, or stemlet upon which they are borne, is the *caulicle*.

Draw: (1) The embryo separated from the albumen ($\times 2$).¹ (2) A longitudinal section of the kernel cutting the cotyledons in halves ($\times 3$).

White Lupine. — The parts all become visible on removing the seed coats and separating the well-marked halves of the seed. Note caulicle, cotyledons, and between the latter a third part, the *plumule*, of several diminutive members. Compare with the embryo of Castor Bean, noting striking differences.

Draw the embryo with one cotyledon removed, so as to show the plumule ($\times 3$).

Indian Corn. -- Lying just beneath the surface of the grain is a roughly wedge-shaped body. Remove this, leaving the pasty portion — the albumen. In one face is a cleft. Pull this apart, exposing structures within.

Study the embryo now in hand. A longitudinal section will help. In order to identify more surely the members of the embryo, study also a sprouted seed, in which root and plumule show plainly. The large single cotyledon is one feature to be especially noted.

Compare and correlate all its different portions with the parts of the embryos of Castor Bean and Lupine.

Draw surface and sectional views of the embryo to show the structure ($\times 3$).

From the examples above answer the question, To what extent is the new plant already formed within the seed before germination begins?

EXERCISE II. THE PROVISION OF FOOD DESIGNED FOR THE EARLIEST GROWTH OF THE YOUNG PLANT

1. **Where is the nourishment stored?** Answer this for Castor Bean, Lupine, and Indian Corn. In addition, examine seeds of the Four-o'clock, and others provided by the teacher.

Longitudinal sections will generally show at once the location of the food store, whether outside the embryo, in which case the seed is said to be *albuminous*, or within the much swollen tissues of the nascent plant itself, when the seed is called *exalbuminous*, or lacking in albumen.

Classify the seeds studied as albuminous or exalbuminous.

¹ This means the drawing is to be two times the size of nature.

In the Four-o'clock remove the integuments, and separate embryo and albumen carefully.

Draw the food mass of Four-o'clock. Indicate by dotted lines the natural position of the embryo. Use the hand lens ($\times 3$).

2. **What substances constitute the food of the seedling?** The very numerous substances of which plants are composed are capable of being recognized by appropriate tests. A test consists of the treatment of the tissues with certain chemicals. The success of the test depends upon observing some change of appearance, as of color, known to be due to the action of the chemical employed upon the substance for which search is being made.

Test for starch. — Treat a piece of laundry starch with dilute iodine. Note the color imparted. Starch alone receives this hue from this reagent. Experiment upon the seeds supplied in order to determine which contain starch, and in what parts the starch, if found, is lodged. It may be necessary to pulverize or boil a part of the seed in some cases.

A second food material, of frequent occurrence in seeds. — Crush a whole kernel of Castor Bean. If this is done with the fingers, the characteristic feeling of the expressed liquid when the fingers are rubbed together shows the nature of the food material in question. Seeds of Flax and of Cotton may be crushed out with the flat of a knife blade for the same substance.

Other forms of reserve food matter. — Several of these are not readily discovered without chemical tests or microscopic examination. But a form occurring in the seeds of a number of plants of considerable economic importance is well seen in the date seed. Cut the "stone" of a date in halves transversely. Examine with the hand lens the small embryo lying crosswise of the seed.

Note the toughness of the main bulk of the seed. It is not gritty, like the stone of a cherry, but hornlike. It is the albumen, dissolved during germination and used for the support of the seedling.

From the studies in Exercise II answer the question, What provision is made in the seed, in the way of food, for the growth of the seedling and its establishment as an independent individual?

THE SEEDLING. GERMINATION

EXERCISE III. WHAT INTERNAL PROCESSES ARE DISCOVERABLE AS THE EMBRYO BEGINS TO GROW, AND GROWTH PROGRESSES?

Experiment 1. — Select seedlings of Bean in the first stages of germination, the caulicles coming into view. Remove the seed coats. Drop a dozen of the denuded beans into a four-ounce or six-ounce bottle filled with water which has been recently boiled to drive off dissolved air, and allowed to cool.

The cork, pierced by two glass tubes that penetrate a quarter of an inch or so beyond the inner surface, should be put in with care to exclude even the smallest bubbles of air; and the water should rise to fill the tubes completely as the cork is pushed in. Place the fingers tightly over the glass tubes and invert the bottle. Stand it mouth down in a dish of water (*e.g.* a tumbler). Be sure no air is present in the bottle.

Displace the water in the bottle by hydrogen gas. Lead the hydrogen from the flask into the bottle only after all air has been driven off in the flask. Allow the apparatus to stand as now adjusted in some situation favorable to the growth of the beans.

Beside it place a quite similar arrangement, also with sprouted beans, but let this one contain air in place of hydrogen.

Make full notes of the preparation and conditions of this experiment. Several days may be required for the result to be plainly seen. Thereafter finish the notes on the experiment.

In this exercise hydrogen, a harmless gas, is used to give an atmosphere devoid of oxygen. The second jar, filled with air, has of course a supply of the latter gas. What is your inference concerning the presence of oxygen?

Experiment 2. — In a fruit jar one-third full of sprouting corn place a small beaker of limewater. Cover the jar tightly. Another beaker with like contents is to be placed in an empty jar beside the first, and this jar likewise closely covered. After an interval of from one to several hours observe the appearance of the liquid in both beakers. Note any difference.

Take a small beaker of fresh limewater. Breathe gently upon it till a change is produced. This action of one's breath upon limewater has what bearing in explaining the effect observed in the jar of sprouting corn? What is the object of the second jar and beaker?

Experiments 1 and 2 will enable the student to infer —

(1) Whether the atmosphere supplies anything more than moisture to the germinating plant; (2) Whether the plant gives back anything into the atmosphere.

What action necessary to the life of animals does this double process in growing plants resemble?

Experiment 3. — Having removed the beaker from the jar of seedlings used in the previous experiment, tie a cloth over the mouth of the jar. Near by lay a thermometer. When the mercury column has become stationary, note the reading accurately (without handling the bulb), and passing the instrument through a small hole in the cloth, insert its bulb amongst the seedlings.

Within five or ten minutes observe with exactness the temperature of the seedlings. Is it higher or lower than that of the room?

The jar must not stand in direct sunlight, the effect of which would be to render the contents warmer than the room.

It would be well to find by means of another thermometer whether the temperature outside the jar changes in the same direction equally, during the time of observation.

Is there any connection between the activity of the seedlings, detected by Experiments 1 and 2, and their heat condition indicated by the thermometer in Experiment 3?

EXERCISE IV. INFLUENCE OF TEMPERATURE ON GERMINATION

Experiment 4. — Take 100 seeds of Bean, 100 grains of Indian Corn, and 100 grains of Wheat. Soak all the seeds for twenty-four hours in water. Note the change or changes produced.

The seeds of each kind are then to be divided into two sets of 50 each. Place one set of each kind in a suitable receptacle, where they will be kept moist, but not covered with water (*e.g.* place between layers of wet blotting paper, or in moist cotton, or in wet sphagnum moss, the receptacle being closed to prevent evaporation). Put the receptacle in a warm place where the temperature will be as nearly 75° Fahr. as possible. Treat the other sets in like manner, but expose to a low temperature — but, of course, above freezing. Each day record in a table the number of seeds of each kind that have sprouted. What is your inference concerning the influence of temperature?

EXERCISE V. DIRECTION OF GROWTH OF PLUMULE AND ROOTLET

Experiment 5. — By a chance position of the seed in the soil the nascent root, or *radicle*, on emerging may have its tip directed toward any point but the right one. Ascertain as follows how an inverted seedling behaves. Fit a double roll of blotting paper into a beaker. Moisten. Between the paper and the glass place seedlings, well sprouted, with the roots pointing upward, the plumules downward. They are held in place by the pressure of the paper. But if some of the seeds are large, — like the Lupine, — tuck wads of cotton in on either side to support the radicle, and prevent it from falling or bending over.

Pour a little water into the beaker. This, soaking up on the blotting paper, will keep the seedlings moist. Cover the beaker to prevent drying up. Draw some of the seedlings well enough to record their positions. After two or three days examine and draw again.

Record the preparation and results of this experiment. Is there indicated anything which might be termed *sensitiveness*, together with active *growth* toward or away from the direction of gravity?

Or are the affected parts simply *bent* by their own weight?

EXERCISE VI. THE DEVELOPMENT OF THE SEEDLING

Experiment 6.—An exceedingly important change undergone by the seedling as it comes out of the soil or the seed into the light, may easily be overlooked. In order to single out this effect from others observed in the course of the young plant's development, next to be studied, germinate some seeds in the dark, and let the seedlings develop quite away from the influence of light. Their increase of size and the succession of parts will be much like that of ordinary seedlings, and their appearance similar except in the one vital particular—a characteristic of plants so commonplace that it is hard to realize its true importance.

In the course of the studies below let the above seedlings, and perhaps others grown in very dim light, be compared with those grown in full light.

Turning now to the general development of the seedling, the student should consider afresh that in the buried seed there is a nascent plant, and that at the start it is confronted by a complicated problem. In many cases the very first difficulty is how to escape from the wrappings of the seed itself. After that there is the question how, through growth from a very limited food supply, on the one hand to reach the air and spread a small crown of leaves, and on the other to establish connection with the soil.

Germinate seeds of Squash, Onion, White Lupine, Pea, and Morning Glory, to various stages. Write notes along the lines indicated below, and illustrate by drawings.

1. Any special methods of getting free from seed coats.
2. Whether the cotyledons are raised out of the ground or not.
3. The mode of extracting cotyledons or plumule from the soil.
4. Whether the cotyledons serve as food sacs, as foliage leaves, or as both.
5. In which cases the plumule develops early, in which late; reasons.
6. In albuminous seeds, what organ of the embryo acts to absorb the albumen.

On points calling for individual judgment rather than statement of facts, let the opinion formed by the pupil be expressed distinctly as such.

Supplementary Topics for Investigation (optional)

1. The rudimentary embryos of orchids. Material, seeds of native or greenhouse plants. Polyembryony of *Spiranthes cernua*.
2. Embryos of certain Conifers. *Pinus Lambertiana*, *P. pinea*, or even smaller seeded species for the seeds. *Larix Americana* (Hackmatack) and *Picea excelsa* (Norway Spruce) for germination.

3. The dependence of seedlings upon the nourishment in the cotyledons. Compare the growth of entire plantlets with that of plantlets deprived of one or both cotyledons.

4. To what size will the food store of the seed, with the addition of water alone, bring the seedling? Exclude light; for in darkness the seedling can make no new food. Sprout several kinds of seeds, choosing a variety as regards the amount of albumen or size of the embryo. Tie mosquito netting loosely over the mouth of a dish, and fill the dish with water until it touches the netting, upon which place the sprouted seeds with the radicles going down into the water. Report the results, and illustrate with the plants grown.

Investigations 3 and 4 may be made at home.

Divisions of the Vegetable Kingdom. The Course of Study

One has but to draw upon his everyday observation to realize how varied is the plant realm. There are such diverse types as the trees and herbs that we see everywhere about us, the ferns, the mosses, the molds and toadstools, and the seaweeds. These differ so widely from one another that at first sight there seems to be little upon which one could base any notion of a common relationship.

Nevertheless, the multitude of forms have been brought together into comparatively few grand divisions, and close study has revealed a considerable measure of agreement running through the whole series. We may reasonably suppose that all plants are of one stock, and that the higher groups have sprung from forms resembling the lower.

In his present work the student is concerned with but one type, the highest of all, that of the **FLOWERING PLANTS**, or **PHANEROGAMS**. It comprises nearly all the plants of large size, and by far the greater part of those which are useful to mankind—the forests, the grasses, the grains, the fruits, the fiber plants,—those that at present make the earth green and habitable.

All the lower plants of diverse sorts, from the ferns downward, are termed **FLOWERLESS PLANTS**, or **CRYPTOGAMS**. They are reserved for the latter part of the course.

Phanerogams and Cryptogams have much in common, as has just been stated: the highest Cryptogams closely resemble the lowest Phanerogams. Yet the latter, as a whole, form a well-marked group by themselves. One mark of distinction may be stated thus:—

Phanerogamous plants grow from seed and bear flowers destined to the production of seed. By many recent authorities they have been termed *Seed Plants*, or *Spermatophytes*; and this designation is more significant than the earlier and commoner one of flowering plants.

The reproduction of Cryptogams is carried on by means of *spores*, bodies very much smaller and simpler than the smallest and most rudimentary seed. The spores contain no ready-formed plants. They go through a series of changes, quite unlike anything to be observed in the germination of seeds, before the form of the plant which gave rise to them is reproduced. The pollen of flowering plants, which must be familiar even to those who have paid little or no attention to plant structure, closely resembles the spores of the flowerless plants. This may enable one to see, at a single glance, the wide difference between spores and seeds.

The Members of a Complete Plant

The seedlings studied in the last Exercise were complete plants. They were provided with all necessary organs of vegetation. All phanerogamous plants consist of (1) root, and (2) shoot; the shoot consisting of (a) stem, and (b) leaf. It is true that some exceptional plants, in maturity, lack leaves, or lack roots. These exceptions are few. The parts of the phanerogams studied are to be assigned to root, stem, or leaf. Let it be understood that when in the studies on flowering plants the question is asked, "What is the morphology, or nature, of this part?" this is equivalent to asking, "Is the part in question of the nature of root, or of stem, or of leaf?"

II. SEEDS AND SEEDLINGS

1. **The seed** carries within it a minute plant. The seed originates in the flower, within an often globular or pod-like structure (Fig. 1), which, though generally the least conspicuous of the floral organs, may have attracted the student's attention on account of its central position and peculiar form. This receptacle may contain a very great number of the rudiments of the future seeds, or only a few, or even only one; and may be the

1. Central portion of one of the flowers of *Hermannia Texana*, showing the seed rudiments.

2. Buds, flowers, and ripened seed vessels (fruit) of *Hermannia Texana*.

sole seed-bearing part, or one of several in the same flower. After the floral leaves with their wide expanse and bright colors have performed the part they play in the life of the flower, and have fallen away, this seed receptacle enters upon a new period of its history. It grows, often vigorously, and through alteration of form

and texture approaches nearer and nearer to its final condition of fruit (Figs. 2, 3).

2. The seed rudiments meanwhile undergo fundamental changes : the embryonic plants are formed, seed coats

3. *a*, the fruit, or matured form of the central organ of the flower (Fig. 1), cut across to show the seeds ; *b*, a seed, magnified ; *c*, a section of the seed ; *d*, the embryo removed from the seed.

develop, fitted to secure the dispersal of the seeds far and wide, or to protect the embryo, and a store of food for rearing the young plant to a certain stage is provided (Fig. 3).

3. At length, when the seed is fully ready for its mission, the now ripened fruit falls to the ground and decays, liberating the seeds, or is borne away by currents of wind or water, or by animals. Or, remaining on its stem, it either opens (Fig. 3), allowing the seeds to be scattered by a variety of agencies, or in a number of cases bursts, forcibly ejecting the seeds from their receptacle.

4. Seed of an Orchid, with loose, buoyant coat, and a rudimentary embryo (magnified).

4. The primitive plant, or *embryo*, inclosed in the seed, may be so rudimentary that it shows no distinction of organs. Such a case is furnished by Orchids, epiphytic¹ upon trees in tropical forests. Their flowers are often large ; but the extremely numerous seeds are of the smallest size, and of the

¹ *Epiphytes* grow upon, but derive no sustenance from, other plants. *Parasites* live at the expense of their hosts.

simplest structure throughout (Fig. 4). Floating through the air like chaff, they are borne to situations suited to the life habit of these plants. The very much reduced embryo is a minute rounded body with no sign of leaf and stem appearing until germination has considerably advanced.

5. But every well-developed embryo consists essentially of a nascent axis, or stem, — the *caulicle*, — bearing at one end a leaf or leaves, — the *cotyledons*, — while from the other end a root is normally to be produced (Fig. 3, *d*).

6. **The number of cotyledons.** — Several of the embryos examined in the laboratory were *dicotyledonous*, that is, two-cotyledoned. Plants which are thus similar in the plan of the embryo, agree likewise in the general structure of their stems, leaves, and blossoms; and thus form a class, named from their cotyledons, the **DICOTYLEDONS**.

7. Figure 5 represents the Pine seed seen in section, together with the young tree after its cotyledons are fully expanded. Of these there are several, a case which is much less usual, but constant in the various kinds of Pine, where in some species the cotyledons number twelve, or even more. And in some other *Coniferæ*, or cone-bearing trees, the same peculiarity is found. The embryo is here said to be *polycotyledonous*.

8. The term *monocotyledonous* denotes the possession of but a single cotyledon. This condition goes along with other peculiarities of external and internal structure, and is thus characteristic of a class of plants — exemplified by the true Lilies and the Grasses — called the **MONOCOTYLEDONS**.

9. In addition to the parts already referred to, many embryos show in miniature one or two lengths of the stem which is to carry the growth of the plant upward above

5. Section of a Pine seed; seedling showing 6 cotyledons.

the cotyledons, with several of the first leaves which it will bear (Fig. 6). This bud of the ascending axis, already developed in the seed, is the *plumule*.

6. Embryo of the Yellow Pond Lily (magnified).

In the Bean and similar strong embryos the leaves of the plumule are already perfect as concerns outline, veining, and so on, and need only to gain green color and a larger size to become useful to the seedling as foliage. These

plants, therefore, very soon after coming out of the ground are found actively acquiring the means of further growth, while still using nourishment inherited from the parent plant.

10. Food. — Along with the incipient plant is sent a store of food in a form easily used, with which its start in

an independent career will be made.

The amount is as variable as the size of the embryo itself. It may be

relatively very large, as seen in the seed of *Actæa* (Fig. 7). In Fig. 8 the embryo is relatively larger than

8. Seed of the Purslane, in section, the embryo surrounding the reduced albumen (magnified).

the mass of nutrient material. This example prepares us for the condition seen in the seed of many families of plants, where a supply of nutriment separate from the germ itself is never developed (Fig. 9).

11. Food matter external to the embryo is termed *albumen*, or *endosperm*, and seeds having it are called *albuminous* seeds. Those lacking albumen are called *exalbuminous*.

12. It will readily be seen in most cases that embryos unfurnished with albumen are not in consequence the worse off, for they are of larger size and their tissues are

7. Section of the seed of *Actæa*, showing the minute embryo and the relatively abundant albumen (magnified).

9. Exalbuminous seed of *Gynandropsis*, in section (magnified).

swollen out with nutrient substances. This is the arrangement in seeds like the Peanut, Walnut, and Chestnut ; the edible kernel is really a rudimentary plant.

13. The seed food of embryonic plants consists chiefly of starch, fat, sugar, and in smaller quantities proteid substances ; that is, substances resembling the white of egg and the curd of milk. Transformed by the growing embryo and seedling into living substance and framework, with the addition of water alone, these concentrated formative matters may enable the young plant to grow to many times the size of the original seed.

14. The resting state. — The germ may remain long dormant in the seed. Its condition is then like that of the buds of trees and the underground bulbs of herbaceous plants in winter. Life sleeps, so to speak ; and the living parts can endure extremes of dryness, cold, and so on, which they are unable to bear in their more active periods. Thus the embryo passes uninjured through change of seasons that would cause the death of a seedling. Dormant and well protected, it may be carried to great distances. If at first unfavorably lodged, the seed may long await a change of circumstances. When a forest is cleared away, a great variety of field plants at once spring up, doubtless from seed deposited in the soil long before.

15. Retention of vitality. — De Candolle kept seeds of many kinds for fifteen years, when those of a few species germinated. In another case the known age of seeds which still kept their vitality was forty-three years.¹ On the other hand, certain seeds must be planted as soon as separated from the fruit.

16. The conditions of germination. — When the slow inward changes of the dormant period have fully prepared the seed, — or when ripeness has come, even without a resting stage, — germination will begin, if a few necessary conditions are fulfilled. There must be water, warmth, and oxygen.

¹ The stories of the germination of seeds from mummy cases are without foundation.

17. Water. — Seeds are usually rather dry on issuing from the fruit. Dryness makes the seed hardy. In contact with water therefore, at the time of germination, they often swell to two or three times their dry volume. Actual growth in plants, too, always requires much water.

18. Warmth. — Moderate heat has a strong influence in hastening germination. For Indian Corn and Squash the most favorable temperature is given as about 81° Fahr. A few exceptional seeds will sprout at the freezing point of water. Thus seeds of a Maple have been germinated on a block of ice, the rootlets penetrating to a depth of more than two inches into the dense, clear ice, in which they melted out cylindrical cavities for themselves. Heat for growth is here generated by the seedling itself.

19. Oxygen is actively inhaled and combines with the substances of the embryo. This oxidation furnishes energy which appears in growth and in vital heat ; that is, in heat in the seedling similar in all respects to the bodily warmth of animals.

20. As a result of oxidation carbonic acid gas is formed and exhaled. The young plant thus breathes in and out. *Respiration* is common to all living things. But in plants the in-take of the one gas and the out-going of the other are slow, continuous, and imperceptible processes.

21. The development of seedlings. — If one looks under the White Oak in late autumn, he is likely to find that the acorns have sprouted. He will then discover that many of the nuts, if lying on proper surface, for instance on short-cropped pasture sward, are already fast-bound to the earth, the *radicles*, or incipient roots, having penetrated the soil. It appears, therefore, that seeds may germinate and attach themselves without being covered up ; though a covering of some sort, as sand, soil, or dead leaves, is advantageous, and some fruits, or their carpels, are even provided with mechanical contrivances for partially burying themselves.¹

22. Suppose that a seed lies thus, like the acorn, cleanly upon the surface, and that it has been drenched by rain

¹ See Fig. 279.

and dew until germination actually begins. Plainly the first need in this case is a root developed in the soil, whence it may suck up the water and other substances required for the continued growth of the plantlet. To achieve this object the caulicle is pushed out of the shell, and the radicle begins to develop; and at once it may be seen that the elongating axis manifests something very like a rudimentary sense, or a number of senses. It is affected by outward influences. The radicle of the oak is found, for instance, to have been turned sharply downward; or in many instances the movement of curvature has gone still farther, and the growing radicle has followed the under surface of the shell backward to the dampest spot in the im-

10. Germination of the White Oak.

mediate neighborhood; namely, the place where the acorn, resting on the turf, has collected a little of the moisture exhaling from the earth—or at least preserved a humidity higher than that of the open. Here the root has made another turn, under the combined influence of gravity and humidity, and has entered the soil (Fig. 10).

23. The curving movements of the radicle are made a little way back of the tip, and the growth of the latter is thereby directed toward the proper surroundings.

24. Seedlings from buried seed come into the air by a

variety of methods. When the cotyledons are designed to act in the sunlight as green foliage for a time, they are, in general, brought out of the ground by the lengthening of the caulicle. As it grows, this usually bends abruptly just below the cotyledons; and the top of the loop thus formed is seen when the cracking of the soil allows one the first sight of the springing seedling. The extraction of the leafy parts is thus managed with the least danger of injury from the resistance of the soil (Fig. 11), and at the same time the seed coats are often slipped off.

11. Germination of the Morning Glory. At the left, the seedling as it appears when breaking from the soil; at the right, the same seedling a little later, the seed coats thrown off, the stem straightened, and the cotyledons opened.

25. The main part of the original seed may remain permanently buried, while the nutrient contents are gradually absorbed and carried away to the actively growing regions of the root and the ascending shoot. This is the case in the Horse-chestnut. The cotyledons are mere reservoirs of food. Their stalks elongate (see Fig. 12), freeing the caulicle and plumule from the shell. The root develops strongly, and the plumule rises, looped, toward the surface.

26. The end of the root for a greater or less length, according to the size of the plant, is always elongating in growth, and slipping forward between the particles of soil, which it avoids or pushes aside as the occasion demands. A portion just behind this smooth thrusting tip, having become fixed in position, throws out a velvety coating of so-called *root hairs*. These penetrate sidewise into the minutest interspaces of the soil, and adhere to

12. Germination of the Horse-chestnut.

the stony particles. Each hair is a microscopic tube (Fig. 27), out-growing from a surface cell, and serves to conduct water and draw food materials into the tissues of the root, whence they are conveyed to the leaves above.

27. Color.—The embryo in the seed is pale or colorless. The seedling—except the root—is dark green, after a short exposure to the light. But if the seedling is thrown into strong alcohol, this newly acquired green color is extracted, the coloring matter proving to be separable from the leaves and stems, where it is generated. It is a definite substance, to which the name *Chlorophyll* has been given. Without this substance, plants cannot turn mineral matters of soil and atmosphere into nourishment.

III. LABORATORY STUDIES OF BUDS

Buds appear as conspicuous features on most of the perennial plants of temperate and cool climates, after the autumnal fall of leaves. Such winter buds are to be the subjects of the following studies.¹

EXERCISE VII. THE GENERAL STRUCTURE OF BUDS

Buds of the following common species will show what winter buds usually contain, in what a compact way the parts are pressed together, and how some parts are shielded by others.

Lilac.—View the bud endwise. What is the arrangement of the scales? How were the leaves arranged on the twig?

Remove the scales and little leaves one after another, laying them down in the order of removal. Note a gradual change in the outlines. From the last-removed members it is easy to see the morphology of all the parts, including the scales. What are the scales? Cut a longitudinal section. Use the lens. All parts are seen in position and proper attachment.

Draw: (1) An outer, a transitional, and an inner member, as taken off ($\times 3$). (2) A longitudinal section ($\times 10$). Label all parts.

¹ The parts of the leaf—blade, petiole, and stipules—should be shown on the board to the class.

Horse-chestnut. — Note the arrangement of the scales. Of the leaf scars on the twig.

Remove the scales by cutting at the base. Separate the wool-covered members within and remove them, counting and noting down the number of pairs. Holding one of these parts by its stalk, scrape off much of the wool, first from the back, then from between the leaflets.

Cut longitudinally down through the bud core, or axis, after removing all scales and leaves. With the lens notice the short, narrow, conical part upon which the leaves proper, not the scales, were inserted. How many internodes¹ in this bud axis? (Refer to the number of pairs of leaves removed.) How many internodes in the last season's growth on the same twig? Does the bud contain an ordinary year's growth, as to number of internodes and leaves?

Draw: The bud entire ($\times 2$). One of the young leaves, spread out ($\times 3$).

Witch-hazel.² — Note the surface of the bud leaves. Scrape. Use the lens. Beneath the exterior coating is the leaf soft, green, and apparently alive, or leathery and dead? Pull the bud to pieces. Are any parts different from the outer leaves? The latter, as well as the inner ones, finally develop into foliage leaves. There are no scales. Such buds are termed *naked buds*. Draw the bud entire ($\times 2$).

EXERCISE VIII.

The Tulip Tree (*Liriodendron*). — Note the flattish form of the bud; the nearly round-scar near the base. Separate the two exterior scales at the tip, and pull them off. Relatively to the little leaf now seen, in what position does the next pair of scales stand? Examine all remaining parts. What is the round scar at the base of the outer pair of scales? What is the morphology of the scales?

Draw the bud after removal of the outer envelop.

Magnolia. — Does the caplike covering of the bud consist of two parts fused in growth, or is it single? What is the small scar at one side of the bud? Examine the contents of the bud. What is the morphology of the bud cap? Draw the bud, showing the scar.

ADDITIONAL STUDIES

Make a study of several other buds as directed by the teacher. Among these, the buds of Mountain Ash (*Pyrus Americana* or *P. Aucuparia*), Green Brier (*Smilax rotundifolia*), Mullein, Dandelion, and some subterranean bud like those of *Smilacina*, *Trillium*, *Sanguinaria*, or *Uvularia*, are suggested.

¹ Interspaces between leaves.

² For alternative material, see Appendix.

EXERCISE IX. THE NUMBER AND POSITION OF THE BUDS

The position of buds in general, with reference to the leaves of the previous season, must have already attracted attention. What is that position? When two or more buds occur together they have, relatively to one another, one of two characteristic arrangements, as seen in the following species.

Red Maple.—How many buds in a group? Which ones may be termed *extra*, or *accessory*?

Draw enough of the twig to show the essential relations of the buds, both to the leaf scar and to one another.

Pipevine.—Examine the neighborhood of the leaf scar with the lens. Cut a longitudinal section of the stem through the middle of the scar. Examine the cut surfaces of the bark. Growing points, distinguished by superior greenness, can be made out. Note their number and relative position.

Make a drawing (enlarged) to show the disposition of accessory buds here found.

EXERCISE X. THE WINTERING OF THE YOUNG SHOOT

Refer to the records and drawings made in the laboratory for the materials of a comparative account of buds, with reference to their adaptations to winter conditions. Protection against sudden chilling is sometimes perfect; in other cases temperature seems to be disregarded. Arrange the various modes of meeting the dangers of cold in an orderly manner in your account.

Are there any other sources of destruction besides low temperature? If so, what? And are buds protected against these dangers?

EXERCISE XI. THE DEVELOPMENT OR UNFOLDING OF BUDS¹

The Lilac, forced to grow indoors, may be studied. Determine what parts have grown since the bud came out of the typical winter state. Have all grown equally? Have some not grown?

Draw enough to show what happens to the different members of the winter bud.

If possible, compare with the Lilac the unfolding buds of two other species, as the Buttonwood and the Sycamore Maple.

EXERCISE XII. THE NONDEVELOPMENT OF BUDS

Select a branch of the Horse-chestnut five years old, or thereabouts. Count the total number of leaf scars. Of these, how many now subtend buds, or have subtended buds? In how many cases have buds developed into branches or flower clusters?

¹ This may be a home experiment.

Add the ages of all the existing buds, individually. Then divide this total by the whole number of buds. This gives the average age of the buds. How old is the oldest bud on the branch? Cut some of the oldest ones open. Should you judge them to be still capable of development, in case of need?

Record in your notes all numbers and ages.

EXERCISE XIII. COMPARATIVE VIGOR OF DEVELOPMENT

Select a lateral branch of the Maple provided, showing a few years' growth. Hold the branch in the position in which it grew. Certain of the leaf scars now look upward, part of them to right or left (horizontally), and part toward the earth. That is, there are two sets, the vertical (above and below) and the horizontal. In each set count the whole number of pairs of leaf scars; also the number (pairs) where the buds have made some growth.

Record in a table like the following:—

HORIZONTAL		VERTICAL	
Whole number (pairs)		Whole number (pairs)	
Number, where buds developed to twigs		Number, with twigs	

Measure roughly the combined length of all the horizontal twigs developed from lateral buds. Combined length of vertical twigs. Compare the numbers obtained thus:—

Total length of all horizontal twigs

Total length of all vertical twigs

Count the whole number of present winter buds on all the twigs of each set separately. This gives a hint as to their comparative vigor.

Record thus:—

Buds on horizontal twigs

Buds on vertical twigs

Is there any advantage to the tree in the superior development of one system over the other?

This exercise is intended to bring out two facts: first, that certain buds are more likely to develop than others; second, that certain buds develop more vigorously than others. The exercise is not intended to teach—what would not be universally true—that the horizontally directed buds, for example, are *always* more vigorous than vertically directed buds; or *vice versa*.

General summary. — The pupil should by this time be self-informed as to —

- a.* What a bud, as a whole, is.
- b.* What the reason for its formation is.
- c.* What rudiments of future growth are present.
- d.* How nearly these approach the full-grown condition as to form.
- e.* What parts are of merely temporary use.
- f.* What the morphology of these parts is.

Make a brief statement covering these points, by way of summary of the work on buds.

For Supplementary Work, see the end of Chapter IV., where suggestions for outdoor and indoor observations are made.

IV. BUDS

GROWING BUDS

28. In actively growing herbs the tip of the stem and the rudiments of the coming leaves — appearing at first as small prominences close to the apex — are usually protected from accidents. Bites of insects or other animals, and extremes of heat, light, dryness, and cold, are guarded against by the maturer leaves standing together over the younger parts (Figs. 13, 14), or by special coverings. The forming

13. Terminal portion of a shoot of *Coleus*; young leaves shielding the growing tip.

members of the *Begonia* shoot are sheathed by a pair of scalelike appendages — stipules — at the base of the highest full leaf (Fig. 15). In addition, in this plant, the hot rays of the sun are in nature fended off by the leaves themselves, which are raised umbrellalike over the

growing point; a mode of protection quite perfectly represented, also, by the Castor Bean plant (Fig. 16). In the Mullein, protection is assured both in the growing

14. End of the stem, and two nascent leaves, in *Coleus*, after removal of several pairs of the leaves of the growing bud.

15. Protection of the growing bud of *Begonia*.

season and in winter by a thick, woolly covering of plant hairs, or *trichomes*. These are produced by all the leaves in their earliest stages when crowded together in the bud,

16. Protection of the terminal bud in the Castor Bean.

and persist when the leaves are mature. The tender sprouts of many plants are well supplied with trichomes of a special kind, secreting distasteful liquids which discourage the attacks of herbivorous insects.

RESTING BUDS

29. The most conspicuous buds are the scaly *resting* buds of most trees and shrubs of temperate or cold climates. When these are formed at the end of a stem or branch, they are referred to as *terminal* buds. In the angle, or *axil*,

of nearly all the leaves others are found, termed *axillary* or *lateral* buds (Fig. 17).

30. **Accessory or supernumerary buds.** —

There are cases where two, three, or more buds spring from the axil of a leaf, instead of the single one which is ordinarily found there. Sometimes they are placed one over the other, as in the *Aristolochia*, or Pipevine; and in *Pterocarya* (Fig. 18), where the upper bud is a good way out of the axil. In other cases three buds stand side by side in the axil, as in the Red Maple.

31. **Formation of winter buds.** —

Such plants as prepare for winter by the production of winter buds form them early in the foregoing summer. In many woody plants the axillary buds do not show themselves until spring; but if searched for, they may be detected, though of small size, hidden under the bark. Sometimes, though early formed, they may be concealed all summer long under the base of the leaf stalk, which is then

18. The accessory buds of *Pterocarya rhoifolia*, somewhat above the axil, and already partially developed in the first summer.

17. Buds of the Hickory.

hollowed out into a sort of inverted cup, as in the Button-wood, or Plane Tree (Fig. 19).

19. Sub-petiolar bud of the Plane Tree.

32. Large and strong buds, like those of the Horse-chestnut and Hickory, contain besides the scales several leaves or pairs of leaves, ready formed,

folded, and packed away in small compass, just as the seed leaves of a strong embryo are folded away in the seed; they may even contain all the blossoms of the ensuing season plainly visible as small buds. Buds containing

20. Underground stem (*st*), thickened roots (*rt*), and resting bud of Bellwort (*Uvularia*).

both leaves and flowers are termed *mixed buds*. Under the surface of the soil, too, or on it, covered with the dead leaves of autumn, similar strong buds of our perennial herbs may be found (Fig. 20).

33. The resting state.—Buds, like seeds, remain in a state of rest, or dormancy, during the winter, although life is hardly reduced to such low terms in buds as it is in seeds. Buds are therefore more easily aroused to activity;

and they are less hardy. Yet in the coldest weather buds are frozen without injury, providing the freezing and subsequent thawing are not too sudden. Some buds which will grow and unfold when placed in water in the latter part of the winter, refuse to open at an earlier period, behaving like those seeds that will germinate only after a definite length of time.

34. Protection. — The means and the degree of protection are various. Against sudden changes of temperature thick, woolly covering is often provided, growing from the young leaves and around their bases. To this several thicknesses of scales —

modified leaves — may be added. The scales usually fall away soon after the bud bursts open in spring; but in many instances, like the Buckeye (Fig. 21),

make a little growth toward foliage. In *Pterocarya* (Fig. 22) the younger leaves are shielded only by the somewhat broadened stalks of the partly developed outer ones. When the

22. Naked bud of
Pterocarya
fraxinifolia.

latter become, in the spring, the full leaves of the season, such buds are termed *naked buds*, *i.e.* without specialized protective scales.

35. The slender, pointed axillary buds of the Horse Brier, or Green Brier, lie in the groove of the petiole of the subtending leaf, and are partly

21. Development of the parts of the bud in the Buckeye.

23. Remains of the petiole protecting the bud in Horse Brier.

covered by the margins of the groove. When the leaf falls off in autumn, the base remains as protection to the bud (Fig. 23).

36. Store of food. — In trees, the stems which bear the buds are filled with abundant nourishment deposited the summer before in the wood and in the bark. Subterranean buds are supplied from thick roots, root stocks, or tubers, charged with a great store of nourishment for their use. (See Figs. 20, 47, 48.)

37. Renewal of growth. — We see that the on-coming of spring finds plants ready to resume their interrupted activities, since new shoots are complete in the buds, and food is at hand for their development. As soon as the tide of warmth has fairly set in, therefore, vegetation pushes forth vigorously from such buds, and clothes the bare and lately frozen surface of the soil, as well as the naked boughs of trees, with a covering of green, and often with brilliant blossoms. Only a small part, and none of the earliest, of this vegetation comes from seed.

24. Buds and branching of Lilac.

38. Nondevelopment of buds. — It never happens that all the buds grow. If they did, there might be as many branches in any year as there were leaves the year before. And of those which do begin to grow, a large portion perish, sooner or later, for want of nourishment or for want of light. In the Hickory (Fig. 17), and most other trees with large scaly buds, the terminal bud is the strongest, and has the advantage in growth; and next in strength are the upper axillary buds; while the former continues the shoot of the last year, some of the latter give rise to branches, and the rest fail to grow. In the Lilac (Fig. 24), the uppermost axillary buds are stronger than the lower; but the terminal bud rarely appears at all; in its place the

uppermost pair of axillary buds grow, and so each stem branches every year into two, — making a repeatedly two-forked ramification.

39. Latent buds. — Axillary buds that do not grow at the proper season, and especially those which make no appearance externally,

may long remain latent, and at length upon a favorable occasion start into growth, so forming branches apparently out of place as they are out of time. The new shoots seen springing directly out of large stems may sometimes originate from such latent buds, which have preserved their life for years. But commonly these arise from

40. Adventitious buds.— These are buds which certain shrubs and trees produce anywhere on the surface of the stem, especially where it has been injured. They give rise to the slender twigs which often feather the sides of great branches of our American Elm. They sometimes form on the root, which naturally is destitute of buds; they are found even upon some leaves; and they are sure to appear on the trunks and roots of Willows, Poplars, and Chestnuts, when these are wounded or mutilated.

41. Definite annual growth from winter buds is marked in most of the shoots from strong buds, such as those of the Horse-chestnut and Hickory. Such a bud generally contains, already formed in miniature, all or a great part of the leaves and joints of stem it is to produce, makes its whole growth in length in the course of a few weeks, or sometimes even in a few days, and then forms and ripens its buds for the next year's similar growth.

42. Indefinite annual growth, on the other hand, is well marked in such trees or shrubs as the Sumac, and in sterile shoots of the Rose, Blackberry, and Raspberry. That is, these shoots are apt to grow all summer long, until stopped by the frosts of autumn or some other cause. Such stems commonly die back from the top in winter, and the growth of the succeeding year takes place mainly from the lower axillary buds.

43. Forms of trees determined by the development of the buds.— The main stem of Firs and Spruces, unless destroyed by some injury, is carried on in a direct line throughout the whole growth of the tree, by the development year after year of a terminal bud: this forms a single, uninterrupted shaft,—an *excurrent* trunk, which cannot be confounded with the branches that proceed from it. Of such *spiry* or *spire-shaped* trees, the Firs or Spruces are characteristic and familiar examples.

44. On the other hand, when the terminal bud fails to take the lead regularly, there is no single main stem, but the trunk is soon lost in its branches. Trees so formed commonly have rounded or spreading tops. The American Elm is a good illustration of this type, in which the stem is said to be *deliquescent*.

Supplementary Work. Ecology of Buds

The following outline is meant to suggest some lines of individual research that may be followed throughout the year in any place where plants grow. Notes made from nature will not, of course, follow this scheme; for such a

summary could come only after a good deal of looking into particular cases. Observations should be numbered in the notebooks; and specimen parts of the plants whose buds are described should be kept properly numbered, for determining with certainty what the plants are that have been studied. There are several popular works from which the names of plants in flower, or of trees even not in flower, may be made out to some extent. If one learns the use of the Manual, names may be determined without other help. Assistance may often be had from a trained botanist through correspondence, if none is available near at hand.

I. Summer. Growing buds. Protection of the tender tips: against (a) *insects*, (b) *snails* (water plants and low under-herbs), (c) *any other animals?* (d) *excessive light, heat, and drying*; by means of (a) *stipules*, (b) *petioles* of older leaves, (c) *trichomes*, (d) *convergence and overshadowing* by all the parts generally, (e) *other arrangements*.

II. Summer, fall, and winter. Resting (or "winter") buds. A. When are they formed, in different plants? B. Sources of danger. Determine some of these by actual observations on (a) *birds*—*e.g.* note the food of flocks of northern birds that visit your locality in winter—and (b) *other animals*. As to temperature, it may be asked, *Do buds freeze?* *Does freezing kill?* *Does prolonged freezing kill?* *Does thawing kill?* C. Methods of offsetting the dangers by (a) *special scales* (what is the nature, or morphology, of the scales?), (b) *coatings* of the parts (wool, glandular secretions), (c) *seclusion* (1) under bark, (2) in hollows, (d) other means.

III. Experimental. Earliest date at which buds of different species can be made to open, within doors. Effects of removing some or all of the scales in certain species. Do buds grow at all, in diameter or length, between December 1 and March 1, or otherwise change?

V. LABORATORY STUDIES OF THE ROOT

EXERCISE XIV. THE GENERAL MORPHOLOGY OF THE ROOT

The root suggested is that of Shepherd's Purse. (Do not remove the leaves from the plants.)

Note the general habit of the root system, consisting of one main root (*taproot*), and numerous lateral roots and rootlets.

What is the direction of growth of the taproot? Of the lateral roots? Examine the taproot with the lens for contraction wrinkles. Of what service is contraction of the roots, in the case of such a plant?

Place some of the fine, fibrous rootlets on the stage of the dissecting microscope in water, and carefully pick apart with needles, so as to see their length, branching, and relative slenderness. Can root hairs be made out? Does the branching show regularity? Is the root jointed where branches spring out? At what angle do the branches spring?

Chip away one side of the main root to show the wood at the center. (In doing this, save half or more of the upper part uncut, for later use.) This is the central *cylinder*. All outside of this is the *cortex* (bark). By scraping and stripping, a distinct external layer, like a skin, may be detached from the taproot. This resembles the external

layer of the leaf and stem in being more or less impermeable by water. Does the central cylinder of the taproot connect directly with those of the lateral roots and rootlets?

Experiment 7.—What part of the root conveys liquids up to the leaves of the shoot? Determine this by cutting off the lower half of the main root and the ends of some other roots, and placing the still leafy plant with these cut surfaces in water colored with eosin. After a time cut off the cortex on one side of the root, at different levels, to find whether the eosin water has been taken up; and, if so, what path it has followed. Save a thin cross section of the taproot for drawing.

Draw: (1) The general habit of the root system, to show the points already mentioned. Show the rings or wrinkles due to longitudinal contraction. (2) A piece of the branching fibrous root (as seen with the dissecting microscope, and therefore much magnified), showing the points noted above. (3) Longitudinal section of taproot (short piece), showing the wood, cortex, and coating, and the connections with branches ($\times 3-4$). (4) Cross section of the taproot ($\times 4-5$).

EXERCISE XV. ROOTS FOR CLIMBING

Make a drawing of the given stem with its climbing roots, to show the mode of occurrence of the roots, whether in rows or not, and whether at or near the nodes of the stem or not. With the lens, examine the roots for root hairs. Is there any sign that they play a part in the adhesion of the roots to supporting surfaces?

EXERCISE XVI. ROOTS FOR STORAGE

Compare the internal structure of the given root with that of Shepherd's Purse. Are all the regions which were observed in that root found in this one? In what region or regions of the storage root is thickening most pronounced? In what part or parts is nourishment stored? How can you test this? What part does this root play in the life history of the plant? Will the root grow—i.e. give rise to shoots—when planted in a pot of earth? (Try it.)

Is any part of the stem of the plant present and closely incorporated with the root? Distinguish root and stem carefully in such a case.

Draw whatever diagrams are necessary to illustrate your notes.

Supplementary Subjects

1. The roots of epiphytic Orchids. Note their origin and structure, and behavior toward water. What is the habitat of these plants?
2. Roots of the Dodder.
3. Contraction of the roots of plants.
4. Direction of growth of roots under influence of moisture.
5. The rate of growth of the roots of seedlings.
6. Root pressure shown by guttation.

VI. THE ROOT

45. Origin. — Roots ordinarily come from stems, not, as is generally thought, stems from roots. It is true that in

25. The Bloodroot, producing in spring leaves and flowers from an underground stem which is popularly mistaken for a root.

springtime flowering herbs like the Trillium, and the Bloodroot (Fig. 25), are seen to break from the ground as if produced from a root; but the subterranean stock in all such cases is a true stem.

46. Exceptions to the general rule are not uncommon, for many roots, especially if severed from the stem, have a power of forming afresh within their tissues, buds developing into leafy shoots.¹

47. The initial stem of the embryo produces from its end a root which becomes the first or *primary root* of the plant. Some plants keep this as a main

or *taproot* throughout the whole of their life, and send out only small side roots (Fig. 42); but commonly the main root divides off very soon, and is lost in its branches. A root system is thus formed with no marked central axis. In plants of large size, as trees, the roots often extend on all sides, not far below the surface, sometimes to a considerable distance beyond the limits of the aërial parts.²

¹ The reproduction of lacking parts (as buds by roots, roots by stems, and both roots and stems by cut leaves) is termed *regeneration*. The faculty is common to many plants, and to not a few animals, especially those of the lower types.

² "Those of an elm have been known to fill up drains fifty yards distant from the tree." — Goodale, "Physiological Botany," p. 235.

48. Every flowering plant, with some rare exceptions, has thus at the beginning one or more primary roots developed from the tip of the caulicle; but when occasion arises, additional roots are freely produced from other parts of the stem. The Poison Ivy is a woody vine, sometimes assuming a partially erect, shrublike habit. Wherever, in clambering over the rocks, the stem finds shade and moisture, it produces a thick growth of fibrous, clinging rootlets (Fig. 26). The higher shoots, rising well above the under shrubbery, and thus exposed to sun and air, are quite devoid of them. In this case the accessory roots owe their existence to causes which are in a sense accidental, and they are accordingly said to be *adventitious*.

49. Any part of the stem may give rise to adventitious roots, but they come most readily from the nodes, as may be seen upon examining almost any creeping plant (see Figs. 34, 45).

THE FUNCTIONS OF ROOTS

50. Roots serve as organs of absorption and storage, and as holdfasts.

51. Absorption. — They absorb water and dissolved mineral matters, and in some cases organic matter left by the decay of former vegetation, or even the juices of living plants.

52. Water and salts. — If we uncover the roots of a tree, we find that they have a bark impermeable by water. This impermeable covering is thicker or thinner according as it is older or younger, but is never altogether lacking until we reach the young rootlets. Even here the surface is coated with a substance that hinders the free entrance of

26. Adventitious roots of the Poison Ivy.

water, except for a short distance from the tip backward. *Only the parts most recently formed are active in absorption.*

53. The production of new rootlets is thus of high importance. Accordingly, as long as the plant grows above ground, and expands fresh foliage from which moisture largely escapes into the air, so long it continues to extend and multiply its roots in the soil beneath, renewing and increasing the fresh surface for absorbing moisture in proportion to the demand from above; and when growth ceases above ground, and the leaves die and fall or no longer act, then the roots generally stop growing, and their soft and tender tips harden. From this period, therefore, until growth begins anew the next spring, is the best time for transplanting, especially for trees and shrubs.

54. The action of root hairs.—It has already been noted in the laboratory that the tip of the seedling root is for a space smooth, but that at a little distance back a thick covering of root hairs soon arises. These not only insinuate themselves into the interspaces of the soil alongside of the root, and suck up whatever water may be there; but they apply themselves closely to the soil particles, the walls even becoming lobed and distorted in order to gain closer contact with the uneven particles composing the soil (Fig. 27). For adhering to the surfaces of the latter are certain substances much needed by the plant. These substances, mineral salts,¹ are not removed by the simple flow of soil water,² but remain firmly bound until acted upon by the root hairs. At the points of contact, the root hairs excrete an acid which acts to release

27. A root hair, much magnified. It is seen to be a tubular outgrowth from an exterior cell of the root, in this case much distorted.

For adhering to the surfaces of the latter are certain substances much needed by the plant. These substances, mineral salts,¹ are not removed by the simple flow of soil water,² but remain firmly bound until acted upon by the root hairs. At the points of contact, the root hairs excrete an acid which acts to release

¹ Salts such as potassium nitrate (saltpeter), magnesium sulphate, calcium phosphate, etc.

² Fertilizers applied to land and dissolved by the rain are held in the same manner by the soil, until taken by the roots of the crops. But if applied when the ground is frozen, the fertilizers do not penetrate the absorbent soil to the same extent, and much is washed away by surface drainage, and lost.

the mineral matters in question. These then pass into the root in solution, and are conveyed to the parts of the plant where their presence is required.

55. As the food sought becomes exhausted the root hairs cease to act, and after a short time die and fall away. Meanwhile further on new hairs have been put forth in soil lately invaded. These likewise serve their turn and shrivel. In this manner the root tip in its progress is followed by a belt of absorptive organs which explore the soil on every side of the line of advance.

56. Root hairs are the chief organs for the absorption of water and dissolved mineral salts, in the usual cases. They are, however, wanting in many aquatics and even in some terrestrial plants.

57. Protection of the root tip.—In growth new tissue

is formed close to the end of the root (see Fig. 28). The very forefront, subject to wear and tear by the resistance of the soil to the root's advance, is furnished with a

shield of tissue, somewhat in the form of a thimble, which is renewed from the growing point within as fast as it is worn away externally. This is called the *root cap*.

58. Aërial roots are such as are produced above ground. Some of the most highly specialized aërial roots are those adapted to the absorption of rain and dew. *Epiphytes*—that is, plants seated upon other plants, but not living at their expense—are obliged to depend upon occasional supplies of water, which the roots take up rapidly at the time and pass on to the leaves and stem to be stored for future use. Epiphytic orchids accomplish this by means of a thick spongy layer covering nearly the entire length of their numerous aërial roots (Fig. 29).

59. Absorption of organic food.—The waste from decaying vegetation is made use of by a very large number of plants having no other means of support. These are *saprophytes*. They are mainly Crypto-

28. The end of a growing root, tipped and protected by the root cap: *g*, the growing point. (Considerably magnified.)

gams of small size, but among them are several flowering plants. The Indian Pipe is common in woods, where its short stems push up in

29. An epiphytic Orchid with numerous aërial roots for the absorption of rain and dew. — SCHIMPER.¹

little groups through the leaf mold. The pale hue of its stem, leaves, and flower remind one of the toadstools in company with which it grows. The roots are adapted to absorb organic matters in solution from vegetable mold.

60. Parasitic roots. — Part of the roots of the Yellow *Gerardia* are, or may be, transformed by the development of suckers near their tips, by which they grow fast to the roots of other plants and steal nourishment (Fig. 30). At the same time the *Gerardia*, possessing

¹ A. F. W. Schimper, "Pflanzen-Geographie," 1898. An account of plants in the world-wide aspects of distribution and adaptation.

green coloring matter, is able like all green plants to provide for itself; and it does carry on the work of forming plant food in a quite normal

30. Roots of the Yellow Gerardia, some of them parasitic on the root of a Blueberry bush.

31. Plants of the Dwarf Mistletoe parasitic on a branch of the Spruce.

way even while taking the sap of other plants. This is, therefore, the case of a *partial* parasite.

61. Parasites proper, which strike their roots into the tissues of living plants, or form attachments to their surface so as to suck up their juices, are amongst the most interesting of all vegetable forms. Of this sort is the Mistletoe (Fig. 31),¹ the seed of which germinates on the bough where it falls or is left by birds; and the forming root penetrates the bark and engrafts itself into the wood, to which it becomes united as firmly as a natural branch to its parent stem; and indeed the parasite lives just as if it were a branch of the tree it grows

and feeds on. A most common parasitic herb is the Dodder (Fig. 32), which abounds in low grounds in summer, and coils its long and slender, leafless, yellowish stems — resembling tangled threads of yarn — round and round the stocks of other plants; wherever they touch, piercing the bark with minute and very short rootlets in the form of suckers, which draw out the nourishing juices of the plants laid hold of. Other parasitic plants, like the Beech Drops and Pine-

¹ Not the Mistletoe proper of the Old World. The plant represented is an American relative of the well-known European plant, very much smaller, and properly denominated the Dwarf Mistletoe.

sap, fasten their roots underground upon the roots of neighboring plants, and rob them of their juices.

62. Roots as holdfasts.—This function comes to be

of great importance as the plants become tall and have to stand against the violence of the winds. And so the main roots of a tree, spreading abroad underground, correspond in girth with the largest of the branch trunks spread in the air above. They increase, like the trunk and limbs, by the annual formation of wood. Yet notwithstanding their great size and strength, every heavy wind storm leaves here and there a tree overturned.

32. Dodder parasitic on the stem of an herb. Note the absence of leaves (except a few small scales, *l*), the development of sucking roots, *h*, and the flower cluster. The plant has no connection with the ground, except in the seedling stage.

63. Roots for climbing are well shown by the Trumpet Creeper (Fig. 34). Near the nodes, on the shaded and moister sides of the stem, aërial roots are produced in longi-

tudinal rows, and become matted together like felt by means of the numerous root hairs that cover them throughout. As the young stems of the vine push upward close to the face of a wall or building, these webs of roots grow out until they strike the stone, when they flatten out and

become firmly glued to the surface. Firm support is thus afforded to the ascending creeper.

64. Roots used for storage.—The roots

of almost all plants that persist for more than a single season serve, in common with the stem, as organs of storage, to some extent. But their forms are not altered for the special purpose

33. A section through Dodder and host plant at the point where the *haustorium*, or sucker, of the former penetrates the bark of the host; *p*, stem of the parasite; *s*, sucker, piercing to the wood of the host, *h* (much magnified). — SACHS.

34. Roots of Trumpet Creeper, used in climbing.

35. Thickened storage roots in cultivated plants. On the left Carrot, on the right Radish. In both cases the root is confluent above with an exceedingly shortened stem bearing the leaves.

of storage in ordinary cases. Yet roots are sometimes much enlarged to hold the nourishment made by the plant during one growing season for its use in the next. Among the plants that owe their early appearance in the spring to food stored up in a somewhat fleshy root is the Dandelion (Fig. 42). In certain plants the tendency to a thickening of the root has been fostered by cultivation and selection until from the original wild stock, not more promising in the beginning than some of our common herbs, such useful food plants as the Beet, Turnip, Parsnip, and Radish have been produced. These make use of

the taproot alone (Fig. 35). The *Anemonella* (Fig. 36), flowering in early spring with the more familiar and closely related *Anemone*, draws upon supplies of food held in a cluster, or *fascicle*, of roots. A fine example of adventitious roots, some of which remain fibrous for absorption, while a few thicken and store up

36. *Anemonella thalictroides*. The early spring growth supplied from a fascicle of storage roots.

37. Roots of the Sweet Potato.

food for the next season's growth, is furnished by the Sweet Potato (Fig. 37).

DURATION OF ROOTS

65. Roots are said to be annual, biennial, or perennial. These terms apply also to the whole plant.

66. *Annuals*, as the name denotes, live only for one year, generally for only a part of the year. They are of course herbs;

they spring from the seed, blossom, mature their fruit and seed, and then die, root and all. Annuals of our temperate climates with severe winters start from the seed in spring, and perish at or before autumn. Where the winter is a moist and growing season and the summer is dry, *winter annuals* prevail; their seeds germinate

under autumn or winter rains, grow more or less during winter, blossom, fructify, and perish in the following spring or summer. Annuals are fibrous rooted.

67. Biennials, of which the Turnip, Beet, and Carrot are familiar examples, grow the first season without blossoming, usually thicken their roots, laying up in them a stock of nourishment, are quiescent during the winter, but shoot vigorously, blossom, and seed the next spring or summer, mainly at the expense of the food stored up, and then die completely.

68. Perennials live and blossom year after year. A perennial herb, in a temperate or cooler climate, usually dies down to the ground at the end of the season's growth. But subterranean portions of stem, charged with buds, survive to renew the development. Shrubs and trees are of course perennial; even the stems and branches above ground live on and grow year after year.

VII. LABORATORY STUDIES OF THE STEM

At the beginning of the study of the stem, it is well to recall the fact that a flowering plant typically consists of root, stem, and leaf. Stems and leaves may be so disguised as not to be readily recognized in their true character. Thus some stems are so modified as very closely to resemble leaves, while others assume the general appearance of roots. Yet there are, with few exceptions, certain marks of the stem proper even in these dissembled forms.

The Marks of the True Stem

1st. The stem is characterized by a general plan of construction, as viewed externally, differing essentially from that of either root or leaf.

What is the Plan?

2d. It bears appendages at certain definite places.

What are the Appendages?

Where inserted upon the stem?

3d. If the stem in question is an offshoot from an older one, its point of origin has a certain definite location. *Position* determines the fact that a lateral member is a *branch stem*, and not a leaf.

What is its Position?

These are the questions to be kept in mind in the following exercise.

EXERCISE XVII. THE CHARACTERISTIC FEATURES OF STEMS

Red Maple. — Examine with care all marks and features of form and the position of the branches and buds with respect to certain of these markings. Examine especially the newest parts. A low power of the hand lens brings out the desired points well.

Most trees and shrubs upon the approach of cold weather shield the tender extremities of their stems by numerous scales. When growth is resumed at the beginning of the next season, the scales fall away, leaving scars to mark the occurrence of winter. These are to be looked for on the material in hand, and noted as interesting traces of events in the recent history of the twigs. But such annual demarkations are not to be found on all stems. Refer to the questions immediately preceding this exercise, and answer them in the notes. The sections of the stem at which leaves are borne are called *nodes*; the lengths between leaves are *internodes*.

Draw the terminal, and one or two adjacent, annual lengths of the twig — enough to show all the points learned in the study.

EXERCISE XVIII. THE INTERNAL STRUCTURE OF STEMS¹

Looking at the plants of the fields about us, we perceive the greatest variety in the size, proportions, and attitude of stems. In some the stem is so short as to seem to be quite wanting, the leaves appearing to spring directly from the root. In other cases the stem, elongated, reclines upon the ground, or twines for support upon any object within reach.

Yet there is a prevailing type. Its erect habit and height most clearly show the purpose of stems in general. What is this purpose?

As height from the ground means encounter with winds, the tall stem must also be strong. Furthermore, the sap has a considerable distance to travel from the root to the leafy crown, and hence the conduction of water becomes one of the functions of the stem.

¹ See also Chapter XVII. If compound microscopes are available, the minute structure may be taken up more in detail than the directions here given require. In any case use should here be made of figures and explanations from Chapter XVII. The cambium region, especially, should be located even under the dissecting microscope, and its meaning explained.

These considerations lead us at once to examine the internal structure. We shall expect to find out whether the internal construction answers to the uses of the stem or not.

1. **A comparison of dicotyledonous and monocotyledonous stems.**—*Begonia* (*dicotyledon*), *Asparagus* (*monocotyledon*).

(1) Even a naked-eye examination of the cross sections, held up side by side to the window light, shows marked differences. Consider carefully wherein they are alike and wherein dissimilar, and write a comparative account of the cross sections as you see them.

(2) Place the *Begonia* section under the highest power of the dissecting microscope. Notice the following points:—

- (a) The central space is filled with a more or less irregular and indistinct network, in which some meshes (*cells*) of tolerably regular form may be made out.
- (b) Outside of this is an interrupted circle of somewhat wedge-shaped, denser spots, nearer the circumference than the center of the section.
- (c) Exterior to these is a region filled by a network of large cells. Toward the margin, however, the cells become gradually smaller.

The outermost layer of cells, which may not be distinguishable, is of a distinct nature, and forms the *epidermis*.

The three regions thus noted are characteristic of dicotyledonous stems. They are (*a*) pith, (*b*) hollow cylinder of wood, and (*c*) bark. Strictly the bark includes the outer ends of the elongated areas noted under (*b*), and only the inner half or two-thirds is wood. (The lens will probably show the division line.) In this fleshy herbaceous stem the wood does not form a complete ring in the cross section, it will be noticed. The *Lilac*, soon to be studied, will show an apparent difference in this respect.

Draw a sector of the cross section, showing the character of the three regions ($\times 5-10$).

(3) Examine in the same manner the section of *Asparagus*.

NOTE:—(*a*) The large cells composing by far the greater part of the section. They are replaced by cells of a different character in two instances; namely, in

- (b) The scattered darker parts which much resemble the denser areas in *Begonia*; and in
- (c) A distinct dense ring, not far from the edge of the section. Finally there is
- (d) The outermost zone, composed of round cells of uniform size (the *epidermis*).

The monocotyledonous stem has no separate region of wood including pith and surrounded by bark, such as one finds in dicotyledons. A cylinder of firm tissue (*c*), giving a degree of rigidity to the stem,

is found at or near the surface. Throughout the loose cellular tissue (*a*) the wood is scattered in bundles, or strands (*b*). The bundles are tough and add strength to the stem, and, more important still, furnish the means by which water ascends. The sap ducts appear in the cross section as large circular apertures on the periphery of the bundles.

Draw a sector (60°) of the monocotyledonous stem ($\times 5-10$).

2. The woody dicotyledonous stem.—Lilac.

(1) The first cross section examined should be of the end twigs; that is, of the stem not more than one year old.

NOTE:—(*a*) The pith.

(*b*) The wood, which seems now to be a solid ring. A high power of the microscope, however, would show traces of pith tissue running out to the bark between the wood wedges.

(*c*) The bark, beginning at the outer edge of the wood. Careful looking, aided by lenses of even moderate power, will show in the inner bark region a ring of somewhat glistening bodies, distantly resembling a string of beads. These are the ends of bundles of *bast fibers*. What is a possible use of strong fibers in this position in the twig?

Immediately under the dark outer line of the bark are several rows of *cork cells*, the examination of which may require the use of a compound microscope. What is the use, to the plant, of this layer of cork?

Draw a sector of the cross section (90°), to show these parts.

(2) Make smooth cuts across the twig of Lilac where it is one, two, and three years old respectively. Examine the ends with the lens. In what part of the stem (what part of the cross section) is new wood annually formed?

Draw the three cross sections in diagram ($\times 3$).

EXERCISE XIX. THE STRUCTURE OF WOOD (OPTIONAL)

First, decide which side of the block furnished for examination was toward the center of the trunk. Then note:—

(1) The annual additions of wood.

(2) The difference in appearance between spring wood and fall wood. What makes the difference (use lens)?

(3) The radiating lines, crossing all the annual layers (medullary rays).

These features are seen on the cross-sectional face. Look on the other faces for the ends of the medullary rays and the sap ducts.

Show by drawings the points learned from the study.

Examine also a piece of board containing a knot. Explain the

nature and origin of the knot. Are trees grown in the open, or those grown in a thick forest, more likely to give timber free from knots?

EXERCISE XX. THE ASCENT OF SAP IN THE STEM

Experiment 8.—In order to trace the course followed by the sap current as it passes from the root to the leaves, make use of water tinged with eosin. Put the cut end of the given (leafy) stem in the colored water. After fifteen or twenty minutes examine the stem. If it is translucent, like the Balsam (*Impatiens*), the course of the eosin water is readily seen without dissection. Note the branching of the conducting tissue at the nodes.

If the path of the coloring fluid is not seen from without, dissect.

Having determined the facts, write a statement, and illustrate by a diagram or diagrams.

EXERCISE XXI. GEOTROPISM OF THE STEM

The manner in which the growing plumule behaves toward the attraction of gravitation has been seen. It is well to find out whether the stem retains this power of reaction to the effect of gravity at a later date.

Experiment 9.—This may be done by turning an upright potted plant—as a young Sunflower or a young Nasturtium—into a horizontal position, pot and all. Make a diagram of pot, stem, and one or two selected leaves. Leave for a day. Then compare with the diagram. Indicate any changes by making dotted lines for the new positions.

Alternative. Experiment 10.—The leafy scapes of the Shepherd's Purse (*Capsella Bursa-pastoris*), not too old, make excellent subjects for this experiment. Fit the scape into a small bottle by splitting and grooving the cork. Fill the bottle quite full of water before inserting the scape and cork. Fix the bottle to a block with a rubber band, to keep the bottle from rolling when the arrangement is laid on its side. After making a diagram of the stem, etc., set it away in a safe place in a horizontal position until the next day.

Compare with the diagram. Represent any new position by dotted lines on the original diagram.

Write full notes.

NOTE:—The same scape will show the reaction of the stem to light in a marked manner, at least if taken while still freely growing. When the reaction to gravity is completely apparent, and the end of the scape has become vertical, place the scape, still in its bottle, so that it faces a window. In front and shading it place an opaque object two or three inches wide. Draw a diagram of the whole arrangement, and

note the time. Observe the scape again later, looking for a change from the original attitude of the stem.

EXERCISE XXII. SPECIAL USES AND FORMS OF STEMS

Creeping or underground stem. — Study the rhizome. Look for stem, leaf, and root. Which are present? What are the marks showing the true nature of stem, if that is present? What is the distribution of the roots, if present? If thickened, does the rootstock contain food in store?

Draw what is needed to illustrate your notes.

Tuber of Potato. — First, try to distinguish between the tip and the base of the tuber. By base is meant the end by which the Potato was originally attached to the Potato plant.

Holding the tuber right end up, examine it. With the lens look at several minute prominences within the depression of each eye. These are buds.

Below is a ridge, and frequently at its middle point may be seen a small, erect scale. What is the morphology of this scale (subtending a bud)? Test the pulp with iodine. Morphologically, what is the tuber? What is the proof? What is its purpose in the life history of the potato plant?

Draw an enlarged view of the eye, showing ridge, scale, and rudimentary buds ($\times 3-4$).

Houseleek. — (Optional.) Examine: (1) The green heads, with close-set, thickish leaves.

(2) The dull-colored, rootlike parts connecting them. Precisely whence do the latter spring? In what do they end, and how? Cut away leaves enough to determine these questions clearly. Have they any scars, scales, or appendages? What is their morphology? Proof? Cut a longitudinal section of one of the heads. Note the sudden enlargement of the axis at the point where the leaves begin to be crowded. Apply dilute iodine.

Compare the stem of Houseleek with the tuber of Potato in all respects, — as to organs present, the comparative development of these organs, the purpose of the whole, and any other points.

Draw the longitudinal section of the head.

Asparagus. — Select a sprig which branches several times. At the base of every branch at least one small, scalelike structure is found. What is it? Follow up the successive subdivisions of one of the branches, arriving finally at the smallest members of the ramification. At each dividing note a similar scale. Is it found at the foot of the needlelike "leaves"? If so, what is their morphology? Note the color of all parts of the plant. What is the function of stem in Asparagus?

Draw enough of the stem or stems to show the points discovered ($\times 3$).

Crocus.—Remove the scales. What is the morphology of the denuded bulb?

Draw the stem, showing *nodes*, *internodes*, *buds*, *stolons* (underground, propagative branches), if present.

Cut a cross section. Is the plant monocotyledonous or dicotyledonous? Test for starch. What is the life history of this plant?

Flowering Quince (*Cydonia Japonica*).

Draw a thorn, bearing a lateral bud, with accessory buds at the base, and the subtending leaf scar ($\times 3$).

Boston Ivy (*Ampelopsis Veitchii*).—Are the tendrils associated in any way with leaves or leaf scars? Answer in drawing ($\times 3$). Examine the tendril itself with the lens. Are there any indications of leaf formations at the bases of the branches? Answer in drawing ($\times 5$). What is the use of the flattened ends of the branches? Include these disks in one of the drawings.

VIII. THE STEM

69. The stem is the axis of the plant and the stock from which spring all the other organs. Side stems, or branches, spring from just above the axils of the leaves. Leaves are present on the stem of every flowering plant at some stage of its existence, though they may often be reduced to the merest rudiments. This is the case with stems that run along beneath the surface of the soil, where leaves would be of no use. But the tendency to produce leaves never quite disappears, and on underground stems manifests itself in scales and prominences at more or less uniform distances; the joints or nodes thus made, serving to distinguish such stems from roots, which they otherwise closely imitate.

70. The stem of an annual herbaceous plant is composed largely of living tissue, and is commonly seen to be green, pulpy, more or less translucent, and full of sap. A few strands of woody fiber run through it; but the general mass is succulent, and abounds in living substance. As age and height and the weight of foliage and fruit increase, woody strengthening tissue may be largely devel-

oped even in annual stems. If the plant is a perennial, especially if it grows to a considerable height, the wood increases and the living tissue becomes a relatively smaller part of the whole. In the stems of trees the living portions comprise only the growing tips of branches, the younger bark, and a film of active tissue just outside the wood. The bark (except those parts freshly formed), and the cylinders of wood, are essentially dead, and serve merely mechanical purposes in the support and protection of that which is alive.

71. The growth of stems. — Stems increase in length at or near the young tips. In plants of definite annual growth the number of internodes — or interspaces between leaves — is predetermined in the bud. Early in the following season these internodes gain their full extension and thereafter remain fixed in length. Girth increases through the formation of wood by the living tissue that surrounds the woody cylinder. Growth is, of course, interrupted as often as severe cold or extreme drought sets in ; and in those parts of the world where this is a regularly recurring event, the wood is formed in successive layers. When cut across, the layers appear as rings. Stems of trees and shrubs grown in temperate climates show in the cross section the spring wood — laid down when growth is particularly active — differing in color or texture from the fall wood. The age of trees, therefore, is easily made out when the trunk is cut off. Sometimes, however, two rings are formed in a single season, when midsummer drought interrupts the regular growth. Allowance must be made for these cases in estimating the age of trees.

72. The direction of growth. — Most stems grow upward : that is, toward the light ; for it is the benefit got by full exposure of the foliage to the sun that has led to tall stems. Leaves of tall-stemmed plants are raised out of the shade cast by crowding neighbors.

73. Upright stems include, besides the ordinary rigid and self-sustaining type, many climbing forms. Certain ones gain the advantages of elevation by twining upon the

stems of other plants for support (Fig. 38), and often grow until they spread their own leaves above those of the plants that they encumber. The way in which such climbers bend from side to side until they strike some vertical support may be told in the words of Darwin : —

38. Twining stem of the Morning Glory.

“When the shoot of a hop rises from the ground, the two or three first-formed joints, or internodes are straight and remain stationary; but the next-formed, whilst very young, may be seen to bend to one side and to travel slowly around towards all points of the compass, moving like the hands of a clock, with the sun. The movement very soon acquires its full ordinary velocity. From seven observations made during August, and on another plant during April, the average rate during hot weather and during the day is two hours eight minutes for each revolution; and none of the revolutions varied much from this rate. The revolving movement continues as long as the plant continues to grow; but each separate internode, as it becomes old, ceases to move.”

74. The revolutions are less rapid at night than in the daytime, but are maintained until some object of support is met with, when the free extremity still goes on revolving and the stem shortly encircles the support. The movement then continues in an upward-winding spiral, the coils tightening and the twiner steadily ascending.

75. Most species of twining plants wind in a definite direction. That is, as we look down upon the plant, the revolving tip moves with the hands of a watch lying face upward, in some species; opposite to the hands, in other species.

76. Another class of climbing plants includes those that simply clamber in a haphazard fashion through and over the surrounding herbage. The thorns of many Brambles and the minute backward-pointing hooks studding the angles of the stems and the margins of the leaves in

Galium (Fig. 39), catching on leaves and branches, prevent these climbers from slipping from their supports.

39. The stem and leaves of *Galium*, or Bedstraw, studded with backward pointing hooks (magnified).

If we attempt to pull a tangle of *Galium* away from the foliage of the herbs and shrubs over which it runs, the plant itself is torn in pieces before we succeed in dislodging it.

77. Of special organs for climbing, the clinging rootlets of the Trumpet Creeper have already

been described. Leaves, and parts of leaves serving the same general purpose, but adapted in a much more remarkable manner to a climbing habit, will be described in the next chapter. In the list of specialized climbing organs there still remain certain stems, modified into either adherent or twining tendrils.

78. Adhesive disks. — The Virginia Creeper illustrates the first case. The tips of certain branches are flattened into disks with an adhesive face (Fig. 40). This is applied

to the supporting object, to which it becomes firmly glued. Then a shortening of the branches by coiling brings up the growing shoot close to the support. This is an adaptation to climbing mural rocks and walls or the trunks of trees, to which the vine would not be able to cling by means of twining tendrils.

40. Tendrils of Virginia Creeper.

79. Twining tendrils. — Some tendrils are leaves or parts of leaves, as those of *Cobæa* (Fig. 73). The nature of a

tendrils is known by its position. A tendril from the axil of a leaf, like that of the Passion Flower (Fig. 41), is, of course, a stem, *i.e.* a branch.

80. In the young stage, when still extended, tendrils are endowed with motion and with sensitiveness to contact. Their movements are like those of twining stems, — they describe circles or ellipses until brought against some object.

41. Tendrils of the Passion Flower.

When, by the curving of the tip, a hold has been secured upon this object, the tendril coils in a double spiral. The coil or spiral itself is of importance in all such cases, for its elasticity prevents a sudden stress caused, for example, by a blast of wind, from snapping the tendril off, as might be the result were the tendril straight and already tightly drawn at the moment of onslaught.

“I have more than once gone on purpose, during a gale, to watch a Bryony growing in an exposed hedge, with its tendrils attached to the surrounding bushes; and as the thick and thin branches were tossed to and fro by the wind, the tendrils, had they not been excessively elastic, would instantly have been torn off and the plant thrown prostrate. But as it was, the Bryony safely rode out the gale, like a ship with two anchors down, and with a long range of cable ahead to serve as a spring as she surges to the storm.” — DARWIN.

81. The tendrils of the Passion Flower are wonderfully sensitive to slight pressure. In Darwin's experiments, “A bit of platinum wire, $\frac{1}{50}$ of a grain in weight, gently placed on the concave point, caused a tendril to become hooked, as did a loop of soft, thin cotton thread $\frac{1}{32}$ of a grain. The point of a tendril of *Passiflora gracilis* began to move distinctly in twenty five seconds after a touch, and in many cases after thirty seconds.”

82. So-called stemless plants. — At the opposite end of the scale from the plants with tall stems, rising as high as possible toward the sources of light, are those that, like the Dandelion (Fig. 42), reduce the leaf-bearing axis to the shortest possible span. Owing to the extreme brevity of the stem, and perhaps as well to the difficulty of

42. Root, shortened stem, buds, and leaves, of the Dandelion.

distinguishing the stem portion from the taproot, these plants are sometimes spoken of as stemless. A better term is *acaulescent* (which literally means *becoming stemless*). The summit of the stem—in the Dandelion—is at the level of the ground, or slightly lower.¹ Crowded together by the shortening of the internodes, the leaves radiate in

¹ The roots of some plants, after gaining a firm hold on the earth, contract and gradually draw the stem into the soil.

the form of a rosette, and pressing back the grass and other low herbage, make a way for the inflow of light. At the same time the stem, with the growing point and much of the foliage, is safe from the teeth of grazing animals: though it would be hard to say just how much this kind of security has had to do with the development of the shortened stem. For other advantages of the acaulescent habit may have played a part in the gradual acquirement of a shortened stem through successive generations of Dandelionlike plants; such as the increased moistness of the half-subterranean situation, and the relatively stable temperature of the soil.

83. Certain stems develop wholly beneath the surface, as we shall presently see, the leaves alone, with the flowering axis, appearing above ground. To such forms as these the Dandelion and other acaulescent plants offer a natural transition from the ordinary aërial type. In the buried stems the habit of taking refuge in the soil is fully formed. In the Dandelion it may be in process of formation. At least we may see in the latter one stage in the change of habit by which the Jack-in-the-pulpit, for example (Figs. 50, 173), has become, as to its stem, a confirmed dweller beneath ground.

84. Thus far only vertical stems, or stems of a more or less upright character, have been considered. There are all gradations between these and prostrate or horizontal forms, many species habitually taking a leaning attitude, between the vertical and the horizontal.

85. Of the creeping, or repent, kinds the Partridge Berry is a good example. It frequents moderately shaded situations, especially open woods, where it runs along upon the ground, striking root at short intervals and spreading its small, rounded, evergreen leaves quite close to the surface. Each year it is covered by the leaves fallen from the trees. These accumulate from season to season upon the older parts of the stem, which thus finally becomes partly subterranean through burial by the leaf mold, loses its leaves, and gradually decays at the older extremity. The young, growing sections of the shoot, not more than a year or two old, push forward continually, over the dead leaves, and thus remain subaërial. Such cases

as this perhaps represent the first step in the process of change by which the ancestors of our Bellwort (Fig. 20) and Bloodroot (Fig. 25) became subterranean in habit.

86. Stems for propagation; that is, for the establishment of new individual plants. Many plants reproduce their kind without the intervention of seed. Some part of the original plant is separated from the parent stock and develops into a new plant. This is termed vegetative reproduction, to distinguish it from reproduction by seed. The Potato is regularly propagated by this method, as also in the tropics are Sugar Cane, the Banana, and the Pineapple, none of which ordinarily produce seed.

43. Bulblets of the Tiger Lily.

87. A curious mode of vegetative reproduction is by the bulblets, or small bulbs, formed in the axils of the leaves of certain garden Lilies (Fig. 43), and often in the flower clusters of the Onion.

They never grow into branches, but detach themselves when full grown, fall to the ground, and take root there to form new plants.

88. A stolon is a branch from above ground, which reclines or becomes prostrate and strikes root (usually from the nodes) wherever it rests on the soil. Thence it may send up a vigorous shoot, which has roots of its own, and becomes an independent plant when the connecting part dies, as it does after a while.

89. An offset is a short stolon, or sucker, with a crown of leaves at the end, as in the Houseleek (Fig. 44), which propagates abundantly in this way.

44. Houseleek, propagating by offsets.

90. A runner, of which the Strawberry presents the most familiar and characteristic example, is a long and slender, tendril-like stolon, or branch from next the ground, destitute of conspicuous leaves. Each runner of the Strawberry, after having grown to its full length, strikes root from the tip becoming fixed to the ground, then forms a bud there, which develops into a tuft of leaves, and so gives rise to a new plant, which sends out new runners to act in the same way. In this manner a single Strawberry plant will spread over a large space, or produce a great number of plants, in the course of the summer, all connected at first by the slender

runners; but these die in the following winter, if not before, and leave the plants as so many separate individuals.

91. Subterranean stems and branches. — These are very numerous and various. The vegetation that is carried on

46. Rhizome of the Iris.

45. Rhizomes of the Peppermint.

underground is hardly less varied or important than that above ground. All their forms may be referred to four principal kinds: namely, the *Rhizome*, or *Rootstock*, the *Tuber*, the *Corm* or solid bulb, and the true *Bulb*.

92. The rootstock, or rhizome, in its simplest form, is merely a creeping stem or branch growing beneath the surface of the soil, or partly covered by it (Fig. 45).

93. Rootstocks are commonly thickened by the storing up of considerable nourishing matter in their tissue. The common species of Iris (Fig. 46) in the gardens have stout rootstocks, which are only partly covered by the soil, and which bear foliage leaves instead of mere scales, closely covering the upper part, while the lower produces roots.

94. A tuber may be understood to be a portion of a rootstock thickened, and with buds (eyes) on the sides. Of course, there are all gradations between a tuber and a rootstock. *Helianthus tuberosus*, the so-called Jerusalem Artichoke (Fig. 48), and the common Potato, are typical and fa-

48. Tubers of *Helianthus tuberosus*.

47. Corm or Caudex, of *Trillium*.

miliar examples of the tuber.

The stalks by which the tubers are attached to the parent stem

are at once seen to be different from the roots, both in appearance and manner of growth. The scales on the tubers are the rudiments of leaves; the eyes are the buds in their axils. The Potato plant rears annual stems that bear ordinary leaves expanded in the air, to digest what they gather from it and what the roots gather from the soil, and convert these substances into nourishment. A large part of this nourishment, while in a liquid state, is carried down the stem, into the underground branches, and accumulated in the form of starch at their extremities, which become tubers, or depositories of prepared solid food, — just as in the Turnip, Carrot, and Anemonella (Figs. 35, 36), it is deposited in the root. Taking advantage of this, man has transported the Potato from the cool Andes of Chile to other cool climates, and made it yield him a copious supply of food, especially important in countries where the season is too short, or the summer's heat too little, for profitable cultivation of the principal grain plants.

49. Cyclamen.

50. Indian Turnip (*Arisæma*).

95. The corm or solid bulb, like that of Cyclamen (Fig. 49), and of Indian Turnip or Jack-in-the-pulpit (Fig. 50), is a very short and thick fleshy subterranean stem, often broader than high.

96. The bulb, strictly so-called, is a stem like a reduced corm as to its solid part (or plate); while the main body consists of thickened

51. Bulb of White Lily. The longitudinal section shows two buds of the next year.

scales, which are leaves or leaf bases. These are like bud scales; so that in fact a bulb is a bud with fleshy scales on an exceedingly short stem. Compare a White Lily bulb (Fig. 51) with the strong scaly buds of the Hickory (Fig. 17), and the resemblance will appear. In corms, as in tubers and root-stocks, the store of food for future growth is deposited in the stem; while in the bulb, the

greater part is deposited in the bases of the leaves, changing them into thick scales, which closely overlap or inclose one another.

97. A scaly bulb (like that of the Lily, Fig. 51), is one in which the scales are thick but comparatively narrow.

98. A tunicated or coated bulb is one in which the scales enwrap each other, forming concentric coats or layers, as in Hyacinth and Onion.

99. Stems as foliage. — All green parts of the plant, whether belonging to the leaf or to the stem, serve the same purpose as the foliage to some extent; for example, the green twigs of a tree and the green stem of an herb.

52. Flattened leaflike stems of *Muhlenbeckia platyclados*, bearing flower clusters at the nodes.

A considerable number of plants have come to dispense with leaves entirely, modified stems doing their work. Thus, in the Asparagus what appear to be needle-like leaves are in reality branches springing from the axils of the true leaves; the leaves themselves being minute, dry scales. In *Muhlenbeckia* (Fig. 52) the nodes of the stem

are very well marked, but they bear only small temporary leaves or none at all. The stems are adapted to function as leaves by being flattened and by retaining the green color necessary for active foliage. Thus many desert

53. *Opuntia filipendula*. A Prickly Pear Cactus, and typical desert plant, having a thickened stem with green rind, numerous protective spines but no foliage leaves. The roots are partly transformed by tuberous swellings into organs of storage; when planted they grow, like the thickened roots of the Sweet Potato.

plants like the Cactuses (Fig. 53) have no foliage leaves. The green rind takes on their function. The total surface of these plants is thus very small compared with the surface exposed by a leafy plant of the same bulk, growing in moist climates. The water that the desert plants are able to obtain through their roots in the wet

season is therefore not lost, or lost only with extreme slowness, in the dry period.

100. To all more or less flattened stems thus modified to serve as foliage (*e.g.* *Asparagus*, *Muhlenbeckia*, Prickly Pear) the name *phyllocladia* (singular *phyllocladium*) has been given.

101. The longevity of trees.—The duration of the stem is the duration of the plant, for the stem is the permanent seat of life in plants, the part from which new organs arise and new shoots of the same individual are produced. When the stem dies, the plant as an individual perishes.¹ In considering stems, therefore, the length of life of plants is naturally suggested. Annual, biennial, and perennial are terms already explained in the chapter on the root. Many of the perennial herbs, such as the acaulescent kinds, live for a comparatively long time, without forming any considerable quantity of wood or much increasing the length of the stem, probably for a dozen or a score of years.² The continuance of life in shrubs and trees in these cases is often great compared with that of human life, and in not a few cases, is exceedingly great, so that single trees still living are known to have sprung from the seed long before any but the oldest of existing nations came into being. “The celebrated Lime of Neustadt in Würtemberg is between eight hundred and one thousand years old; the age of the Fir of Béqué is estimated at twelve hundred years, and a Yew in Braburn (Kent) is at least as old.”³ John Muir cites two cases of Sequoias, the Big Trees of California, determined by the annual rings as being respectively thirteen hundred and twenty-two hundred years old; though the latter was “not a very old-looking tree.” “Under the most favorable conditions these giants probably live five thousand years or more, though few of even the larger trees are more than half as old. I never saw a Big Tree that had died a natural death; barring accidents they seem to be immortal, being exempt from all the diseases that afflict and kill other trees. Unless destroyed by man, they live on indefinitely until burned, smashed by lightning, or cast down by storms, or by the giving way of the ground on which they stand. . . . The colossal scarred monument in the King’s River forest mentioned above is burned half through, and

¹ Though, as has been stated, the roots even when cut away—or when the stem is removed—may produce new buds. But these are out of the ordinary course of events, and in a sense result in new individuals, not the continuance of the old.

² The only available data seem to be casual observations. The subject is an excellent one for definite observations and record.

³ Strasburger, “Text Book of Botany,” 1898, p. 239.

I spent a day in making an estimate of its age, clearing away the charred surface with an ax, and carefully counting the annual rings with the aid of a pocket lens. The wood rings in the section I laid bare were so involved and contorted in some places that I was not able to determine its age exactly, but I counted over four thousand rings, which showed that this tree was in its prime, swaying in the Sierra winds when Christ walked the earth."¹

102. Types of adaptation. — Plants are machines fitted to do work under certain conditions. The work done by the plant is to take certain materials into itself, move them about, break them up chemically, recombine them into new compounds, and build up its body, adding to old parts and organizing new parts. Certain new parts finally become new individuals. Growth and reproduction, and the moving of materials for these purposes, are the work of the plant machine.

The conditions under which the work is done are dependent upon the nature of surrounding materials and the nature of certain forces affecting the plant. Of materials, there are soil, water, and air; of forces, chiefly heat and light. Each of these conditioning factors varies from place to place. The composition of the soil, the amount and purity of the water, even the composition and density of the atmosphere, change as we go from one part of the earth's surface to another. So, also, light is intense or feeble, and temperature high or low.

Every new condition requires a new adjustment of the running parts of the machine. It is peculiar to the machines which we call plants and animals that they have the power of becoming adjusted to new or changed conditions. Even in the individual plant there is often seen a certain degree of the capacity for accommodation. When we regard generations rather than individuals, this capacity becomes still further apparent. Finally, when we look at the whole history of plants we see that the plasticity of the plant machine is in the long run perfect (within certain limits). Thus, plants become accustomed to extremes of temperature. Arctic plants remain frozen for months without harm. At a temperature very near the freezing point, arctic and mountain plants are often active. On the other hand, tropical plants resist heat. In the Punjab (India), air temperatures of 120° Fahr. are not uncommon. Schimper states that in a hot spring of Venezuela certain low Algæ thrive at above 176° Fahr. The vegetable machine, then, has the power of adapting itself in the course of time to any kind of heat condition within the absolute death limits. And heat is taken merely for illustration. Adaptation to light and shade, or to variations of any other of the external factors of plant existence, might have been given.

Next, it is to be noted that plants of very different kinds often become adapted to like conditions by taking on much the same structural

¹ "The Mountains of California," by John Muir, p. 181.

features. That is, the general type of machinery that serves one species under given conditions comes to be assumed by all the species living under the same conditions. As a result we are able to distinguish certain types of adaptation prevailing wherever certain sets of conditions are found. The adaptation is seen in external form and in internal anatomy. The types are the most marked where the conditions are extreme.

1. *The Xerophytic Type* is exemplified in desert plants. The extreme condition is scarcity of water. The plant surfaces from which moisture might be lost (leaf surfaces, particularly) are in these plants reduced to the smallest limits. See, for example, *Opuntia*, in § 99, which at maturity is without foliage leaves. A similar form is exhibited by certain Spurges (*Euphorbia*) and Groundsels (*Senecio*), quite unrelated plants. The internal anatomy is characterized by the development of tissue for water reservoirs, and of a thick waterproof cuticular covering of the epidermis (see § 526).

Between the extreme desert type and that of ordinary plants there are all gradations. When leaves are present on xerophytic plants they are likely to be leathery, or thick and succulent, or thickly covered with hair; the pores (§ 527) are sunken in the thick epidermis and the leaf is often turned edgewise to light and heat. Xerophytic characters are found in plants growing in dry situations in ordinary, moist climates.

Other causes besides dryness of soil and air may lead to scarcity of water in the plant, at particular times or in particular locations. In temperate climates, for example, the winter brings frozen soil, and consequent arrest of absorption at the root. Hence, the plants are placed temporarily in xerophytic conditions, and most perennials meet the emergency by the loss of leaves. So, also, the coldness of far northern and high mountain soils produces a condition of drought, with the resultant appearance of xerophytic characters in the vegetation. Root absorption may also be diminished by the presence of salts dissolved in large quantities in the water about the root. Such an effect is wrought in salt marshes, and on sea shores above the tide, where the plants show characteristic xerophytic adaptations. Plants fitted to life in such conditions are termed *Halophytes*.

2. *The Hydrophytic Type*.—Submerged plants, and such as grow largely submerged in fresh water, are in general characterized by a thin epidermis, weak development of the framework, and large air passages traversing the entire plant body. These interspaces allow the penetration of air for respiration to submerged parts, as well as give buoyancy to floating parts. For characteristic forms of the leaves see §§ 130–135.

2. *The Mesophytic Type* of structure is that of plants living under ordinary conditions. The common tillage plants are Mesophytes.

It must be understood that the terms, Xerophyte, Hydrophyte, Mesophyte, are merely abstract designations for general types of adaptation. When we say Xerophyte, we mean any plant showing adaptation to a dry habitat. The same plant may be at different periods of the year mesophytic (as the Maple or Elm in summer) and xerophytic (as the same tree in winter).

IX. LABORATORY STUDIES OF THE LEAF

EXERCISE XXIII. THE ACTIVITIES OF THE LEAF

Experiment 11. — Select a healthy green *Nasturtium* plant. Place it in darkness for three days. Then cut one or two leaves, boil them in water, decolorize them in strong alcohol (this may take a day or so), and then treat with iodine to determine the presence or absence of starch.

Meanwhile, when the plant is first taken from darkness, cover a part of one of the leaves in the following manner: Cut disks from a cork stopper; place them on opposite sides of the leaf; stick two pins through both corks and leaf, to hold the corks in place. A portion of one leaf being thus entirely darkened, expose the plant for at least a day in sunlight. Then test two or three of the leaves, including the partly darkened one, for the presence or absence of starch, in the same manner as before directed. Compare with the former results.

Where is starch formed in plants? What is one condition of its production, as determined by this experiment? (There are other conditions.)¹

Experiment 12. — Pour a little water into a fruit jar, enough to cover the bottom. Put in a few leaves, with their stalks in the water. Put in, also, a small beaker with limewater. Close the jar tightly. Place the jar in the dark.

Arrange a second jar, water and limewater, without leaves, and place it beside the first.

After twenty-four hours examine the limewater in both beakers for the action of carbon dioxide, as in the experiment on respiration of germinating seeds.

Experiment 13. — Select a plant with a single stem below, bearing a good number of leaves. Wrap the pot in sheet rubber, which is to be brought up around the stem of the plant and securely tied. The evaporation of water from the pot and soil is thus prevented.

Weigh the plant as thus fixed, and record both weight and time. In doing this, set the scales in the sun if possible, and having found

¹ Experiment 6, from Ganong's "Teaching Botanist," may well be introduced here if the apparatus is available. See also Appendix, where important experiments are recommended.

the weight, leave the plant counterbalanced on the scales. In a relatively short time it will be seen whether the plant gains or loses.

Set the plant in a sunny or well-lighted place. If possible weigh again some hours later the same day; if not, the next day. Record weight and time.

Let the plant now remain in darkness as nearly as possible an equal length of time. Again weigh, and record weight and time.

What has caused the change of weight? (Before the answer is required, the next experiment will naturally have been done; there will be additional reason to assign the change of weight to one particular cause.) What effect has light upon the rate of change?

Experiment 14.¹—Two tumblers, a piece of pasteboard, a piece of sheet rubber large enough to cover the mouth of the tumbler, and a leaf, are needed. One tumbler is nearly filled with water. The pasteboard, with a hole in it, is placed on this tumbler. A puncture is made in the middle of the rubber, the rubber stretched, and the leaf-stalk put through the puncture. The leaf is now put on the tumbler, its stalk descends into the water through the hole in the pasteboard. The blade of the leaf is now covered with the second tumbler, and the apparatus set in the sun.

In a few minutes an effect, due to the activity of the leaf under the influence of light and heat, should be seen.

Experiment 15.—Relative activity of the upper and under sides of the *Begonia* leaf.—Two dry watch glasses are to be placed on opposite sides of a *Begonia* leaf (still on the plant) and held in place by a clip, or by two wooden strips and elastic bands, as in the figure. Two inclosed spaces are thus made, on the under and upper faces of the leaf respectively. Neither should be in direct sunlight. Examine the watch glasses for a deposition of moisture after fifteen or twenty minutes, or longer. Which side of the leaf exhales moisture the more rapidly?

Experiment 16.—Secure two mature leaves of the India Rubber Plant (*Ficus elastica*). After smearing the under face of one and the upper face of the other with vaseline, as well as the cut end of the leaf stalk in each case, so as to prevent the escape of moisture from these surfaces, hang the two leaves side by side to dry. When either one is

54. Method of holding watch glasses (*w*) upon *Begonia* leaf.

¹ Experiments 14, 15, and 16 may be given to different pupils, or groups, simultaneously, as one or two preparations of each experiment will serve for a whole class or division.

considerably dried, record the result and the conclusion as to which surface exhales vapor more freely.

Experiment 17. — A growing plant of *Nasturtium*, which has been standing for several hours in one position so that the light has steadily come from one direction, is to be observed. Do all the leaves face in one direction? Or several leaves? If so, mark the side of the pot toward which they incline with some distinctive mark (e.g., *A.B. 9.30*). Young leaves, or at least those not declining in vigor, should be chosen for record. In the notebook record the position of one of these leaves diagrammatically, as seen from above. The diagram will consist of a circle, for the pot; a radial line (marked *le*), for the petiole of the selected leaf; a line across the end of this, for the blade; and an arrow (marked *li*) outside the circle, for the direction of the principal body of light.

Note the attitude of the stem, as seen from the marked side of the pot. Represent it by a diagram: make a straight level line for the rim of the pot; another rising from this, for the stem. Record the time. Now expose the plant to strong light from a new direction. Indicate this on the first diagram by a second arrow (*li'*).

Leave till a change is plain. At length indicate the position of the selected leaf by new lines (*le'*) on diagram 1, and the attitude of the stem, as seen from the original side of observation, by a dotted line on diagram 2. If any movements of leaf blades are discovered, find how far they are due to the curvings of the petioles.

Experiment 18. — So-called sleep movements.

Note the position of the leaflets on seedlings of the Sensitive Plant (*Mimosa pudica*) when standing in the light. Now place over the pot carefully, without jarring the plants, a box or blackened bell jar, so as to exclude all light. In fifteen minutes or so, uncover carefully. What change in the position of the leaves? *Oxalis* may be used for this experiment. If *Lupine* or *Bean* is used, the time will be longer. They may be left in a dark closet over night.

Experiment 19. — Sensitiveness of *Mimosa*.

Use the seedlings of the last experiment. Touch one of the leaflets very gently. Touch others less gently. Note the several effects in any one leaf, and if they occur, the resulting effects on surrounding leaves. Are the cotyledons sensitive? Select a plant which is still in the normally expanded condition. Press a hot needle against one of the cotyledons, without shaking the plant. Wait for the effect.

If a large plant is available, apply a match flame to the tip of one of the leaves. Note what parts are affected in succession, and the manner in which the effect travels over the plant. Measure the greatest distance to which the effect is transmitted, and the time taken in transmission.

This experiment may be done before the whole laboratory division, one plant serving for all. If time and facilities permit, it will be of

interest to determine the effect of low temperature on the sensitiveness of the plant; temperature between 40° and 50°, for instance, to which the plant has been exposed for a few hours. The effect of varying the humidity of the surrounding air may be ascertained by keeping some well-moistened young plants under a bell jar, and comparing with others kept in a very dry place.

EXERCISE XXIV

(1) *The parts of a typical leaf.* — Draw the given leaf in simple outline to show *the blade; the petiole, or stalk; the stipules* (a pair of members at the base of the petiole, like leaflets).

(2) *The structure of the blade* ¹ — Examine the blade under the lens by transmitted light, shielding it from direct light.

NOTE: — (a) The translucence.

(b) The distribution of the green color.

(c) The relative thickness of the ribs and the rest of the blade (use direct light).

Trace the main framework of one half of the leaf, including in the drawing only the most prominent ribs and their conspicuous connecting veins.

How many ranks or orders of ribs and veins do you distinguish? Determine this as follows: Follow the midrib, then one of its large branches, then one of the main branches from this, — and so on; counting the number of turns made to arrive at the smallest veinlet's end.

Draw a small square to show the veinlets of the two or three lowest ranks, as seen through the lens.

Experiment 20. — Place a leaf with its stalk in water colored with eosin, and later trace the water courses of the leaf.

Experiment 21. — Take a wilted leaf, and after noting with care how flaccid it is, put it entirely under water for a day. Then note again the degree of rigidity.

Does contained water play any part in the support and stability of the leaf blade? ²

EXERCISE XXV

Take a shoot of the Pea three or four weeks old at least, with several leaves fully formed and a growing bud.

Note the stipules. Where is the growing tip of the shoot, and how is it protected? What two uses do the stipules here subserve? The

¹ For the minute structure see Chapter XVII.

² To determine whether in this experiment water is taken up readily through the general surface, use several uninjured leaves, some of which have the petioles raised above water.

lateral tendrils occupy the same relative positions on the main axis (or *rhachis*) of the leaf as what other parts? What is the morphology of the lateral tendrils? What three very distinct and different offices does the leaf of the Pea fulfill?

Draw the entire leaf with its parts labeled. Show (by another drawing if necessary) the mode of protecting the bud; indicate the position of the bud by dotted lines.

EXERCISE XXVI. TYPES OF VENATION

Consider the character of the veining, and the arrangement or plan of the framework, in the given leaves.

Compare and assort the leaves. Divide them into groups according to the similarities and differences in these respects.

Draw the margins and main structure lines of the several leaves (half the leaf will show the points wanted).

After the notes covering the above, write a concise description of each leaf, under the headings (1) Venation, (2) General Shape, (3) Margin, (4) Apex, (5) Base; referring to pages 77, 78, and 92-96 of this book for the proper terms.

EXERCISE XXVII. COMPOUND LEAVES

To which of the types of frame plan, studied in the last exercise, does each of the compound leaves correspond, in the arrangement of its leaflets? Are the leaflets jointed to the main stalk?

Draw the given leaves in simple outline. Label each with the proper descriptive term (see pages 96-99).

EXERCISE XXVIII. SPECIAL USES OR MODIFICATIONS OF THE LEAF

Barberry. — Study the leaves subtending the lateral buds or leaf clusters on a shoot of barberry. What is the use of these leaves?

Draw two or three examples to show transition from the foliage to the spinelike condition.

Onion. — The material suggested is the Onion "set," or young bulb, slightly sprouted. Note the outer, thin scales, — for what purpose are they formed? What are they morphologically? Cut the bulb in half, lengthwise. Study the parts. Note the *stem*, producing *roots*, and *leaves*. Some of the outer leaves are thickened, and do not extend upward. What is their use?

Draw the longitudinal section of the bulb, somewhat enlarged.

Foliage of Acacia (Optional). — What is the morphology of the flat, green appendages of the stem? Answer after noting (*a*) their position on the stem, (*b*) direction in which the surfaces look, whether to

sky and earth like normal leaf blades, or to right and left. Do they belong to the class of leaf formations or that of modified stems? They represent how much stem? leaf?

Draw the body in question, with enough of the stem to show the position.

X. THE LEAF

103. We have seen that as soon as the seedling comes up the cotyledons are spread, and the leaves of the plumule, if already formed, are shortly unfolded to catch the sunlight; and that even within the first day after emerging from the soil, the leaves of the seedling take on a deep green color, the sign of healthy activity in plants. In buds, leaves have been studied in their early stages and in the resting condition; and it has been seen how both above-ground and beneath-ground leaves are prepared long before they are needed as foliage, and are held in reserve in order that upon the return of warm weather in the spring the plants may begin with little delay to make new growth. The varied developments of the stem, as rigid shafts of great height, as twining or as climbing stems, have the object of displaying the leaves to the light to the best advantage. All these things point to the activity of the leaf in carrying on vegetable life.

THE OFFICE OF THE LEAF

104. The leaf is doubly active in nourishing the plant. In the first place, it absorbs, like the root; only, while the root takes up liquids and solutions, the leaf takes in gases. Secondly, the leaf is especially the organ in which solar energy is caught and stored by the formation of certain substances. These substances are the food of the plant,—using now the word *food* in the same sense in which it was used in the chapter on seeds and seedlings. The food formed in the leaf contains energy to be used in growth and motion.

105. The food provided for the seedling by the mother plant is of small amount. Very soon after germination

the seedling must feed itself. In the soil there is no supply of starch, oil, sugar, or the like, or, if there is a small proportion of these matters present through the decay of former vegetation, yet these would not be enough to furnish material for all the new plants that grow. If there is none at all,—if, for example, we grow the seedling in clear sand watered with distilled water, with the addition merely of a few mineral salts in very small quantity,—the young plant grows perfectly well. In other words, it is able to form its own food. This food it makes largely through the agency of its leaves.

106. Soil and air furnish the raw materials. These are water, sucked up by the root, and carbonic acid gas (carbon dioxide), absorbed by the leaf from the atmosphere. These two meet in the soft green tissue of the leaf. By the power of sunlight, in the presence of chlorophyll (the green coloring matter), the water and the gas are decomposed, and their elements recombined in such a manner that a solid makes its appearance; namely, starch. Starch is in its nature very like the living substance itself, and may be used in growth. It is then food, in the most appropriate sense of the word. Water, carbon dioxide, and small quantities of other substances, since they can be added only indirectly to the living substance, are not food in the same sense as starch.

107. The formation of organic substance (as starch) from these raw materials is called *carbon assimilation*; when brought about through the agency of light, as in all ordinary cases, it is called *photosynthesis*.

FORM AND QUALITIES OF THE LEAF

108. The form of the leaf results from its use. Thinness gives full exposure to light and good aëration. The leaf is translucent as well as thin, so that all parts of the tissue are reached by the energizing rays. It is comparatively strong and elastic,—qualities given by the woody framework of ribs and veins. The strengthening ele-

ments are also conduits of water and of the prepared plant food when this is drawn away from the leaf in a liquid form to other parts of the plant. The smallest veinlets penetrate to every section of the active green tissue, assuring an abundance of water. That water throughout the whole body of the leaf plays an important part in keeping the leaf elastic and outspread is seen when, from lack of watering, the leaves of plants wilt and droop.

109. The parts of the leaf.—When most highly developed, the leaf has three parts,—the *petiole*, or stalk, a pair of *stipules* at the base of the petiole, and the *blade*, or *lamina* (Fig. 55).

110. Stipules.—In the majority of leaves stipules are quite wanting; if produced at all, they are in many cases soon lost. In the Pea, however, where

55. Leaf of the Quince;
b, blade; p, petiole;
st, stipules.

56. Stipules of the
Locust tree, de-
veloped as pric-
kles.

the terminal part of the blade is converted into a tendril, the stipules are large and take part in assimilation. Ordinarily, the stipules originate when the leaf is very small, attain their growth early, and overarch and protect the young and tender blade; or, as in *Begonia* (Fig. 15), the stipules of each leaf regularly inclose and shield the younger leaves of the shoot. In very many winter buds the scales are of the nature of stipules. The chief use of stipules is, then, protective.

111. A special modification of stipules to serve quite other uses is seen in the case of the prickles of the Locust (Fig. 56).

112. In *Acacia spadicigera* the stipules are developed as hollow thorns, an inch or more in length, which become the dwelling places of certain small and exceedingly warlike ants. At the ends of the leaflets this *Acacia* bears small food bodies, rich in fat, and in special glands secretes nectar. These mate-

rials constitute the food of the thorn-inhabiting ants, for whose subsistence the tree seems thus definitely to provide. In return the warlike ants defend the *Acacia* from animal foes, in particular from leaf-cutting insects.

113. The petiole.—The petiole is sometimes lacking, and in this case the leaf is said to be sessile. The general office of the petiole is to aid in securing the best position for the blade in respect to light. This it would do merely by its length, since the space available for all the leaves around the stem is increased in proportion to the length of the petioles.¹ But further

57. An erect shoot of *Galium*. The whorled leaves spread in radiating directions about equally on all sides.

58. A prostrate shoot of *Galium*. The leaves now dispose themselves in horizontal positions, and without much over-shading of one by another.

than this the petiole, by its own movement, so disposes the blade that it receives the best illumination possible under any given circumstances (Figs. 57, 58). If a potted plant, not too old, is taken from a position where it has

been lighted from above or on all sides, and placed at a little distance from the window in a room where the light enters only at one side, and the plant is closely watched, it will shortly be seen that nearly all the leaves are very slowly moving. The whole plant indeed seems to be alive to the new direction of light and gradually turns its leaves in that direction. This result is effected by the leaf stalks, though young portions of the stem are pretty sure to take part in the general movement.

¹ Strictly the area in any one plane is proportional to the square of the length of the lines. If the petioles are doubled in length, the space available for the blades becomes quadrupled.

114. At the junction with the blade and at the base, next to the stem, portions of the petiole may possess a special structure by which more or less rapid movements are secured when the blade is stimulated through contact or injury or by changes in the intensity of light. These portions, marked off from the rest of the petiole and often somewhat swollen, are called *pulvini* (singular, *pulvinus*). They are well seen in the Bean and other plants of the same family.

115. Of periodic movements executed by the action of the petiole, the "sleep" movements of numerous plants are to be noted. Figure 59 represents the leaflets of the White Lupine at night. The blade is here divided into five or more parts, or *leaflets*. Each has a short stalk, or *petiolule*. When daylight fails, the petiolules bend more or less sharply downward. When this action is most vigorous, as in some of the younger leaves, the leaflets are brought closely together; and they are retained in this position with some force. With the return of daylight the petiolules are stimulated to elevate the leaflets again.¹

59. The "sleep" of the White Lupine.

116. When the cotyledons of seedlings exhibit sleep movements, they usually fold upward, the inner faces approaching each other more or less closely.

117. It must not be supposed that the lowering of leaves or leaflets in such cases is an act of resting on the part of the plant; although Linnæus gave the name

¹Try the effect of keeping seedlings of Clover, Oxalis, Bean, or Lupine in the dark until late in the forenoon, or even all day. Are the sleep movements habitual or effected only in response to change of illumination? Is lamp light or electric light bright enough to wake sleeping plants?

“Sleep of Plants” to all such movements from the evident suggestion of rest. A definite advantage is gained by the nocturnal position. The surfaces of the blades being vertical, or nearly so, and the several leaflets brought together in a cluster (in the case of compound leaves), there is less likelihood that the leaves will be chilled or, in cool climates, frost-bitten.

118. The “Sensitive Plant.”—The most striking exhibition of leaf movements after stimulation is perhaps given by the house plant, known from its peculiar behavior as the Sensitive Plant (*Mimosa pudica*). The merest touch on one of the leaflets causes the successive closing together of all the neighboring leaflets, or perhaps all parts of the entire leaf. If the shock is slightly increased, the effect may not only traverse the entire leaf and cause it to droop on the stem, but be transmitted to the other leaves as well.¹

119. Leaves without blades.—In a few cases the blade of the leaf is quite lacking, while its place is supplied by the enlarged and flattened petiole. Certain Acacias of Australia normally have no other

60. Terminal portion of the shoot of a seedling Acacia: 1, the last of the seedling leaves to show true blades; 2 and 3, bladeless, flattened petioles, or phylloides.

foliage. In the seedling, however, leaves appear bearing blades. As the seedling grows older, the petioles of these bladed leaves are seen to be flattened. Finally the blades fail altogether, on leaves produced at a little later stage, only *phylloides* (*phylloдия*) appearing (Fig. 60). The flattening is vertical, so that the phyllode (*phylloidium*) presents its edges

to earth and sky. This fact, even in the total absence of blade or blades, would distinguish these formations from normal leaf blades.

The Blade

120. Framework and venation.—The framework consists of wood, —a fibrous and tough material which runs from the stem through the

¹ The most remarkable effects are produced by applying a flame, as a match flame, to one of the terminal leaflets. The impulse to contraction may often be followed from one leaf to another over the whole plant. Measure the greatest distance to which the stimulus is transmitted.

leaf stalk, when there is one, in the form of parallel threads or bundles of fibers; and in the blade these spread out in a horizontal direction, to form the *ribs* and *veins* of the leaf. The stout main branches of the framework are called the *ribs*. When there is only one, as in Fig. 61, or a middle one decidedly larger than the rest, it is called the *midrib*. The smaller divisions are termed *veins*; and their still smaller subdivisions, *veinlets*. The latter subdivide again and again, until they become so fine that they are invisible to the naked eye. The fibers of which they are composed are hollow; forming tubes by which the sap is brought into the leaves and carried to every part.

121. *Venation* is the name of the mode of veining; that is, of the way in which the veins are distributed in the blade. This is of two principal kinds; namely, the *parallel-veined*, and the *netted-veined*.

122. In *netted-veined* (also called *reticulated*) leaves, the veins branch off from the main rib or ribs, divide into finer and finer veinlets, and the branches unite with each other to form meshes of network. That is, they *anastomose*, as anatomists say of the veins and arteries of the body. The Willow leaf, in Fig. 61, shows this

61. Reticulated venation of a Willow leaf. — ETTINGSHAUSEN.

62. Parallel venation of the Lily of the Valley leaf. — ETTINGSHAUSEN.

kind of veining in a leaf with a single rib. The Maple, Basswood, and Plane or Buttonwood show it in leaves of several ribs.

123. In *parallel-veined* leaves, the whole framework consists of slender ribs or veins, which run parallel with each other, or nearly so, from the base to the point of the leaf, — not dividing and subdividing, nor forming meshes, except by minute cross veinlets. The leaf of any grass or that of the Lily of the Valley (Fig. 62) will furnish a good

illustration. Such parallel veins Linnæus called *nerves*, and parallel-veined leaves are still commonly called *nerved* leaves, while those of the other kind are said to be *veined*, — terms which it is convenient to use, although these “nerves” and “veins” are all the same thing, and have no likeness to the *nerves* and little to the veins of animals.

124. *Netted-veined* leaves belong, with comparatively few exceptions, to the dicotyledonous plants; while *parallel-veined* or *nerved* leaves belong in general to the Monocotyledons. So that a mere glance at the leaves generally tells what the structure of the embryo is, and refers the plant to one or the other of these two grand classes. For when plants differ from each other in some one important respect, they usually differ correspondingly in other respects also.

125. Parallel-veined leaves are of two sorts, — one kind, and the commonest, having the ribs or nerves all running from the base to the point of the leaf, as in the examples already given; while in another kind they run from a midrib to the margin, as in the common Pickerel weed of our ponds, in the Banana, in Calla, and many similar plants of warm climates.

126. Netted-veined leaves are also of two sorts, as in the examples already referred to. In one case the veins all rise from a single rib (the midrib), as in Fig. 61. Such leaves are called *feather-veined* or *pinnately veined*: both terms meaning the same thing, namely, that the veins are arranged on the sides of the rib like the plume of a feather on each side of the shaft.

127. In the other case (as in Fig. 15), the veins branch off from three, five, seven, or nine ribs, which spread from the top of the leaf-stalk, and run through the blade like the toes of a web-footed bird. Hence these are said to be *palmately* or *digitately* veined, or (since the ribs diverge like rays from a center) *radiate-veined*.

128. Since the general outline of leaves accords with the framework or skeleton, it is plain that *feather-veined* leaves will incline to elongated shapes; while in *radiate-veined* leaves more rounded forms are to be expected.

129. The shape of the blade. — Infinite variety is exhibited by plants as regards the figure of the blade. Some of the chief influences to which the forms are owing are (1) the character of the natural surroundings, (2) the mode of folding and of growth in the bud, and (3) the advantage of certain shapes in respect to the equal illumination of all the leaves.

130. Natural surroundings. — As examples of the influence of the natural surroundings, or *habitat*, we may take aquatic plants with submerged, and again others with

floating, leaves. In general, submerged plants possess long and narrow, or *linear*, leaves (Fig. 63). Or, they may have leaves of a more or less rounded form, but much divided, or *dissected*, into linear parts (Fig. 64). Since submerged plants of many widely separated families in common show this type of leaf, — or these types, — the form must in some way be due to the circumstances of life in water. In exactly what

64. One of the submerged leaves of Cabomba, a near relative of the Water Lily.

respect these circumstances call for linear leaf forms is, however, an open question. They may be advantageous from any one or all of the following causes. *First*, light diminishes rapidly as depth

63. Fresh water Eelgrass.

of water increases. It will, therefore, be an advantage for the blade to reach upward as far as possible in its growth; that is, to take a linear form.

131. *Secondly*, the narrow and dissected forms have been attributed to the scarcity of carbon dioxide and oxygen in water. The amount of these necessary substances that will be absorbed by a leaf, other things being equal, is proportional to the extent of the surface in contact with the water. The more divisions the leaf has, or the longer and narrower it is, the greater the surface for any given quantity of tissue; and hence the more rapid the absorption of the dissolved gases.

132. *In the third place*, Sir John Lubbock has suggested that, while the forms under discussion do offer a large amount of surface relatively to the total mass of the leaf, we must not forget that the buoyancy of the water favors

the dissected or the slender conformation; in so far as the water supports the weight, to that extent a compact and rigid framework is rendered unnecessary. He compares such leaves as those of Cabomba (Fig. 64) to the gills of fishes, which while in water float apart, but have not enough strength to support their own weight, and consequently collapse in air.

133. *Finally*, it is evident that in running water and in waves the slender forms give readily to the movements of the water, and are therefore less likely to be torn than broader forms would be.

134. **Floating leaves** show as pronounced a tendency to become circular as the submerged ones to become linear. The circle, or ellipse, may be complete with the leaf stalk

65. Floating leaves: *a*, of the Water Shield; *b*, of the Water Lily.

running to the center, as in the Water Shield (Fig. 65, *a*). In this case, the form is said to be *peltate*. Or the circumference may be interrupted by a cleft, or *sinus*, leading to the summit of the petiole (e.g. the Water Lily, Fig. 65, *b*). The point of attachment of blade and petiole is the real base of the blade. The circle is filled out, in fact, by the growing backward of the blade at each side of the base. This leaf is described as *orbicular*, and *cordate* (heart-shaped), or *cordate cleft*, at the base.

135. We may suppose that the circle is the most advantageous form in leaf building, since the parts are equidistant from the petiole, and thus conduction of food

matters to and from the leaf stalk is most easily performed; and that floating leaves are free to acquire this shape because they do not overshadow one another.

136. Again, the rounded forms are plainly better balanced, ride the waves better, and are less likely to be tipped and partially submerged. It is important that the upper surface of floating leaves should be kept free, as is shown by the fact that they are coated with a waxy substance which prevents wetting, and which causes water thrown upon the leaves to roll away in all directions. The pores which admit carbonic acid gas and oxygen are in this upper surface. The circular blade with the petiole attached near the center is well adapted to keeping every part afloat.

66. Leaf of the Tulip Tree (*Liriodendron*).

67. Winter bud of *Liriodendron*, with some of the outer scales turned back.

137. The influence of the mode of folding of the blade in the bud on its final shape is well illustrated by the leaf of the Tulip tree (*Liriodendron*, Fig. 66). The end of the lamina is seen to be cut off, as it were, or *truncate*. There are also projections, or *lobes*, on either side. Figure 68 shows how the lobes, and recesses, and the truncation fit the space which the very young blade occupies between and around other parts of the developing bud. Figure 67 shows the blade, with its two halves flatly folded together, in the winter bud.

138. The benefit of equal illumination for all the leaves may well be the cause

of many leaf shapes. Leaves standing side by side on the same bough or around the same stem are thus shaped

68. A young bud of *Liriodendron*, much enlarged, showing the manner in which the blade of a young leaf is shaped in its growth by the configuration of the parts upon which it lies folded. — LUBBOCK.

so that they fit well together with little overshadowing. Divided and compound blades (see § 177) seem to be better than entire forms in the matter of allowing sunlight to filter through to foliage on lower parts of the stem.

139. Perhaps enough cases have been given to make it clear that the philosophy of leaf forms is to be sought in the circumstances of life of the different sorts of plants.

140. Division of the blade: the margin. — The margin of the blade may be even, or *entire*, throughout. Oftener it is more or less indented. If slightly irregular, and the projections are pretty sharp, the

margin is toothed, or *dentate* (Fig. 111); or, if the teeth point forward like those of a rip-saw, the margin is *serrate* (Fig. 110). If the depressions are rather deep and sharp, like cuts, the margin is *incised* (Fig. 115). Large projections, especially if somewhat rounded, are termed *lobes*. All degrees and kinds of marginal irregularity are similarly designated by proper terms for the ready description and recognition of the various species of plants: in two or three words the botanist may describe any one of the almost endlessly diversified shapes of leaves so as to give a definite idea of it.

141. Compound leaves. — The blade is often so deeply divided that it consists of quite separated parts. The blade (and the leaf) is then *compound* (Figs. 59, 124). Each part often has a stalklet of its own, and the stalklet (or *petiolule*) is often jointed with the main leaf stalk just as this is jointed with the stem.

142. Leaves with no distinction of petiole and blade. — The leaves of *Iris* show one form of this. The flat but narrow leaves of

Jonquils, Daffodils, and the cylindrical leaf of Onions are other instances. *Needle-shaped* leaves, like those of the Pine, Larch, and Spruce, are examples.

LEAVES OF SPECIAL CONFORMATION AND USE

143. Leaves for storage. — A leaf may at the same time serve both ordinary and special uses. Thus in those leaves of Lilies, such as the common White Lily, which spring from the bulb, the upper and green part serves for foliage and elaborates nourishment, while the thickened portion or bud scale beneath serves for the storage of this nourishment. The thread-shaped leaf of the Onion fulfills the same office, and the nourishing matter it prepares is deposited in its sheathing base, forming one of the concentric layers of the Onion. When these layers, so thick and succulent, have given up their store to the growing parts within, they are left as thin and dry husks.

144. Leaves as bud scales have already been studied.

145. Leaves as spines occur in several plants. A familiar instance is that of the common Barberry (Fig. 69). In almost any summer shoot most of the gradations may be seen between the ordinary leaves, with sharp bristly teeth and leaves which are reduced to a branching spine or thorn. The fact that the spines of the Barberry produce a leaf bud in their axils also proves them to be leaves.

69. The common Barberry.

70. Tendril leaves of *Solanum jasminoides*.

146. Leaves for climbing. — The leaves of several common climbing or clambering plants, one of which has been figured in another place (page 54), are roughened on the ribs and margins like the stem, as an aid to climbing. Even without roughening, the outstanding leaves and side-stems of plants of this general habit support the shoots as they weave their way through the thickets and latticed herbage. It is but a step from the mere resting of the leaf on chance supports to the habit of hooking over them, more or less; and but

another step to winding about them in the fashion of a tendril. The complete adoption of the clasping habit,

71. Tendril leaves of *Gloriosa superba*.

taken on in this case by the petiole, is seen in the *Solanum jasminoides* of the gardens (Fig. 70) and the common Clematis.

147. Or the tendril habit may originate in the blade itself. Thus the prolonged medium portion of the blade in *Gloriosa* (Fig. 71) curves round the supporting object. This is a simple leaf. Several compound

leaves, as those of the Pea and Sweet Pea, have the extremity of the main stalk, or *rachis*, developed

72. Tendril leaves of *Lathyrus Aphaca*, the stipules performing the duty of foliage.

into a tendril having all the qualities of the stem-tendrils before described. The leaflets also, in these cases, may be transformed for the same purpose. In

73. Tendril leaf of *Cobæa macrostemma*; *st*, main stem of the plant; *lf*, the extent of a single leaf.

Lathyrus Aphaca (Fig. 72) only the stipules remain to perform the offices of the blade.

148. One of the most remarkable of tendril leaves is that of the *Cobæa* figured herewith (Fig. 73). The tendril portion branches several times. Each branch again divides and subdivides. The final subdivisions are clawed (Fig. 74).

74. *a*, mode of attachment of the tendril tips to a support; *b*, the clawed extremity, enlarged.

Owing to the dichot-

omous—or two-forked—branching, neighboring claws

coöperate in catching slender objects coming into the axils

of the dichotomy, as the

jaws of a pair of ice tongs

act together in holding the

block of ice. The tendril,

therefore, catches with great

readiness upon anything it

may strike as the leaf is

swayed by the breeze. Yet

the leaf is far from depend-

ent upon the winds for mo-

tion. Like the extremity

of a twining stem, it makes

regular revolutions. The

leaf from which the figure

was drawn made complete

revolutions in one hour and

ten minutes, the end swing-

ing round a circle about one

foot in diameter. The mo-

tion is easy to see, since the

average rate of progress is about one-third the rate at

which the end of the second hand of a watch travels.

75. Coiling of the tendril after having fastened to a support.

average rate of progress is about one-third the rate at which the end of the second hand of a watch travels.

The actual motion is often faster than this, since the forward movement is interrupted by retracings of the path and by up and down or oblique deviations from the level course.

149. In case a twig or stem of another plant is encountered, the tendril bends round it and the clawed extremities catch in the bark (Fig. 74, a). The several divisions of the tendril, with their numerous hooks, lay hold on the newly found support, and soon twist about it, while the rachis shortens by coiling (Fig. 75), in the manner characteristic of tendrils.

150. The leaves of insectivorous plants.—The habitat of insectivorous plants is chiefly marshes, like peat bogs.

76. A leaf of *Drosera rotundifolia*, or round-leaved Sundew ($\times 2$).

Those that the student will be most likely to meet are the Sundews and Pitcher Plants. The commonest, Sundew (*Drosera rotundifolia*), is a little plant, generally acaulescent, with its five or six rounded leaves spread out horizontally in a rosette from two to four inches in diameter. The leaves are thickly set with hairlike organs (Fig. 76), each tipped with a glistening drop of sticky secretion. To judge from the number of small insects,

mainly gnats and flies, usually found sticking on the leaves of the Sundew, it seems not unlikely that the plants exercise upon them some attraction, perhaps through an odor, perhaps only by the brilliance of the clear secretion drops shining in the sun, and the color of the purplish glands.

151. The gland-tipped outgrowths are tentacles. The marginal ones are the longest, and when fully spread out in all directions, double the total diameter of the leaf. If

a small fly touches the viscid globule at the extremity of one of these tentacles, he is at once securely held; the liquid being extraordinarily sticky, and so tenacious when drawn out into little strings that considerable motion may be imparted to the whole leaf through a single filament before it is broken. In its efforts to free itself, the fly is likely to strike neighboring tentacles with its legs and wings. All the tentacles touched begin almost at once to bend inward, toward the center of the leaf. The fly is, in fact, finally deposited on the shorter tentacles of the blade. Then from all sides the tentacles converge toward the captured insect, and their glands pour upon it secretions of digestive fluid, which now begins to flow, resembling the digestive secretions of the animal stomach. The soft parts of the insect are dissolved and the products of digestion absorbed by the glands. Subsequently the tentacles re-expand, and the secretions dry up, so that the remains of the insect may be blown away or shaken off. The secretions appear again after a time, in readiness for new prey.

152. Bending of the tentacles was distinctly observed by Darwin ten seconds after excitation. The closing together of the tentacles takes from one to four or five hours. The tentacles expand again in from one to seven days, according to the nature of the exciting object.

153. Pitcher Plants. — Pitcher Plants, of the type represented by the genus *Sarracenia*, are also low bog plants. Their general habit, and the shape of their leaves — the upward-curving tube, the wing on one side, and the rounded, more or less arching hood at the apex, — are seen in the accompanying illustration (Fig. 77). In some species the hood quite overarches the mouth of the pitcher. Its surface and that of the throat of the pitcher are set with stiff downward-pointing bristles. The tube is habitually half filled with water, in which the fragments of insects, in all stages of decomposition, may be found in considerable quantities. In most species these insects have been lured by secretions of honey to the rim of the pitcher; and then slipping on the extraordinarily smooth

surface, their descent aided by the direction of the bristly

77. *Sarracenia purpurea*, the Pitcher Plant of the Northern United States.

hairs, they have fallen helplessly into the liquid below. The liquid exudes from the tissues of the leaf itself; though the spreading hood of *Sarracenia purpurea* must catch a certain amount of rain. To what extent the dissolution of the captured insects is promoted by digestive elements produced by the pitcher, to what extent by ordinary

decay, is not certain. It is held, however, that the organic solutions are absorbed and used by the plant.

154. Insects are caught in another way, and more expertly, by the most extraordinary of all the plants of this country, the *Dionæa* or Venus's Fly-trap, which grows in the sandy bogs around Wilmington, North Carolina. Here (Fig. 78) each leaf bears at its summit an appendage which opens and shuts, in shape something like a steel trap, and operating much like one. For when open, no sooner does a fly alight on its surface, and brush against any one of the two or three bristles that grow there, than the trap suddenly closes, capturing the intruder. If the fly escapes, the trap soon slowly opens, and is ready for another capture. When retained, the insect is after a time moistened

78. *Dionæa*, the Venus's Flytrap.

by a secretion from minute glands of the inner surface, and is digested.

155. The Bladderwort, one of the most interesting of our carnivorous plants, should be sought in still water of ponds and large pools—where it is common—and examined under the lens. *Nepenthes*, the East Indian Pitcher Plant, is not uncommon in greenhouses. In nature it grows as an epiphyte on trees.

156. The development of devices for entrapping animals, on the part of the carnivorous plants, has the following significance. These plants are found in places where nitrogenous compounds are scarce. If their roots reach soil, it is merely wet sand or mud, poor in combined nitrogen. Often the plants are aquatic or epiphytic. The animals caught are rich in nitrogenous food, and so supply just that nutritive element which could not otherwise be obtained.

157. Duration of leaves.—The leaves of such trees as the Elm, Maple, Chestnut, Linden, and so on, last but a single season and then fall off. Their leaves are deciduous; and the trees themselves are spoken of as deciduous trees, meaning trees with deciduous foliage. Evergreen leaves last more than one season at least. Those of the Pines and Firs persist for two to five years, or in some cases more. In the Conifer, *Abies Pinsapo*, the age of the leaf reaches sixteen or seventeen years.

158. The fall of deciduous leaves is not caused by their death. Even before they begin to turn yellow in the autumn, the disarticulation is begun which, when complete, allows them to drop away, leaving a clean scar. Before this event, a large part of the useful substances in the active tissue of the blade is withdrawn and saved to the plant. The brilliant colors of autumn foliage are the signs that the living matter is being chemically changed preparatory to this withdrawal. Frost and cold have only an indirect effect, if any, in bringing about the high coloration.

The Arrangement of Leaves

159. It has come to the student's notice in the study of buds and of the stem that leaves are given off from the stem in somewhat definite fashion; at least in such cases as that of the Horse-chestnut, where they occur in pairs, on opposite sides of the stem. The regularity would not be so apparent in the leafy branch of the Apple. Yet here, too, a little attention shows a pretty definite system in the disposition of the leaves. The study of leaf arrangement is called Phyllotaxy.

160. The attachment of the leaf to the stem is the *insertion*. Leaves are *inserted* in three different modes. They are

Alternate, that is one after another; or with only a single leaf to each node;

Opposite, when there is a pair to each node, the two leaves in this case being always on opposite sides of the stem;

Whorled or *verticillate*, when there are more than two leaves on a node, in which case they divide the circle equally between them, forming a *verticel* or whorl. When there are three leaves in the whorl, the leaves are one-third of the circumference apart; when four, one-quarter; and so on. So the plan of opposite leaves is merely that of whorled leaves, with the fewest leaves to the whorl; namely, two.

161. Phyllotaxy of alternate leaves.—Alternate leaves are distributed along the stem in an order which is tolerably uniform for each species. The arrangement in all its modifications is said to be *spiral*, because, if we draw a line from the *insertion* (i.e. the point of attachment) of one leaf to that of the next, and so on, this line will wind spirally around the stem as it rises, and in the same plant will commonly

bear the same number of leaves for each turn round the stem. That is, any two successive leaves will always be separated from each other by an equal portion of the circumference of the stem. The distance in *height* between any two leaves may vary greatly, even on the same shoot, for that depends upon the length of the *internodes*, or spaces between the leaves; but the distance as measured around the circumference (the *angular divergence*, or angle formed by any two successive leaves) is practically the same.

79. Three-ranked arrangement, shown in a piece of the stalk of a Sedge, with the leaves cut off above their bases; the leaves are numbered in order, from 1 to 6.

162. Two-ranked.—The greatest possible divergence is, of course, where the second leaf stands on exactly the opposite side of the stem from the first, the third on the side opposite the second, and therefore over the first, and the fourth over the second. This brings all the leaves into two ranks, one on one side of the stem and one on the other, and is therefore called the *two-ranked* arrangement. Next is the

163. Three-ranked arrangement,—that of all Sedges, and of White Hellebore. Here

the second leaf is placed one-third of the way round the stem, the third leaf two-thirds of the way round, the fourth leaf accordingly directly over the first, the fifth over the second, and so on. That is, three leaves occur in each turn round the stem, and they are separated from each other by one-third of the circumference (Fig. 79).

164. Five-ranked is the next in series, and the most common. It is seen in the Apple (Fig. 80), Cherry, Poplar, and the greater number of trees and shrubs. In this case the line traced from leaf to leaf will pass twice round the stem before it reaches a leaf situated directly over any below. Here the sixth leaf is over the first; the leaves stand in five perpendicular ranks, with equal angular distance from each other; and this distance between any two successive leaves is just two-fifths of the circumference of the stem.

165. The above arrangements of spirally placed leaves are the most common. A three-eighths or five-thirteenths divergence is not uncommon. It will be noted that the precise arrangement may be indicated by a fraction, thus: the two-ranked by $\frac{1}{2}$, the three-ranked

80-81. 5-ranked arrangement: 80, shoot with its leaves 5-ranked, the sixth leaf over the first, as in the Apple Tree; 81, diagram of this arrangement.

82. Opposite leaves of Eucalyptus, or Spindle Tree, showing the successive pairs crossing each other at right angles.

by $\frac{1}{3}$, the five-ranked by $\frac{2}{5}$, and so on with the $\frac{3}{8}$, $\frac{5}{13}$, and other arrangements, the whole fraction indicating the angular divergence of the leaves, while the denominator shows the number of vertical ranks. It will be seen that, beginning with $\frac{2}{5}$, any one of the fractions may be derived by adding the numerators of the two preceding fractions for the following numerator, and in like manner adding the two preceding denominators for the new denominator.

166. Phyllotaxy of opposite and whorled leaves.— This is simple and comparatively uniform. The leaves of each pair or whorl are placed over the intervals between those of the preceding, and therefore under the intervals of the pair or whorl next above. The whorls or pairs alternate or cross each other, usually at right angles, that is, they *decussate* (Fig. 82). Opposite leaves, that is, whorls of two leaves only, are far commoner than whorls of three or four or more members.

TERMS USED IN THE DESCRIPTION OF LEAVES

[Inserted for reference use by classes making the determination of plants a part of their course.]

167. Forms of leaves as to general outline.—It is necessary to give names to the principal shapes, and to define them rather precisely, since they afford easy marks for distinguishing species. The same terms are used for all other flattened parts as well, such as petals; so that they make up a great part of the descriptive language of Botany. Beginning with the narrower and proceeding to the broadest forms, a leaf is said to be

Linear (Fig. 83), when narrow, several times longer than wide, and of the same breadth throughout.

Lanceolate, or *Lance-shaped*, when conspicuously longer than wide, and tapering upwards (Fig. 84), or both upwards and downwards.

Oblong (Fig. 85), when nearly twice or thrice as long as broad and of uniform breadth.

Elliptical (Fig. 86), when similar to oblong but with continuously rounding sides.

Oval, when broadly elliptical, or elliptical with the breadth considerably more than half the length.

Ovate (Fig. 87), when the outline is like a section of a hen's egg lengthwise, the broader end toward the stem.

83–88. A series of shapes of feathered-veined leaves: 83, linear; 84, lanceolate; 85, oblong; 86, elliptical; 87, ovate; 88, cordate.

Orbicular, or *Rotund* (Fig. 97), circular in outline, or nearly so.

A leaf which tapers toward the base instead of toward the apex may be

Oblanceolate (Fig. 89), when of the lance-shaped form, only more tapering toward the base than in the opposite direction.

Spatulate (Fig. 90), when more rounded above, but tapering thence to a narrow base, like an old-fashioned spatula.

Obovate (Fig. 91), when inversely ovate, that is, ovate with the narrower end toward the stem.

Cuneate, or *Cuneiform*, that is, *Wedge-shaped* (Fig. 92), broad above and tapering by nearly straight lines to an acute angle at the base.

168. As to the base, its shape characterizes several forms, such as *Cordate*, or *Heart-shaped* (Figs. 88, 94), when a leaf of an ovate form, or something like it, has the outline of its rounded base turned in (forming a notch or *sinus*), where the stalk is attached.

Reniform, or *Kidney-shaped* (Fig. 96), like the last, only rounder and broader than long.

Auriculate, or *Eared*, having a pair of small and blunt projections, or *ears*, at the base, as in one species of *Magnolia* (Fig. 99).

Sagittate, or *Arrow-shaped*, where such ears are acute and turned downwards, while the main body of the blade tapers upwards to a point, as in the common *Sagittaria* or *Arrowhead*, and in the *Arrowleaved Polygonum* (Fig. 98).

89-92. Feather-veined leaves: 89, oblanceolate; 90, spatulate; 91, obovate; 92, wedge-shaped.

93-97. Various forms of radiate-veined leaves: 93, 94, cordate; 95, 96, reniform; 97, peltate.

98-100. Feather-veined leaves: 98, sagittate; 99, auriculate; 100, halberd-shaped or hastate.

Hastate, or *Halberd-shaped*, when such lobes at the base point outwards, giving the shape of the halberd of the olden time, as in another *Polygonum* (Fig. 100).

Peltate, or *Shield-shaped* (Fig. 97), is the name applied to a curious modification of the leaf, commonly of a rounded form, where the foot-stalk is attached to the lower surface instead of the margin, and therefore is naturally likened to a shield borne by the outstretched arm. The common *Watershield*, the *Nelumbo*, and the *White Water Lily*, and also the *Mandrake*, exhibit this sort of leaf.

169. As to the apex, the following terms express the principal variations:—

Acuminate, *Pointed*, or *Taper-pointed*, when the summit is more or less prolonged into a narrowed or tapering point; as in Fig. 101.

Acute, ending in an acute angle or not prolonged point; Fig. 102.

Obtuse, with a blunt or rounded apex; as in Fig. 103, etc.

Truncate, with the end as if cut off square; as in Fig. 104.

Retuse, with rounded summit slightly indented, forming a very shallow notch, as in Fig. 105.

Emarginate, or *Notched*, indented at the end more decidedly; as in Fig. 106.

Obcordate, that is, inversely heart-shaped, where an obovate leaf is more deeply notched at the end (Fig. 107), as in White Clover and Wood-sorrel; so as to resemble a cordate leaf inverted.

101-109. Forms of the apex of leaves: 101, acuminate; 102, acute; 103, obtuse; 104, truncate; 105, retuse; 106, emarginate; 107, obcordate; 108, cuspidate, 109, mucronate.

Cuspidate, tipped with a sharp and rigid point; as in Fig. 108.

Mucronate, abruptly tipped with a small and short point, like a mere projection of the midrib; as in Fig. 109.

Aristate, *Awn-pointed*, and *Bristle-pointed*, are terms used when this mucronate point is extended into a longer bristle-form or slender appendage.

The first six of these terms can be applied to the lower as well as to the upper end of a leaf or other organ. The others belong to the apex only.

170. As to degree and nature of division, there is first of all the difference between

Simple leaves, those in which the blade is of one piece, however much it may be cut up, and

Compound leaves, those in which the blade consists of two or more separate pieces, upon a common leafstalk or support. Yet between these two kinds every intermediate gradation is to be met with.

171. As to particular outlines of simple leaves (or the parts of compound leaves), they are

Entire, when their general outline is completely filled out, so that the margin is an even line, without teeth or notches.

Serrate, or *Saw-toothed*, when the margin is cut into sharp teeth, like those of a rip-saw, that is, pointing forwards; as in Fig. 110.

Dentate, or *Toothed*, when such teeth point outwards, instead of forwards; as in Fig. 111.

Crenate, or *Scalloped*, when the teeth are broad and rounded; as in Fig. 112.

Reperand, *Undulate*, or *Wavy*, when the margin of the leaf forms a wavy line, bending slightly inwards and outwards in succession; as in Fig. 113.

Sinuate, when the margin is more strongly sinuous or turned inwards and outwards; as in Fig. 114.

Incised, *Cut*, or *Jagged*, when the margin is cut into sharp, deep, and irregular teeth or incisions; as in Fig. 115.

Lobed, when deeply cut. Then the pieces are in a general way called **LOBES**. The number of the lobes is briefly expressed by the phrases *two-lobed*, *three-lobed*, *five-lobed*, *many-lobed*, etc., as the case may be.

When the depth and character of the lobing needs to be more particularly specified, the following terms are employed, viz.:—

Lobed, in a special sense, when the incisions do not extend deeper than about halfway between the margin and the center of the blade, if so far, and are more or less rounded; as in the leaves of the Post Oak, Fig. 116, and the Hepatica, Fig. 120.

Cleft, when the incisions extend halfway down or more, and especially when they are sharp; as in Figs. 117, 121. And the phrases *two-cleft*, or, in the Latin form, *bifid*, *three-cleft* or *trifid*, *four-cleft* or *quadrid*, *five-cleft* or *quinquefid*, etc., or *many-*

116-123. Margins of deeply cut leaves: 116, pinnately lobed; 117, pinnately cleft; 118, pinnately parted; 119, pinnately divided; 120, palmately three-lobed; 121, palmately three-cleft; 122, palmately three-parted; 123, palmately three-divided, or trisected.

cleft, in the Latin form, *multifid*,—express the number of the *segments*, or portions.

Parted, when the incisions are still deeper, but yet do not quite reach to the midrib or the base of the blade; as in Figs. 118, 122. And

110-115. Kinds of margin of leaves: 110, serrate; 111, dentate; 112, crenate; 113, repand; 114, sinuate; 115, incised.

the terms *two-parted*, *three-parted*, etc., express the number of such divisions.

Divided, when the incisions extend quite to the midrib, as in the lower part of Fig. 119, or to the leafstalk, as in Fig. 123; which really makes the leaf compound.

172. The mode of lobing or division corresponds to that of the veining, whether *pinnately veined* or *palmately veined*. In the former the notches or incisions, or *sinuses*, coming between the principal veins or ribs are directed toward the midrib: in the latter they are directed toward the apex of the petiole; as the figures show.

173. So degree and mode of division may be tersely expressed in brief phrases. Thus, in the four upper figures of pinnately veined leaves, the first is said to be *pinnately lobed* (in the special sense), the second *pinnately cleft* (or *pinnatifid* in Latin form), the third *pinnately parted*, the fourth *pinnately divided*.

174. Correspondingly in the lower row, of palmately veined leaves, the first is *palmately lobed*, the second *palmately cleft*, the third *palmately parted*, the fourth *palmately divided*. Or, in other language of the same meaning (but now less commonly employed), they are said to be *digitately lobed*, *cleft*, *parted*, or *divided*.

175. The number of the divisions or lobes may come into the phrase. Thus in the four last named figures the leaves are respectively *palmately three-lobed*, *three-cleft* (or *trifid*), *three-parted*, *three-divided*. And so for higher numbers, as *five-lobed*, *five-cleft*, etc., up to *many-lobed*, *many-cleft*, or *multifid*, etc. The same mode of expression may be used for pinnately lobed leaves, as *pinnately seven-lobed*, *-cleft*, *-parted*, etc.

176. The divisions, lobes, etc., may themselves be *entire* (without teeth or notches), or *serrate*, or otherwise toothed or incised; or lobed, cleft, parted, etc.: in the latter cases making *twice pinnatifid*, *twice palmately* or *pinnately lobed*, *parted* or *divided* leaves, etc. From these illustrations one will perceive how the botanist, in two or three words, may describe any one of the almost endlessly diversified shapes of leaves, so as to give a clear and definite idea of it.

177. **Compound leaves.**—A compound leaf is one which has its blade in entirely separate parts, each usually with a stalklet of its own; and the stalklet is often *jointed* (or *articulated*) with the main leafstalk, just as this is jointed with the stem. When this is the case, there is no doubt that the leaf is compound. But when the pieces have no stalklets, and are not jointed with the main leafstalk, it may be considered either as a divided simple leaf, or a compound leaf according to the circumstances. This is a matter of names where all intermediate forms may be expected.

178. While the pieces or projecting parts of a simple leaf blade are called *lobes*, or in deeply cut leaves, etc., *segments* or *divisions*, the separate pieces or blades of a compound leaf are called **LEAFLETS**.

179. Compound leaves are of two principal kinds, namely, the *pinnate* and the *palmate*; answering to the two modes of veining in reticulated leaves, and to the two sorts of lobed or divided leaves (Figs. 116, 120).

180. *Pinnate* leaves are those in which the leaflets are arranged on the sides of a main leafstalk; as in Figs. 124–126. They answer to the *feather-veined* (i.e. *pinnately-veined*) simple leaf; as will be seen at once on comparing the forms. The *leaflets* of the former answer to the *lobes* or *divisions* of the latter; and the continuation of the petiole, along which the leaflets are arranged, that is, the leaf rachis answers to the midrib of the simple leaf.

124–126. Pinnate leaves: the first with an odd leaflet (*odd-pinnate*); the second with a tendril in place of uppermost leaflets; the third *abruptly pinnate*, or of even pairs.

181. Three sorts of pinnate leaves are here given. Fig. 124 is *pinnate with an odd* or *end leaflet*, as in the Common Locust and the Ash. Fig. 125 is *pinnate with a tendril at the end*, in place of the odd leaflet, as in the Vetches and the Pea. Fig. 126 is *evenly* or *abruptly pinnate*, as in the Honey Locust.

182. *Palmate* (also named *digitate*) leaves are those in which the leaflets are all borne on the tip of the leafstalk, as in the Lupine, the common Clover, the Virginia Creeper, the Horse-chestnut and Buckeye (Fig. 127). They evidently answer to the *radiate veined* or *palmately veined* simple leaf.

127. Palmate (or digitate) leaf of five leaflets of the Sweet Buckeye.

183. Either sort of compound leaf may have any number of leaflets; yet palmate leaves cannot well have a great many, since they are all crowded together on the end of the main leafstalk. Some Lupines have nine or eleven; the Horse-chestnut has seven, the Sweet Buckeye more commonly five, the Clover three. A pinnate leaf often has only seven or five leaflets, or only three, as in the Beans of the genus *Phaseolus*, etc.; in some rarer cases only two; in the Orange and Lemon and also in the common Barberry there is only one. The joint at the place where the leaflet is united

with the petiole distinguishes this last case from a simple leaf. In other species of these genera the lateral leaflets also are present.

184. The leaflets of a compound leaf may be either *entire* (as in Figs. 124–126), or *serrate*, or lobed, cleft, parted, etc.; in fact, may present all the variations of simple leaves, and the same terms equally apply to them.

185. When the division is carried so far as to separate what would be one leaflet into two, three, or several, the leaf becomes *doubly* or *twice compound*, either *pinnately* or *palmately*, as the case may be. For example, while the clustered leaves of the Honey Locust are *simply pinnate*, that is, *once pinnate*, those on new shoots are *bipinnate*, or *twice pinnate*, as in Fig. 128. When these leaflets are again divided in the same way, the leaf becomes *thrice pinnate*, or *tripinnate*, as in many Acacias. The first divisions are called *pinnæ*; the others, *pinnules*; and the last, or little blades themselves, *leaflets*.

128. A twice-pinnate (abruptly) leaf of the Honey Locust.

186. So the palmate leaf, if again compounded in the same way, becomes *twice palmate*, or, as we say when the divisions are in threes, *twice ternate* (in Latin form *bitermate*); if a third time compounded, *thrice ternate* or *tritermate*. But if the division goes still further, or if the degree is variable, we simply say that the leaf is *decompound*; either palmately or pinnately decompound, as the case may be. Thus, Fig. 129 represents a four times ternately compound (in other words a *ternately decompound*) leaf of a common Meadow Rue.

129. Ternately decompound leaf of Meadow Rue.

187. When the botanist, in describing leaves, wishes to express the number of the leaflets, he may use terms like these:—

Unifoliate, for a compound leaf of a single leaflet; from the Latin *unum*, one, and *folium*, leaflet.

Bifoliate, of two leaflets, from the Latin *bis*, twice, and *folium*, leaflet.

Trifoliate (or *ternate*), of three leaflets, as the Clover, and so on.

Palmately bifoliate, *trifoliate*, *quadrifoliate*, *plurifoliate* (of several leaflets), etc.: or else

Pinnately bi-, tri-, quadri-, or pluri-foliolate (that is, of two, three, four, or several leaflets), as the case may be: these are terse ways of denoting in single phrases both the number of leaflets and the kind of compounding.

XI. LABORATORY STUDIES OF THE FLOWER

The object of the flower is the bearing of seed for the reproduction of the plant. It is best to examine at once the seed rudiments with the parts in which they are borne, and those equally important products, the pollen grains, which act upon the seed rudiments to make them capable of growth into seed, as well as the organs which bear the pollen. After that the less important, though more showy, parts of the flower are to be studied.

EXERCISE XXIX. THE RUDIMENTS OF THE SEEDS

Look the flower over as well as possible, without pulling it to pieces, to see what the various parts are like. Note in a general way, without drawing, the number, arrangement, and varied shapes of the parts.

Remove the members at one side in order to get at the central organ, the *pistil*. Cut this off at the end gradually until white, seed-like bodies—the *ovules*—are brought to view.

Cut down the sides wherever necessary in order to split off the outer walls, so as to leave the ovules undisturbed and exposed to view in their natural positions.

Examine with the lens, noting:—

- (1) the arrangement;
- (2) the number of rows in each compartment;
- (3) the attachment of the ovules;
- (4) the number of compartments.

The hollow portion of the pistil is the *ovary*; its compartments are termed *cells*. The middle part of the ovary, where the walls of the cells meet, is the *axis*. The partitions between the cells are the *dissepiments*. The surface where the ovules are attached in a cell is the *placenta*; if there are several cells there are several *placentæ*. The manner in which the ovules are placed, as concerns attachment, is the *placentation*. If they are attached to the axis the placentation is *axile*; if to the walls of the cell, it is *parietal*.

Add to your notes a few words describing the pistil in hand as to the number of cells and the placentation.

Taking up a fresh flower, for the moment, note how the pistil ends above. The somewhat enlarged end with granular or loose tissue on the surface is the *stigma*. Below this the pistil is often narrowed, so

that the stigma is raised on a more or less slender column, the *style*. When seated on the ovary the stigma is *sessile*. Draw the pistil and label the parts.

Draw the ovary with walls removed, side view, to show the ovules in position ($\times 4-6$); end view, to show placentation and number of cells of ovary ($\times 3-5$).

Examine the ovules, removed, with the highest power of the dissecting microscope, or, perhaps, with a compound microscope. Draw a side view, including the little stalk of attachment to the placenta.

EXERCISE XXX. THE POLLEN

Examine the organs standing next to the pistil—the *stamens*. Find one opened and shedding its yellow, mealy contents, the *pollen*; and one not yet opened.

If a high power is available examine and draw the individual grains.

Cut a thin cross section of the unopened stamen to show the cavities in which the pollen is produced—the *pollen sacs*.

Note where the pollen sacs open, or *dehisce*.

Draw a stamen ($\times 2-3$). The stalk is the *filament*. The pollen-bearing terminal portion is the *anther*. The continuation of the filament, or the part that connects the pollen sacs, is the *connective*. Label all parts. Draw anther, side view, to show dehiscence ($\times 3-5$); cross section of anther showing the pollen sacs ($\times 5-10$).

The really essential parts of the flower have now been seen. The ovules, acted upon by the pollen, give rise to new plants. Many flowers have no other parts than pistils or stamens; that is, no protecting envelopes such as the brightly colored leaves of the flower which is now being studied. These leaves are of great service in promoting the transfer of pollen from flower to flower and in protecting the pistil and stamens while they are maturing. But they take only an indirect, not a strictly necessary, part, in reproduction.

EXERCISE XXXI. THE FLORAL ENVELOPES

Are there two sets of the floral leaves? Do they differ in any respect except in position? Draw one member of each set if there is a difference.

Examine one of the floral leaves under the lens with transmitted light, shading meanwhile from direct light, to discover any venation. If any is found indicate this on the drawing.

The leaflike organs together are the *perianth*. When in two distinct sets, the outer set is the *calyx*, the members being the *sepals*; the inner is the *corolla*, made up of *petals*.

EXERCISE XXXII. THE PARTS OF THE FLOWER IN RELATION TO ONE ANOTHER

Cut a new flower neatly in halves lengthwise.

Draw the half flower as seen from the cut side, to show :—

- (1) the shape of the pistil;
- (2) the relative positions and heights of the other parts.

The summit of the flower stem, generally somewhat enlarged, from which the organs spring, is the *receptacle*.

Looking down upon or into the flower, endwise, make out the relative position of the sepals, petals, stamens, and cells of the ovary.

When these have been made out definitely, make a diagram of the flower as seen from above, in the following manner :—

- 1st. Represent the ovary in cross section.
- 2d. In a circle—if so found in the flower—around the ovary, roughly indicate the cross sections of the anthers, properly placed as regards direction from the ovary cells.
- 3d. Represent petals by arcs of a circle, properly placed; the arcs may be thickened a little at the middle to represent midribs of the petals.
- 4th. Outside these draw similar figures for the sepals, in the proper places with respect to the other parts.

The diagram thus constructed shows the ground plan of the flower. The annexed figure shows the method of constructing such diagrams.

In case any two parts of the flower are grown together, as two petals, or a petal and a sepal, as sometimes happens, this fact may easily be indicated in the diagram by drawing a dotted line between the conjoined members.

129 a. Flower and floral diagram of Trillium.

EXERCISE XXXIII. THE ARRANGEMENT OF THE FLOWERS ON THE STEM OR STEMS: OR INFLORESCENCE

When flowers come in clusters they are found in one of two different types of inflorescence. Either a flower, early produced, ends the main stem of the cluster, so that no further growth of the cluster in the line of the axis is possible; in this case new flowers are produced only on side branches, and these side flowers are younger than that

on the central axis of inflorescence; or the cluster goes on growing in the main axis and putting out new flowers for a time,—so that the lower flowers are *older*, the upper ones younger. The first type is called *determinate*, or *cymose*; the second, *indeterminate*, or *racemose*.

Determine the type of inflorescence in the material furnished.

Draw a diagram of the arrangement of the flowers, letting lines represent the stems, branches, and individual flower stalks (or *pedicels*), and putting at the ends dots for the flowers, larger for the older, and smaller for the younger, flowers.

Turn to the figures of the different sorts of cymose and racemose inflorescences (page 140 and following), and select the proper term for the material in hand.

EXERCISE XXXIV. THE FLOWER OF A CONIFEROUS PLANT

1. *The Staminate Flower*

Cut a longitudinal section. Note the positions of the stamens. Draw the outline of the whole flower (or cone) and the central axis, and indicate the position and outline of two or three stamens.

Detach one stamen. Note its general form, and the number of pollen sacs. Do the sacs lie on the under or the upper side of the stamen? Find out about the place where the sacs open for the emission of pollen. Draw one stamen, so as to show the pollen sacs opened.

Are there any scales or other structures answering to the perianth of an angiospermous flower?

Note the size and number of the pollen grains and examine with the compound microscope if possible.

2. *The Pistillate Flower*

Before cutting into the flower (or cone), note the arrangement of the scales.

Note also the outstanding edges of the scales; this feature is related to the method of pollination.

Draw a simple outline of the cone, and then indicate diagrammatically the arrangement of the scales; that is, draw simple continuous lines for the boundaries of the rows of scales. Can you see rows in more than one direction? If so, draw the diagram accordingly.

Break the cone across. Separate one of the scales. On careful examination it will be seen that the scale is double, so that there seem to be two scales with a common base. The under one is the smaller. The upper one is the *placental scale*, or *ovuliferous scale*.

Examine the upper surface of the placental scale for two prominences near the base. Each has a few short filaments projecting toward the axis of the cone. The prominences are the ovules. The

filaments serve to catch the pollen when it has fallen upon the cone and down between the scales to the ovules.

Draw upper and under views, to show the two scales and the ovules.

FURTHER WORK ON THE FLOWER

The study of the flower, as far as many of the details are concerned, depends so much on the available material that specific directions had best be left to the teacher.

For suggestions as to **systematic study of flowering plants**, see the Appendix.

XII. THE FLOWER

GENERAL MORPHOLOGY OF THE FLOWER

188. The flower is destined to produce seed ; the seed, to bring forth a plant of the next generation. At the center of the flower bud, in their proper cavities the beginnings of the seed rudiments are distinguishable long before the flower is ready to open. If, after the bud

130. A flower of the Cherry Tree cut open to show the single ovule in its receptacle, the ovary.

131. The ovary of Mandrake opened at one side to show the numerous ovules, each containing the starting point of a new plant.

finally unfolds and the several envelopes separate, the receptacle seen within is cut open, one or two, often several, and not uncommonly very many, rounded bodies are discovered, — white, shining, and translucent, springing in definite and orderly arrangement from the walls or the central axis. These are the *ovules* (Figs. 130, 131). To these small vesicles the life of the species of plants which bear them is for a time intrusted: Each one car-

ries within it an inheritance of the racial characteristics. the forms of the leaves, the colors of the flower, the height and character of the stem, even the movements of the parent plant are passed down through the ovule (with the aid, as will shortly be seen, of the pollen) to the plant which is to spring from the ovule.

189. The ovule-bearing organ is the *pistil* (Fig. 132). Three parts are usually distinguishable: the hollow lower

132. Pistil of Wild Geranium; *ov*, ovary; *stl*, style; *stg*, stigma.

portion is the *ovary*; the column surmounting this is the *style*; and at the tip of the style—sometimes on its side—a part of the surface without epidermis and moist or even sticky, is termed the *stigma*. The style may be lacking; the stigma is then sessile on the ovary (Fig. 131).

190. The flower commonly contains but one pistil. Such flowers as those of the Pea and Bean illustrate the simplest case of all, when the pistil is solitary and has but one cavity with ovules borne on but one side of it. In the Buttercup (Fig. 133) there are many pistils, each simple, with a single cavity, containing but a single ovule. In the majority of plants, however, the two or more original pistils grow up from a very early stage in their development united throughout the greater part of their length. Compound pistils are thus formed. The several combined pistils are then termed *carpels*.

133. Flower of the Buttercup.

191. The portion of the ovary to which the ovules are attached is the *placenta*, and the manner in which the ovules are distributed on the interior surfaces of the ovary is the *placentation*. When the ovules are numerous, the placenta is apt to be a well-developed cushion or projection

of some sort (see Fig. 138). But the name applies even when no special outgrowth is to be seen.

192. Types of ovary and placentation.—When the pistils are separate and the ovaries, therefore, one-celled, the typical arrangement of the ovules in each ovary is in a double vertical row on the side nearest the center of the flower (Fig. 134). A solitary ovule may be suspended from the top of the cell, or spring from the side toward the flower axis, or rise from the bottom.

134. The several distinct pistils of a single flower. One cut across, and one cut lengthwise, to show the placentation.

193. When the pistil is compounded of several carpels, various arrangements of the parts are possible. The common one is that

135-137. Pistils: 135, a Saxifrage, the carpels or simple pistils united below, free above; 136, common St. Johnswort, the styles of the carpels distinct; 137, another St. Johnswort, the carpels united throughout.

194. With two or more cells and axile placentation (Figs. 135-137).—Such a pistil is just what would be formed if simple pistils, like those of the Larkspur, pressed together in the center of the flower, were to cohere by their contiguous faces. In such a case the placenta are naturally *axile*, or all brought together in the axis or center. The ovary has as many internal partitions, or *dissepiments*, as there are carpels in the composition. When such pistils ripen into pods they often separate along these lines into their elementary carpels.

195. One-celled, with parietal placentæ (Figs. 138, 139).—In this not uncommon case it is conceived that the several original carpellary cavities are thrown into one as the organ grows. The ovules now spring from the lines of junction of the different carpels. A placenta belongs here half to one carpel, half to another. At each placenta a double row of ovules is apt to be found; but the two rows originate from distinct carpels. The number of carpels is still to be told from the number of placenta. The placentation is here termed *parietal*.

196. One-celled, with free central placenta.—The free central placenta of the Pink (compare Fig. 140) have come about by the dissepiments having been suppressed in growth. Indeed, traces of the original partitions are often to be detected. On the other hand, it is equally supposable

138. Placentation of *Parnassia*.

139. Placentation of *Drosera filiformis*.

140. Pistil of *Spergularia rubra*, one of the Pink family, with free central placentation.

that in the Primrose (Fig. 160) the free central placenta has been derived from parietal placentation by the united carpels bearing ovules only at the base. Now, however, the placenta arises directly from the end of the floral axis, not from the carpels.

197. To the great majority of flowers with which one meets, one or another of the above types will apply. These types exhibit most clearly the structural principles of the pistil. Occasionally, some different mode of disposing the ovules or of separating the ovary into chambers will be discovered.

141. The flower of a Gymnosperm. At the right a single carpellary scale bearing two ovules.

198. Pistils of the Gymnosperms.—These are so distinct and the group of plants which produce them is so important that they need a separate description.

199. The fertile flowers of the Pine¹ and other trees of the same group appear in early spring as small richly colored cones (Fig. 141). The scales are soft, and though not very thin are

¹ What is here designated a single female flower is also spoken of as an inflorescence.

rather leaflike. Each fertile scale bears on its upper surface near the base a pair of ovules. In such flowers the pistils, therefore, are not closed, and the seed throughout its history is naked, *i.e.* exposed. Accordingly, the cone-bearing trees and their relatives are designated as GYMNOSPERMS (naked seeded).

200. The corresponding term for plants with closed ovaries is ANGIOSPERMS. Angiospermous flowers will be meant in this chapter unless otherwise stated.

201. The stigma has been described as a definite portion of the surface of the style, or, when the style is lacking, of the ovary. When the tip of the style is enlarged in a knob, or branched, or finely dissected in a plume (Fig. 166), it is convenient to speak of the whole organ — and not merely the surface — as the stigma.

Under the lens and even to the naked eye the stigmatic surface is distinguished by a granular texture and often by a viscid secretion, designed to secure the pollen grains which fall upon it or are brought to it.

202. For the ovules are not the sole conceptacles of racial life as it is passed onward from one generation to the next. Other and simpler bodies produced in the flower are equally freighted with inheritance, namely, the individual pollen grains, emitted in multitudes as yellow dust by the floral organs standing around the pistil or pistils. Each "grain" viewed through the microscope is seen to be a spherical body (Fig. 166) — in

142. Various forms of pollen, magnified, illustrating the manner in which the wall is sculptured in different species of plants.

many cases, however, elongated or otherwise modified — of the simplest description as regards structure. It consists of a minute portion of living substance of jellylike consistency, surrounded by a tough elastic coat or wall. As will shortly be seen, this body is capable of growth, and plays an equally important part with the ovule in the reproduction of plants.

203. The pollen-bearing organ is the *stamen* (Fig. 143)

143. *a*, a stamen; *p*, pollen sac; *c*, connective; *f*, filament; *b*, a stamen with the anther cut through at the time of maturity.

Its parts are the stalk, called the *filament*, and the *anther*, containing the pollen in *pollen sacs*. In the young condition of the stamen four longitudinal pollen sacs are found. The whole mass of tissue filling these sacs is finally converted to pollen. At maturity, if not before, the wall between the two cavities on

the same side of the anther commonly disappears, leaving a single pollen sac in either half-anther. The middle part

or axis of the anther between the two pouches thus formed is the *connective*.

204. The pollen sacs open for the liberation of the pollen usually by a slit along the groove running down each side of the anther; in *Pyrola* and other members of the Heath family, by terminal pores (Fig. 144); and in the Barberry by uplifting valves (Fig. 145). And other modes of dehiscence occur, suited to the various means by which the pollen is to reach its destination.

144, 145. Stamens: 144, of *Pyrola*, the anther opening by terminal pores; 145, of Barberry, the anther opening by uplifting valves.

205. The number of stamens is often large, as in the wild Rose, the Buttercup, the Magnolia, and the Water Lily. In a few species there is but one. Generally speaking, the number is small, not more than ten; and, when small, usually definite for each species. For example, most grasses have three stamens, most Mints four, the Violets five, and the true Lilies commonly six. Each pollen sac produces a vast number of pollen grains. And when the flowers borne

by the plant, or the stamens in the individual flowers, are very numerous, the pollen may be exceedingly abundant.

206. In a few families the stamens are regularly united, either by the anthers—as in the *Compositæ*, of which the Daisy is an example; or by the filaments, as in the Mallows and the *Leguminosæ* (e.g., the Sweet-pea, Bean, etc., Figs. 146–148).

207. The pistils collectively are known as the *gynæcium*; the stamens as the *androeium*. It is well to hold clearly in mind that these two groups of organs, though often concealed or rendered inconspicuous by the vicinity of highly colored floral envelopes, are essentially the flower. That is to say, pistils and stamens perform the essential function of the flower;

146–148. United stamens: 146, of a plant of the Pulse family; 147, in the Mallow family; 148, stamens united by anthers in the Composite family.

149–152. Flowers of a Willow: 149, staminate catkin; 150, one of the flowers; 151, pistillate catkin; 152, a pistillate flower.

and the floral leaves act a subordinate part. Not very rarely flowers consist of pistils or stamens alone. This is practically the case in the Willows. The familiar catkins are of two kinds. The more showy ones are made up of numerous flowers, each comprising stamens, usually two, with a scale at the base. In catkins of the other sort each minute flower is composed of

a single pistil with the basal scale (Figs. 149–152). The seed-bearing flowers of the Pine and other *Coniferæ*, as already described, contain only pistils; their pollen-bearing flowers, only stamens. When a flower lacks both gynœcium and andrœcium, it either becomes merely tributary to other, fertile flowers—as in the case of the marginal florets in the heads of the Sunflower—or it lacks altogether the essential character of a flower proper, as regards purpose, either directly or indirectly; as in the double Rose and other flowers transformed by cultivation.

208. The floral leaves together are called the *perianth*, meaning *about the flower*—a term not far from appropriate if what has just been said is allowed. Commonly, two distinct sets of these leaves are present: the inner called *petals*, together forming the *corolla*; the outer termed *sepals*, composing the *calyx*.

209. The number of sepals and petals in particular species is generally constant. In a majority of the Dicotyledons the sepals are five, and the petals five, though four is a common number; in Monocotyledons the members of the perianth are prevailingly in threes. As the stamens are apt to be as many or twice as many as the petals or sepals, a numerical plan is often prominent in the parts of the flower. We say that the flowers of the Dicotyledons are often *on the plan of five*, those of the Monocotyledons on the plan of three.

153. Flower of the Columbine.

210. Forms of the corolla. — As an example of the *regular* corolla—*i.e.* with petals all alike—the flowers of any of the Rose family may be recalled; but the Columbine (Fig. 153) as well, since *all* the petals are spurred, presents a regular corolla. In the Violet (Fig. 154), on the contrary, only one petal is spurred, and the petals

are of unequal size: such corollas, and all in which the petals are not entirely uniform, are *irregular*.

211. A second important respect in which corollas differ is in the separation or union of the petals. The trumpet-shaped corolla of the Morning Glory (Fig. 155) furnishes an extreme instance of union, where the

155. Calyx and corolla of Morning Glory.

original petals are not easily distinguishable. Frequently the *limb*, or border, is so lobed that the number of component parts is evident. Another familiar form is the two-lipped, *labiate*, corolla (Fig. 169).

151. Flower of the Violet: below, the parts of the perianth separated.

212. In case the petals remain quite separate, the corolla is said to be *poly-petalous*; but if they grow up united when the floral organs are in process of formation, the corolla becomes *gamopetalous*. When the petals are all wanting, the flower is *apetalous*.

213. The **calyx** presents features very similar to the corolla as regards union of sepals and other modifications. It is usually inferior to the corolla in size and coloration, since its service is chiefly to protect the bud, of which it forms the coat. But in numerous plants the calyx shares with the corolla in another duty.

214. **Functions of the perianth.** — The rôle of the perianth in the natural history of the flower is chiefly twofold: (1) it protects the developing organs within while the bud is coming to maturity; and (2) at the time of blooming it aids in the proper distribution of the pollen. Without anticipating the subject of fertilization, it may be said that it is of advantage to plants to secure the dusting of the stigma of each flower by the pollen of some other flower of

the same kind, and that this is most commonly accomplished by the aid of insects. The various forms of the perianth are, as a rule, very definitely related to the work of attracting the attention of insects, or of receiving and supporting them when they alight, or of guiding them to the "honey" or nectar secreted by special glands at the base of the flower. In view of such offices the labiate corolla of the Mints, the tubular or funnelform corolla of the Morning Glory, the spurred (nectariferous) petals of the Columbine, and the irregular flower of the Violet, are readily understood. This subject will be treated more fully under The Ecology of the Flower.

215. The receptacle of the flower is that part which belongs to the stem. It is commonly short, and some-

156. Section through a Strawberry.

what enlarged or knoblike. Flowers with very numerous pistils generally have the receptacle enlarged so as to give them room; it sometimes becomes broad and flat, as in the Flowering Raspberry; sometimes elongated, as in the Blackberry (Fig. 256),

the Magnolia, etc. It is the receptacle in the Strawberry (Fig. 156), much enlarged and pulpy when ripe, which forms the eatable part of the fruit, and bears the small seedlike pistils on its surface. In the Rose (Fig. 157), instead of being convex or conical, the receptacle is deeply concave, or urn-shaped. Indeed, a Rose hip may be likened to a strawberry turned inside out.

157. Longitudinal section of a Rose.

216. In *Nelumbo*, of the Water Lily family, the singular and greatly enlarged receptacle is shaped like a top, and bears the small pistils immersed in separate cavities of its flat upper surface (Fig. 158).

217. Arrangement of the parts of the flower.—This is most easily studied in those flowers, in which all parts are present—calyx, corolla, stamens, and pistils; in

which all the organs of each kind are separate from one another; and each set comprises a small number, as three or five. In such a case¹ it is the rule to find the organs in whorls,² and the whorls arranged so that the organs of one whorl stand above the spaces of the whorl below, just as is the case with whorled foliage leaves. The petals thus stand over the spaces between the sepals, the first row of stamens alternates with the petals, the second row of stamens (if present) with the first, and the pistils alternate with the stamens. When the various members of the flower are more numerous and the receptacle somewhat elongated, as in the *Magnolia*, the parts are spirally placed. In short, the organs of the flower are arranged like leaves.

158. The top-shaped receptacle of *Nelumbo*, the Water Chinquapin, ripening into a float for the dissemination of the seeds.

218. Morphology of the floral parts.—Sepals and petals are evident leaves, as they are commonly and properly

159. Transition from green outer floral leaves (sepals), through petals, to stamens, in Water Lily; indicating the unity of nature of sepals, petals, and stamens.

called. There are numerous cases where green forms, functioning as foliage, pass over by easy gradations to the white or bright-colored forms subserving the purposes of the flower. In shape, in fundamental structure (in possessing veins, etc.), and in arrangement on the axis, the parts of the perianth show the morphology of leaves.

Stamens and pistils, also, agree with leaves in the order of insertion on the axis, as well

¹ Sometimes called a *pattern* flower.

² A whorl is a circular group of several organs standing at the same level on the axis.

as in possessing what answer to the veins or ribs of leaves, —fibrous elements coming out from the flower stem. Occasionally stamens and pistils are found which have failed to develop in their proper character. They then take the shape of foliage leaves, more or less exactly. The conclusion is inevitable, from all these considerations, that the essential organs of the flower, as well as the floral envelopes, are morphologically leaves.¹

219. The carpels, in this conception, become leaves rolled inward, bearing on the inrolled edges rows of ovules. When the pistil is simple (of one carpel or leaf), a seam, the *ventral suture*, marks the closing together of the ovuliferous leaf on the side toward the center of the flower; while a ridge up and down the opposite side of the pistil evidently stands for a midrib.

220. Departures from a simple floral plan. — If one were to examine the first score of different flowers that he should meet on going into the field, he would probably find among them few or none that display the regularity, simplicity, and completeness spoken of in § 217. The fundamental plan — that is, the order and mode of growth, number of parts, etc. — would be found in many cases to be obscured by a variety of adaptations to the special functions of the flower. Some of the commonest modifications to be discovered are the following:—

221. Absence of some of the organs.²— Occasionally the gradual disappearance of some of the organs may be directly noted, as in stamens lacking the anther, or reduced to a mere ridge or rudiment; or in the reduction of one whorl of the perianth to an inconspicuous ring. In many of the trees and shrubs the perianth will be found to consist of only the calyx (*e.g.* in the Elm), or it may even be wanting (*e.g.* in the Buttonwood). And two cases have already been mentioned (the Willow and the Pine) where each flower contains but one kind of essential organ.

222. Union of like parts, or coalescence, of which examples have been given above.

¹ This is not to be construed to mean that what were once merely foliage leaves have in the course of time been modified so as to become carpels, stamens, etc. All that is to be inferred here is that both foliage leaves and floral organs have a common morphological nature, as foliar appendages of the stem.

² It is possible to suppose in some cases that the fewness of parts, or the absence of certain organs, has come about, not by reduction from more highly organized forms, but by inheritance from ancestry characterized by simple flowers from the first.

223. Union of unlike parts, or adnation. — Frequently the stamens seem to grow from the corolla, because the filaments have grown to the petals (Figs. 160, 161). Again, in the flower of *Cuphea*, for example, calyx, corolla, and stamens adhere in a cup around the pistil,

160. Flower of a Primrose laid open;
co, corolla; ca, calyx.

161. Flower of *Cuphea* laid open;
ct, calyx tube; pt, petals.

in such a manner that both stamens and petals seem to be inserted on the margin of the calyx tube (Fig. 161). Finally, in the Purslane (Fig. 162) all the different members are united, with the ovary in the center. The ovary is in such cases said to be *inferior*. When free from the organs, it is *superior* (Fig. 160). The adherence of unlike members is termed *adnation*. In the Purslane, for example, the calyx is said to be *adnate* to the ovary.

Coalescence and adnation come about in the following manner. The rudiments of the carpels, stamens, petals, and sepals appear at first as minute elevations on the young receptacle. As these increase the surface of the receptacle between them may be involved in the growth. Thus, if the tissue between the nascent petals is affected, a circular ridge arises, upon the edge of which the position of the original petal rudiments is indicated by prominences. The ridge, or ring, grows up into a longer or shorter tube (the corolla tube), the original prominences becoming lobes or divisions. By a similar process, in the Primrose (Fig. 160) the rudiments of the stamens become united to the corolla ring at an early stage. In the Purslane (Fig. 162) a single ring arising from the receptacle, and bearing all the floral organs on its summit, comes to form the so-called "calyx tube."

162. Flower of the Purslane.

PROCESSES LEADING TO THE FORMATION OF SEED

224. The student is already aware that the pollen is destined to reach the stigmatic surface of the pistil; and he probably also understands in a general way that the result of the pollination of a flower is the production of seed; that if pollination fails to be brought about, the ovules of the unpollinated pistil do not develop into fertile seed. The history of the pollen from its deposition on the stigma (*pollination*) onward and the resulting effect on the ovule (*fertilization*) are now to be followed.

225. The pollen grain has been briefly described as a simple vesicle filled with living matter, capable of growth. The wall is relatively strong, though thin and transparent, and often beset with projections. The living substance within, termed *protoplasm*, is more or less jellylike in

163. A pollen grain highly magnified. It contains two nuclei (*n*, *n'*) at the stage here represented.

consistency and clearness, but is far from being a simple mass of jelly. The protoplasmic body is in fact very definitely and highly organized; with permanent parts or organs performing definite functions in harmony with one another. These members may be dimly made out in the living protoplasm with the com-

pound microscope. But when killed and stained with proper dyes, the structure stands out with distinctness and its great complication is then seen. A constant component is a rounded central body of especially dense protoplasm, known as the *nucleus* (Fig. 163). In the earlier stages of the pollen grain there is but one nucleus. The pollen grain is then an excellent example of the typical vegetable cell.

226. Cellular structure of plants. — Every plant is made of minute members, or cells, essentially similar to the

pollen grain in internal constitution, though of course not as to form and external appearance. The cells of vegetable tissue take on various shapes. Generally their duration as living elements is limited. The walls become thickened and hardened and remain, after the death of the cells, as components of the plant's framework (*e.g.* the fibers of wood). The simplest plants among the cryptogams consist of but a single cell.

227. The pollen grain a plant.—

In truth the pollen grain itself behaves like a simple plant. For it absorbs water and nutriment from the pistil upon which it is deposited, and uses these materials in growth.

228. Growth is manifested in two ways: (1) in the formation of new nuclei in the protoplasm; and (2) in the extension of the wall in a tube

164. Fertilization of the ovule. The pollen tubes traverse the loose tissue of the stigma and style, finally emerging in the cavity of the ovary. In the figure a tube is represented as applying itself to the micropyle of an ovule. This ovule is seen in section, and shows at the micropylar end the embryo-sac with several nuclei, one of which takes part in the formation of the embryo.

the extension of the wall in a tube

(Fig. 164). The tube penetrates the tissue of the stigma and style, and at length reaches the cavity of the ovary, through which it descends until one of the ovules is reached. Penetrating the ovule at a certain spot, the tube comes in contact with the large cell, termed embryo sac, in which the embryo is to be formed (Fig. 164).

Before this time the original pollen nucleus has given rise, by division, to several nuclei. One of these nuclei, which has followed the tube in its descent, now passes over into the embryo sac and fuses with one of the several nuclei to be found there. From the united body so formed the new plant takes its start. New cells begin to appear in the embryo sac and the embryo gradually assumes form. At the same time the whole ovule, and in fact the entire ovary, begins courses of development resulting in seed and fruit respectively.

229. While every step of this process—which can be followed only by aid of the microscope and numerous dissections—may not be entirely clear to the beginner, the brief account here given should serve to fix in mind the fact that the pollen and the ovule play very definite and necessary parts in the life of plants; and the conception gained of the method and results of fertilization, even if somewhat incomplete, will give the flower and its varied forms an added meaning.

ECOLOGY OF THE FLOWER

230. Self-fertilization and cross-fertilization. — *Self-fertilization* is the action of a flower's pollen on its own ovules; *cross-fertilization*, on the ovules of some other flower of the same species.

231. A limited number of plants bear in addition to the ordinary flowers certain specialized flowers which are fertilized by their own pollen alone. The Violet is one of these. The vernal flowers are cross-fertilized. Later on another set, of a different appearance, are produced. The calyx remains permanently closed, while the corolla is undeveloped. Only two stamens reach maturity, and their

anthers are pressed against the end of the style. The pollen grains are few and unusually small. Fertilization is effected in the closed flowers, and abundant seed results, the pods seeding far more freely indeed than those of the ordinary flowers. In some species of Violet, these *cleistogamous* flowers are concealed under the leaves, or are borne on runners underground.

232. Self-fertilization prevented. — Many flowers are habitually fertilized either (1) by their own, or (2) by foreign pollen, — sometimes in one way, sometimes in the other, as chance decides. In the great majority of flowering plants, however, cross-fertilization is the rule. Self-fertilization may be absolutely prevented. This must be the case when the flower bears only pistils (is *pistillate*), or stamens (is *staminate*). Sometimes the staminate and pistillate flowers are produced on separate individual plants (when the plants are said to be *diœcious*); sometimes on the same plant (when the species is *monœcious*). An equally sure mode of preventing self-fertilization is seen where the pistils and stamens, though both present, are active at different times. This may well be illustrated by the common Plantain. The flowers are borne on long spikes. The unfolding of the flowers “proceeds from base to apex of the spike in regular order, and rather slowly. While the anthers are still in the unopened corolla and on short filaments, the long and slender hairy stigma projects from the tip and is receiving pollen blown to it from neighboring plants or spikes: a day or two afterwards, the corolla opens, the filaments greatly lengthen, and the four anthers now pendent from them give their light pollen to the wind; but the stigmas of that flower and of all below it on that spike are withered or past receiving pollen.”¹

233. When the stamens mature first, as in many flowers, the condition is termed *proterandry*. In the opposite case, *proterogyny*, which is less usual, the pistils have been fertilized or are no longer receptive by the time the anthers open.

¹ Asa Gray, “Structural Botany,” p. 219.

234. Agencies and adaptations for intercrossing.—The agents serving to transport pollen from flower to flower are wind, water, and small animals (mainly insects).

235. Pollination by wind.—Among the adaptations displayed by wind-pollinated flowers are to be mentioned the character and quantity of the pollen produced. Thus

165. A pollen grain of the Pine, provided with two air-filled vesicles to give buoyancy in the air.

the pollen grain of the Pine consists of three compartments, the two lateral ones empty and serving as wings (Fig. 165). "The immense abundance of pollen, its lightness, and its free and far diffusion through the air in Pines, Firs, and other Coniferæ, are familiar. Their pollen fills the air of a forest during anthesis; and the 'showers

of sulphur,' popularly so-called, the yellow powder which after a transient shower accumulates as a scum on the surface of water several or many miles from the nearest source, testifies to these particulars."¹ All catkin-bearing trees—except Willows—and most grasses and sedges are wind-pollinated. Their flowers are mostly

167. A versatile anther.

dull-colored, odorless, and destitute of honey. The stigmas are relatively prominent and apt to be plumose (Fig. 166). The anthers are often poised on the tip of the filament (Fig. 167), so that they are shaken by the wind.

As they turn readily in all directions they are said to be *versatile*.

166. Plumelike stigmas of a grass.

236. The pollen of aquatic plants is sometimes carried from one flower to

¹ Gray, "Structural Botany," p. 217.

another by the water, or water and wind together; the staminate flowers of the fresh-water Eel-grass, for instance, after being detached from the submerged heads, are driven like minute rafts before the wind, and collect about the much larger pistillate flowers on the surface.¹

237. A few species of plants are regularly cross-pollinated by snails, and others by birds.

238. Pollination by insects. — Cross-fertilization in flowering plants is brought about by aid of insects far more frequently than by all other agencies combined. A few cases will be described in some detail.

239. Lady's Slipper (*Cypripedium*) and the South American *Selenipedium*, Fig. 168, show a very perfect mode of compelling the insects that visit them to serve as pollen bearers. One of the petals is shaped into a sac, or labellum, open above and on either side near the base (*e*). The bee alighting on this labellum in search of the honey secreted by glandular hairs within,

168. Flower of South American *Selenipedium Schlumieri*. The dotted lines with arrow tips show the course followed by a visiting bee. In *b*, the flower is seen from the side, the labellum, or saccate petal, being cut open; *p*, a pollen mass; *s*, the stigma; *e*, exits.

and entering through the main opening, is prevented by the incurved edges of the latter, as well as by the depth of the labellum, from escaping except by one of the two

¹ See Kerner and Oliver, "Natural History of Plants," Vol. II., p. 132.

posterior openings, or exits (*e*). As it emerges through this rather narrow portal, it brushes against one of the pollen masses (*p*), which adheres to its head or shoulder. In the next flower visited, the bee in leaving encounters the stigma (*s*), and leaves on the surface some of the pollen brought from the former flower. Finally succeeding in crawling past this obstacle, it brushes a pollen mass from *this* flower, to be carried to the next; and so passes about, always taking away pollen, but not depositing it upon the stigma of the same flower.

240. Sage (*Salvia*, Fig. 169¹).—The corolla is two-lipped, as nearly always in the Mint family, the lower lip serving as a convenient landing stage for insects, while the upper, erect and arched, incloses the two anthers (*a*). The

169. Mechanism of the flower of *Salvia*; *a*, pollen sacs of the anthers, hidden under the upper lip of the corolla; *a'*, their position when dusting the back or sides of a bee; *c*, lobes against which the bee pushes in thrusting its head into the throat of the corolla; *s*, stigma, immature; *s'*, stigma when mature. In *A* the stamens are seen, removed from the corolla; *f*, filament on which the anther turns.

flower is proterandrous, and at the period represented in the figure the stigma is seen protruding from the upper lip, its two branches folded together. The stamens are inserted on the sides of the narrow throat and are hinged near the point of insertion. Each bears a projection (*e*) standing out and partly blocking the throat. When a bee pushes its head

into the corolla tube, these projections are pushed back, and the whole upper parts of the stamens are rotated on the hinges. The pollen sacs, heretofore concealed under the hood, are

¹ From Müller's "Fertilization of Flowers," by courtesy of the Macmillan Company, publishers, New York. The book is a valuable reference work.

brought down into the position *a'* and dust the bee's back with pollen. When the bee withdraws its head, the anthers resume their former station. At a later stage, after the pollen is exhausted or the anther withered, the stigma becomes receptive. It then occupies the position *s'*, and its branches spread to brush pollen from the back of a subsequent visitor.

241. Partridge Berry (*Mitchella*, Fig. 170). — The plant grows abundantly, as a small trailing herb with evergreen leaves,

170. Partridge Berry, with two forms of flowers.

in open woods. The blossoms are of two forms; namely, one form (*a*) with long style and low stamens, the other

(*b*) with short style and high stamens (Fig. 171). The stamens of form *a* are at about the same level as the stigma of form *b*; and the stamens of *b* are level with the stigma of *a*. An insect brushing the stamens of *b* with its sides will subsequently bring these pollen-dusted sides in contact with the stigma of *a*. The proboscis of the insect, smeared with pollen from the stamens

171. *a*, long-styled form; *b*, short-styled form, of flower in the Partridge Berry.

of *a*, will leave some of it on the stigma of *b*. When a species of plants bears two sorts of flowers, as regards the relative lengths of stamens and style, the flowers are said to be *dimorphic*. In many dimorphic flowers the pollen of *a* differs in size from that of *b*; and neither kind of pollen is capable of fertilizing the flower that produces it.

242. The opening and closing of flowers, according to the habits of the insects that pollinate them, — opening by

day when pollinated by diurnal, at night when by nocturnal, insects,—may be illustrated from a flower described by Sir John Lubbock.¹ It is the Nottingham Catchfly, a British and European plant related to our Chickweeds and Pinks. “Each flower lasts three days, or rather three nights. The stamens are ten in number, arranged in two sets; the one set standing in front of the sepals, the other in front of the petals. Like other night flowers, it is white, and opens toward evening, when it also becomes very fragrant. The first evening, toward dusk, the five stamens in front of the sepals grow very rapidly for about two hours, so that they emerge from the flower; the pollen ripens, and is exposed by the bursting of the anther. So the flower remains through the night, very attractive to, and much visited by, moths. Toward three in the morning the scent ceases, the anthers begin to shrivel up or drop off, the filaments turn themselves outward, so as to be out of the way, while the petals, on the contrary, begin to roll themselves up, so that by daylight they close the aperture of the flower, and present only their brownish green under sides to view; which, moreover, are thrown into numerous wrinkles. Thus, by the morning’s light, the flower has all the appearance of being faded. It has no smell, and the honey is covered over by the petals. So it remains all day. Toward evening, however, everything is changed. The petals unfold themselves; by eight o’clock the flower is as fragrant as before, the second set of stamens have rapidly grown, their anthers are open, and the pollen again exposed. By morning the flower is again ‘asleep,’ the anthers are shriveled, the scent has ceased, and the petals rolled up as before. The third evening, again the same process occurs, but this time it is the pistil which grows: the long spiral stigmas on the third evening take the position which on the previous two had been occupied by anthers, and can hardly fail to be dusted by moths with pollen brought from another flower.”

¹ Lubbock, “Flowers, Fruits, and Leaves,” Macmillan, 1894, p. 40.

243. The object of the insects' visits is usually a sweetish liquid, the nectar secreted by glands — commonly in the forms of swellings of the tissue of the receptacle — at the base of the flower. These are the *nectaries*. In flowers with spurred petals, like the Columbine, the nectar is secreted at the end of the spur, whence it can be sucked up only by the long-tongued insects, which are the most effective in transferring the pollen of these plants.

244. In addition to nectar, the pollen itself, a highly nutritious product, is sought by many insects.

245. Protection of the nectar. — Such a desirable food as the nectar is sure to be attractive to insects which, by reason of their size or habits, are not likely to make any return of service to the plant. Ants, for instance, travel all over the herbage in the vicinity of their nests in search of food. Happening upon the wells of honey within the flower, they would drink their fill, and perhaps bring their fellow-ants to the place, as their custom is, with the result that the flower would be drained of its nectar; but these visitors would be too small, in the case of many flowers, to brush the pollen from the tall stalked stamens, or deposit it on the stigma at the summit of the lengthened style. And, further, even were it possible for transference to be made by the adherence of the pollen to the bodies of the ants, the slow movements of these insects, their short-sightedness and blind wanderings, and their indiscriminate visiting of all sorts of plants would make them unprofitable carriers, as regards any one vegetable species, when compared with swift-flying, long-sighted, and often times discriminating insects like the various bees, butterflies, and moths.

246. Consequently, very many flowers are fortified against the invasions of the ants — and other undesirable visitors. One of the common and effective methods of defense is a coating of downward-pointing, or in cases sticky, hairs on the flower stalk or on the calyx. In some instances the secretion from the hairs not only prevents insects from going farther up the stalk, but holds any trespasser firmly, so causing its death.

247. The protection of the nectar from rain is effected sometimes by the habitually drooping attitude of the flower, sometimes by the bending or bowing of the flower stalk on the approach of rain, sometimes by some special construction of the flower.

172. Two of the florets in a head of Dandelion (diagrammatic).

248. The grouping of flowers in a specialized part of the shoot in a manner likely to secure the attention of insects, and so lead to the process of cross-fertilization, should be noted. The Dandelion (Fig. 172) and the Jack-in-the-pulpit (Fig. 173) may be taken as illustrations. In both these cases clusters of flowers are commonly mistaken for single flowers. The apparent "petals" of the Dandelion head are the several separate corollas of as many small flowers or *florets*. On close examination each of these florets is seen to possess its own two-parted stigma, and andrœcium of five stamens united around the style. What might pass at a casual glance for a calyx, surrounding the whole head, is a collection of subtending leaves (*bracts*) serving to protect the bud.

249. In the Jack-in-the-pulpit (Fig. 173), a fleshy spike of small flowers (termed a *spadix*) is surrounded and overarched by a single more or less striped or colored bract (termed in such a case a *spathe*),

173. Inflorescence of the Jack-in-the-pulpit. The bract (spathe) partly cut away below to show the fleshy spike (spadix) of flowers which it surrounds.

250. In both these cases, and countless others, the *inflorescence* — mode of arrangement of the flowers — is determined by the need of cross-fertilization.

EFFECT OF CROSSING

251. The arrangements for cross-fertilization are extremely varied and in many cases extraordinarily complicated. It could not well be doubted that such elaboration has been evolved because some important benefit is derived from intercrossing. And experiment goes to show that this is actually the case. When seeds derived from both self-fertilization and cross-fertilization of the same plant are grown side by side, the offspring of cross-fertilization generally outstrips that produced by self-fertilization. In spite of the fact that a small number of species are propagated indefinitely without intercrossing (seedless plants, reproduced vegetatively), and as far as is known without harmful results, the important truth remains that *intercrossing is a means of giving increased vigor to seedlings*.

Supplementary Reading

1. Adaptations for Securing Intercrossing. Gray's "Structural Botany," p. 220 and following.
2. The Pollination of Orchids. C. M. Weed's "Ten New England Blossoms," Nos. VI. and VII.
3. "The Mayflower." Same source, No. II.
4. The Industriousness of Bees, and the Perception of Color by Insects. Sir John Lubbock's "Flowers, Fruits, and Leaves," pp. 11-14.

Supplementary Studies: Fieldwork on the Ecology of the Flower

252. The account of adaptations to secure cross-fertilization given in this chapter is necessarily brief, hardly more than suggesting some general principles. Subjects not touched, but well worth study in the field, are: **Attraction of Insects** (*a*) by colors, (*b*) by grouping flowers, (*c*) by scent; **Opening of Flowers** at special times to receive special classes of insects; **Guides to Honey**, (*a*) spots and streaks, (*b*) conformation of floral parts; **Reward to Insects**, (*a*) honey and sap (with distribution and form of secreting organs), (*b*) pollen, (*c*) edible tissue, (*d*) shelter; **Dusting the Insect**, (*a*) by irritable stamens (Barberry), (*b*) by springing stamens

(Mountain Laurel), (c) by explosion ; **Movement of Stamens and Style**, (a) to avoid, (b) to secure self-fertilization ; **Protection of Pollen and Honey**, (a) against unwelcome visitors, (b) against weather, (1) by shape and position of the flower, (2) by bowing of the flower stem at times. This outline will serve as a working basis, which may be extended to include cases that arise in actual observation.

TERMINOLOGY OF THE FLOWER

[Inserted for the use of classes that are to take up the determination of flowering plants.]

For the student who is preparing to study Systematic Botany, a knowledge of the descriptive terms applied to the parts of the flower and the inflorescence is indispensable. The relationships of plants are more easily studied in their flowers than in the vegetative parts, because in the flower there are brought together in small compass so many sharply marked and readily described characteristics, varying slowly, for the most part, through wide ranges of related plants. Descriptions written to enable one to determine the names of the plants that he collects are accordingly based very largely on the flower. Many of the more usual terms — not already given — are now to be explained.

253. Terms relating to the general plan of the flower. Flowers are said to be : —

Perfect (hermaphrodite) when provided with both kinds of essential organs, i.e., with both stamens and pistils.

Complete, when, besides, they have the two sets of floral envelopes ; namely, calyx and corolla. Such are completely furnished with all that belongs to a flower.

Regular or actinomorphic, when all the parts of each set are alike in shape and size. Flowers of this type can be divided by at least two planes into equal and symmetrical parts.

Imperfect, or better, *unisexual*, flowers, in which some flowers lack the stamens, others the pistils. Taking hermaphrodite flowers as the pattern, it is natural to say that the missing organs are *suppressed*. This expression is justified in the very numerous cases in which the missing parts are *abortive*, that is, are represented by rudiments or vestiges, which serve to exemplify the plan, although useless as to office. Unisexual flowers are : —

174. Unisexual flowers of the Castor Oil plant : *p*, pistillate, *s*, staminate flowers.

Monœcious (i.e., of one household), when flowers of both sorts or sexes are produced by the same individual plant, as in the Ricinus or Castor Oil plant (Fig. 174).

Diœcious (i.e., of separate households), when the two kinds are borne on different plants; as in Willows, Poplars, and Moonseed (Fig. 175).

Polygamous, when the flowers are some of them perfect, and some staminate or pistillate only.

254. A blossom having stamens and no pistil is a *staminate* or *male* flower. Sometimes it is called a *sterile* flower, not appropriately, for other flowers may equally be sterile. One having pistil but no stamens is a *pistillate* or *female* flower.

175. Unisexual flowers of Moonseed, borne on different plants.

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255. *Incomplete flowers* are so named in contradistinction to complete: they want either one or both of the floral envelopes. Those of the Anemone (Fig. 176) are incomplete, having calyx but no corolla. The sepals, however, are highly colored and petal-like. The flowers of Saururus or Lizard's tail, although perfect,

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have neither calyx nor corolla (Fig. 177). Incomplete flowers, accordingly, are:—

Naked or *achlamydeous*, destitute of both floral envelopes, as in

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178, 179. Mustard: 178, flower; 179, its stamens and pistil separate and enlarged.

180, 181. Violet: 180, flower; 181, its calyx and corolla displayed: the five smaller parts are the sepals; the five intervening larger ones are the petals.

Fig. 177, or—

Apetalous, when wanting only the corolla. The case of corolla present and calyx wholly wanting is extremely rare, although there are seeming instances. In fact, a single or simple perianth is taken to be a calyx, unless the absence or abortion of a calyx can be made evident.

256. In contradistinction to regular and symmetrical, very many flowers are:—

Irregular, that is, with the members of some or all of the floral circles unequal or dissimilar. A special and important case of floral irregularity is shown by—

Zygomorphic flowers which, like

most of those in the Pulse and Mint families, can be divided by one and only one plane into two equal parts.

257. The relation of the perianth and stamens to the pistil is expressed by the terms *hypogynous* (i.e. under the pistil), when they are all *free*, that is, not adnate to pistil or united with each other, as in Fig. 182.

Perigynous (around the pistil), when adnate to each other, that is, when petals and stamens are *inserted* or borne on the calyx, whether

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as in Cherry flowers (Fig. 183) they are free from the pistil, or as in Purslane and Hawthorn (Figs. 184, 185) they are also adnate below to the ovary.

Epigynous (on the ovary), when so adnate that all these parts appear to arise from the very summit of the ovary, as in Fig. 186. The last two terms are not very definitely distinguished.

258. Position of the parts of the flower. — The terms *superior* and *inferior*, or *upper* and *lower*, are also used to indicate the relative position of the parts of a flower in reference to the axis of inflorescence. An axillary flower stands between the bract or leaf which subtends it and the axis or stem which bears this bract or leaf. This is represented in sectional diagrams (as in Figs. 187, 188) by a transverse line for the bract, and a small circle for the axis of inflorescence.

Now the side of the blossom which faces the bract is the *anterior*, or *inferior*, or *lower* side; while the side next the axis is the *posterior*, or *superior*, or *upper* side of the flower.

259. So, in the labiate corolla (Figs. 198, 200), the lip which is composed of three of the five petals is the *anterior*, or *inferior*, or *lower* lip; the other is the *posterior*, or *superior*, or *upper* lip.

260. Terms applicable to corolla and calyx.—*Gamopetalous*, said of a corolla the petals of which are coalescent into one body, whether only at base or higher. The union may extend to the very summit as in Morning Glory, the Datura (Fig. 189), and the like, so that the number of petals in it may not be apparent. The old name for this was *monopetalous*, but that means “one-petaled”; while gamopetalous means “petals united,” and therefore is the proper term.

Polypetalous is the counterpart term, to denote a corolla of *distinct*, that is, separate petals. As it means “many-petaled,” it is not the best possible name, but it is the old one and in almost universal use.

Gamosepalous applies to the calyx when the sepals are in this way united.

Polysepalous, to the calyx when of separate sepals.

261. Degree of union or of separation in descriptive botany is expressed in the same way as is the lobing of leaves. See Figs. 116–123, and the explanations.

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the **BORDER** or **LIMB**. The junction between tube and limb, or a more or less enlarged upper portion of the tube between the two, is the **THROAT**. The same is true of the calyx.

263. Some names are given to particular forms of the gamopetalous corolla, applicable also to a gamosepalous calyx, such as

Wheel-shaped, or *rotate*, when spreading out at once, without a tube or with a very short one, something in the shape of a wheel or of its diverging spokes (Figs. 194, 195).

Salver-shaped, or *salver-formed*, when a flat-

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262. A corolla when gamopetalous commonly shows a distinction (well marked in Figs. 191–193) between a contracted tubular portion below, the **TUBE**, and the spreading part above,

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spreading border is raised on a narrow tube, from which it diverges

196-200. Corollas: 196, a *Campanula* or Harebell, with a campanulate or bell-shaped corolla; 197, a *Phlox*, with salver-shaped corolla; 198, *Dead Nettle* (*Lamium*), with labiate *ringent* (or gaping) corolla; 199, *Snapdragon*, with labiate *personate* corolla; 200, *Toadflax*, with a similar corolla spurred at the base.

at right angles, like the salver represented in old pictures, with a slender handle beneath (Figs. 191-193, 197).

Bell-shaped, or *campanulate*, where a short and broad tube widens upward, in the shape of a bell, as in Fig. 196.

Funnel-shaped, or *funnel-form*, gradually spreading at the summit of a tube which is narrow below, in the shape of a funnel or tunnel, as

in the corolla of the common *Morning Glory* and of the *Datura* (Fig. 189).

Tubular; when prolonged into a tube, with little or no spreading at the border, as in the calyx of *Datura* (Fig. 189).

264. Although sepals and petals are usually all blade or lamina, like a sessile leaf, yet they may have a contracted and stalklike base, answering to petiole. This is called **CLAW**, in Latin *unguis*. *Unguiculate* petals are universal and strongly marked in the *Pink* tribe, as in *Soapwort* (Fig. 190).

265. Such petals, and various others, may have an outgrowth of the inner face into an appendage or fringe, as in *Soapwort*, and in *Silene* (Fig. 201), where it is at the junction of claw and blade. This is called a **CROWN**, or *corona*. In *Passion Flowers* (Fig. 202) the crown consists of numerous threads on the base of each petal.

266. Papilionaceous corolla (Figs. 203, 204).—This is polypetalous, except that two of the petals cohere, usually but slightly. It belongs only to the *Leguminous* or *Pulse* family. The name means butterflylike; but the likeness is hardly obvious. The names of the five petals of the *papilionaceous* corolla are curiously incongruous. They are,

The **STANDARD** or *banner* (*vexillum*), the large upper petal which is **external** in the bud and wrapped around the others.

201-202. Crowns: 201, *unguiculate* (clawed) petal of a *Silene*; with a two-parted crown; 202, a small *Passion Flower*, with crown of slender threads.

The **WINGS** (*alæ*), the pair of side petals, of quite different shape from the standard.

The **KEEL** (*carina*), the two lower and usually smallest petals; these are lightly coalescent into a body which bears some likeness, not to the keel, but to the prow of a boat; and this incloses the stamens and pistil. A Pea blossom is a typical example.

267. Labiate corolla (Figs. 198–200), which would more properly have been called *bilabiate*, that is, two-lipped. This is a common form of gamopetalous corolla; and the calyx is often bilabiate also. These flowers are all on the plan of five; and the irregularity in the corolla is owing to unequal union of the petals as well as to diversity of form. The two petals of the upper or posterior side of the flower unite with each other higher up than with the lateral petals (in Fig. 198, quite to the top), forming the *upper lip*; the lateral and the lower similarly unite to form the *lower lip*. The single notch which is generally found at the summit of the upper lip, and the two notches of the lower lip, or in other words the two lobes of the upper and the three of the lower lip, reveal the real composition. So also does the alternation of these five parts with those of the calyx outside. When the calyx is also bilabiate, as in the Sage, this alternation gives three lobes or sepals to the upper and two to the lower lip. Two forms of the labiate corolla have been designated, viz.:—

Ringent or *gaping*, when the orifice is wide open (Fig. 198).

Personate or *masked*, when a protuberance or intrusion of the base of the lower lip (called a *palate*) projects over or closes the orifice, as in Snapdragon and Toadflax (Figs. 199–200).

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268. Ligulate corolla.—The ligulate or *strap-shaped* corolla mainly belongs to the family of Compositæ, in which numerous small flowers are gathered into a head, within an involucre that imitates a calyx. It is well exemplified in the Dandelion and in Chicory (Fig. 205). Each one of these straps or *ligules*, looking like so many petals, is the corolla of a distinct flower: the base is a short tube, which opens

203, 204. A papilionaceous corolla: 203, front view; 204, the parts of the same displayed: *s*, standard, or vexillum; *w*, wings, or *alæ*; *k*, keel, or *carina*.

out into the ligule; the five minute teeth at the end indicate the number of constituent petals. So this is a kind of gamopetalous corolla, which is open along one side nearly to the base, and outspread.

269. In Asters, Daisies, Sunflower, Coreopsis (Fig. 206), and the

206. A slice of the Coreopsis head enlarged, with one tubular perfect flower (*a*) left standing on the receptacle, with its bractlet or chaff (*b*), one ligulate and neutral ray flower, and part of another (*cc*); *dd*, section of bracts or leaves of the involucre.

like, only the marginal (or *ray*) corollas are ligulate; the rest (those of the *disk*) are regularly gamopetalous, tubular, and five-lobed at summit; but they are small and individually inconspicuous, only the *ray flowers* making a show. In fact, those of Coreopsis and of Sunflower are simply for show, these ray flowers being not only sterile, but *neutral*, that is, having neither stamens nor pistil. But in Asters, Daisies, Golden-

rods, and the like, these ray flowers are pistillate and fertile, serving therefore for seed bearing as well as for show.

270. The Stamens.—First as regards their insertion, or place of attachment.

The stamens usually go with the petals rather than with the pistil, when adherent to either. Not rarely they are

Epipetalous, that is, inserted on (or adnate to) the corolla, as in Fig. 171. When free from the corolla, they may be

Hypogynous, inserted on the receptacle under the pistil or gynæcium.

Perigynous, inserted on the calyx, that is, with the lower part of filament adnate to the calyx tube.

Epigynous, borne apparently on the top of the ovary; all which is shown in Figs. 182–186.

Gynandrous is another term relating to insertion of rarer occurrence, that is, where the stamens are inserted on (in other words, adnate to) the style, as in Lady's Slipper (Fig. 207), and in the Orchis family generally.

271. In relation to each other, stamens are more commonly

Distinct, that is, without any union with each other. But when united, the following technical terms of long use indicate their modes of mutual connection:—

Monadelphous (from two Greek words, mean-

207. Style of a Lady's Slipper (*Cypripedium*), and stamens united with it; *a, a*, the anthers of the two good stamens; *st*, an abortive stamen, what should be its anther changed into a petal-like body; *stig*, the stigma.

ing "in one brotherhood"), when united by their filaments into one set, usually into a ring or cup below, or into a tube, as in the Mallow family (Fig. 208), the Passion Flower (Fig. 202), and the Lupine (Fig. 210).

Diadelphous (meaning in two brotherhoods), when united by the filaments into two sets, as in the Pea and most of its near relatives (Fig. 209), usually nine in one set, and one in the other.

Triadelphous (three brotherhoods), when the filaments are united in three sets or clusters, as in most species of *Hypericum*.

Pentadelphous (five brotherhoods), when in five sets, as in some species of *Hypericum* and in American Linden.

Polyadelphous (many or several brotherhoods) is the term generally employed when these sets are several, or even more than two, and the particular number is left unspecified. These terms all relate to the filaments.

Syngenesious is the term to denote that stamens have their anthers united, coalescent into a ring or tube; as in *Lobelia*, in *Violets*, and in all of the great family of *Compositæ* (Fig. 211).

272. Their number in a flower is commonly expressed directly, but sometimes adjectively, by a series of terms which were the names of classes in the Linnæan artificial system, of which the following names, as also the preceding, are a survival:—

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Monandrous, i.e. solitary-stamened, when the flower has only one stamen,

Diandrous, when it has two stamens only,

Triandrous, when it has three stamens; and so on.

Didynamous, when, being only four, they form two pairs, one pair longer than the other, as in the Trumpet Creeper, in *Gerardia*, etc.

Tetradynamous, when, being only six, four of them surpass the other two, as in the Mustard flower and most of the Cruciferous Family (Fig. 179).

273. The Anther is said to be

Innate (as in Fig. 212), when it is attached by its base to the very apex of the filament, turning neither inward nor outward;

Adnate (as in Fig. 213), when attached as it were by one face, usually for its whole length, to the side of a continuation of the filament; and

Versatile (as in Fig. 214), when fixed by or near its middle only to the very point of the filament, so as to swing loosely, as in the Lily, in Grasses, etc. Versatile or adnate anthers are

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Introrse, or *incumbent*, when facing inward, that is, toward the center of the flower, as in Magnolia, Water Lily, etc.

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Extrorse, when facing outward, as in the Tulip Tree.

274. Anthers may become *one-celled* either by confluence or by suppression.

275. By confluence, when the two cells run together into one, as they nearly do in most species of *Pentstemon* (Fig. 216), more so in *Monarda* (Fig. 219), and completely in the Mallow (Fig. 217) and all the Mallow family.

276. By suppression in certain cases the anther may be reduced to one cell or halved. In *Globe Amaranth* (Fig. 218) there is a single cell without vestige of any other. Different species of Sage and of the White Sages of California show various grades of abortion of one of the anther cells, along with a singular lengthening of the connective (Figs. 220–224).

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225, 226. Pollinia: 225, a pair of pollinia of a Milkweed (*Asclepias*) attached by stalks to a gland; moderately magnified; 226, pollinium of an Orchis (*Habenaria*), with its stalk attached to a sticky gland, magnified; each of the packets or partial pollinia of which it is made up is composed of a large number of pollen grains.

Pollinia. — In Milkweeds and in most Orchids all the pollen of an anther cell is compacted or coherent into one mass, called a *pollen mass*, or **POLLINIUM**, plural **POLLINIA** (Figs. 225, 226).

The Ovule

277. **Ovule** (from the Latin, meaning a little egg) is the technical name of that which in the flower answers to and becomes the seed.

278. Ovules are *naked* in gymnospermous plants (as above described); in all others they are inclosed in the ovary. They may be produced along the whole length of the cell or cells of the ovary, and then they are apt to be numerous; or only from some part of it, generally the top or the bottom. In this case they are usually few or single (*solitary*, as in Figs. 228–230). They may be *sessile*, i.e. without

stalk, or they may be attached by a distinct stalk, the **FUNICLE** or **FUNICULUS** (Fig. 227).

227–230. Ovules: 227, a cluster of ovules, pendulous on their funicles; 228, section of the ovary of a Buttercup, lengthwise, showing its ascending ovule; 229, section of the ovary of Buckwheat, showing the erect ovule; 230, section of the ovary of Anemone, showing its suspended ovule.

279. In structure an ovule is a pulpy mass of tissue, usually with one or two coats or coverings. The following parts are to be noted; viz.:—

KERNEL or **NUCELLUS**, the body of the ovule. In the Mistletoe and some related plants, there is only this nucellus, the coats being wanting.

TEGUMENTS, or coats, sometimes only one, more commonly two, an outer and an inner one.

ORIFICE, or **FORAMEN**, an opening through the coats at the organic apex of the ovule. In the seed it is *micropyle*.

CHALAZA, the place where the coats and the kernel of the ovule blend.

HILUM, the place of junction of the funiculus with the body of the ovule.

280. The Kinds of Ovules.—The ovules in their growth develop in three or four different ways, and thereby are distinguished into

231. Longitudinal section of an ovule enlarged, showing the parts: *a*, outer coat; *b*, inner coat; *c*, nucellus; *d*, raphe.

232–235. Ovules: 232, orthotropous ovule of Buckwheat: *c*, hilum and chalaza; *f*, orifice; 233, campylotropous ovule of a Chickweed: *c*, hilum and chalaza; *f*, orifice; 234, amphitropous ovule of Mallow: *f*, orifice; *h*, hilum; *r*, raphe; *c*, chalaza; 235, anatropous ovule of a Violet; the parts lettered as in the last.

Orthotropous, or *straight*, those which develop without curving or turning, as in Fig. 232. The chalaza is at the insertion or base; the

foramen or orifice is at the apex. This is the simplest, but the least common, kind of ovule.

Campylotropous, or *incurved*, in which, by the greater growth of one side, the ovule curves into a kidney-shaped outline, so bringing the orifice down close to the base or chalaza; as in Fig. 233.

Amphitropous, or *half-inverted*, Fig. 234. Here the forming ovule, instead of curving perceptibly, keeps its axis nearly straight, and, as it grows, turns round upon its base so far as to become transverse to its funiculus, and adnate to its upper part for some distance. Therefore in this case the attachment of the funiculus or stalk is about the middle, the chalaza is at one end, the orifice at the other.

Anatropous, or *inverted*, as in Fig. 235, the commonest kind, so called because in its growth it has as it were turned over upon its stalk, to which it has continued adnate, the attached portions of the stalk being known as the *raphe*. The organic base, or chalaza, thus becomes the apparent summit.

Arrangement of Parts in the Bud

281. *Æstivation* was the fanciful name given by Linnæus to denote the disposition of the parts, especially the leaves of the flower, before *anthesis*, i.e. before the blossom opens. *Præfloration*, a better term, is sometimes used. This is of importance in distinguishing different families or genera of plants, being generally uniform in each. The æstivation is best seen by making a cut across the flower bud; and it may be expressed in diagrams, as in the accompanying figures.

282. The pieces of the calyx or the corolla either overlap each other in the bud, or they do not. When they do not overlap, the æstivation is

Valvate, when the pieces meet each other by their abrupt edges, without any infolding or overlapping, as in the calyx of the Linden or Basswood (Fig. 236).

Induplicate, which is valvate with the margins of each piece projecting inwards, as in the calyx of a common Virgin's-bower (Fig. 238), or

Involute, which is the same, but with the margins rolled inward, as in most of the large-flowered species of Clematis (Fig. 239).

Reduplicate, a rarer modification of valvate, is similar, but with margins projecting outward.

Open, the parts not touching in the bud, as the calyx of Mignonette.

283. When the pieces overlap in the bud, it is in one of two ways; either every piece has one edge in and one edge out, or some pieces are wholly outside and others wholly inside. In the first case the æstivation is

Convolute, also named *contorted* or *twisted*, as in Fig. 240, a cross section of a corolla very strongly thus convolute or rolled up together. Here one edge of every petal covers the next before it, while its other edge is covered by the next behind it. The other mode is the

Imbricate, or *imbricated*, in which the outer parts cover or overlap the inner so as to "break joints," like tiles or shingles on a roof; whence the name (calyx in Fig. 237).

284. The imbricate and the convolute modes sometimes vary one into the other, especially in the corolla.

285. In a gamopetalous corolla or gamosepalous calyx, the shape of the tube in the bud may sometimes be noticeable. It may be

Plicate, or *plaited*, that is, folded lengthwise; and the plaits may either be turned outward, forming projecting ridges, as in the corolla of *Campanula*; or turned inward, as in that of *Gentian* or of *Belladonna*.

Position and Arrangement of Flowers, or Inflorescence

286. *Inflorescence*, which is the name used by Linnæus to signify mode of flower arrangement, is of three classes; namely, *indeterminate*, when the flowers are in the axils of the leaves, that is, are from axillary buds; *determinate*, when they are from terminal buds, and so *terminate* a stem or branch; and *mixed*, when these two are combined.

287. *Indeterminate*, or *indefinite*, *Inflorescence* is so named because, as the flowers all come from axillary buds, the terminal bud may keep on growing and prolong the stem indefinitely. This is so in *Moneywort* (Fig. 241).

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288. When flowers thus arise singly from the axils of ordinary leaves, they are *axillary* and *solitary*, not collected into flower clusters.

289. But when several or many flowers are produced near each other, the accompanying leaves are apt to be of smaller size, or of different shape or character: then they are called **BRACTS**, and the flowers thus brought together form a cluster. The kinds of flower clusters of the indeterminate class have received distinct names, according to their form and disposition. They are principally *raceme*, *corymb*, *umbel*, *spike*, *head*, *spadix*, *catkin*, and *panicle*.

290. In defining these it will be necessary to use some of the following terms of descriptive botany which relate to inflorescence. If a

flower is stalkless, *i.e.* sits directly in the axil or other support, it is said to be *sessile*. If raised on a naked stalk of its own (as in Fig. 241), it is *pedunculate*, and the stalk is a **PEDUNCLE**.

291. A peduncle on which a flower cluster is raised is a *common peduncle*. That which supports each separate flower of the cluster is a *partial peduncle*, and is generally called the **PEDICEL**. The portion of the general stalk along which flowers are disposed is called the *axis of inflorescence*, or, when covered with sessile flowers, the *rachis* (backbone), and sometimes the *receptacle*. The leaves of a flower cluster generally are termed **BRACTS**. But when bracts of different orders are to be distinguished, those on the common peduncle or axis, and with a flower in their axil, keep the name of *bracts*; and those on the pedicels or partial flower stalks, if any, that of **BRACTLETS**.

292. A Raceme (Fig. 242) is that form of flower cluster in which the flowers, each on its own foot stalk or pedicel, are arranged along the sides of a common stalk or axis of inflorescence; as in the Lily

of the Valley, Currant, Barberry, one section of Cherry, etc. Each flower comes from the axil of a small leaf, or bract, which, however, is often so small that it might escape notice, and even sometimes (as in the Mustard family) dis-

appears altogether. The lowest blossoms of a raceme are of course the oldest, and therefore open first, and the order of blossoming is *ascending*. The summit never being stopped by a terminal flower, may go on to grow, and often does so (as in the common Shepherd's Purse), producing lateral flowers one after another for many weeks.

293. A Corymb (Fig. 243) is the same as a raceme, except that it is flat and broad, either convex, or level-topped. That is, a raceme becomes a corymb by lengthening the lower pedicels, while the uppermost remain shorter. The axis of a corymb is short in proportion to the lower pedicels. By extreme shortening of the axis the corymb may be converted into

294. An Umbel (Fig. 244), as in the Milkweed, a sort of flower cluster where the pedicels all spring apparently from the same point, from the top of the peduncle, so as to resemble, when spreading, the rays of an umbrella; whence the name. Here the pedicels are sometimes called the *rays* of the umbel. And the bracts, when brought in this way into a cluster or circle, form what is called an **INVOLUCRE**.

295. The corymb and the umbel being more or less level-topped, bringing the flowers into a horizontal plane or a convex form, the

ascending order of development appears as *centripetal*. That is, the flowering proceeds from the margin or circumference regularly toward the center; the lower flowers of the former answering to the outer ones of the latter.

296. In these three kinds of flower clusters, the flowers are raised on conspicuous *pedicels* or stalks of their own. The shortening of these pedicels, so as to render the flowers *sessile* or nearly so, converts a raceme into a *spike*, and a corymb or an umbel into a *head*.

297. A *Spike* is a flower cluster with a more or less lengthened axis, along which the flowers are sessile or nearly so; as in the Plantain (Fig. 245).

245

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298. A *Head* is a round or roundish cluster of flowers, which are sessile on a very short axis or receptacle, as in the Buttonball, Buttonbush (Fig. 246), and Red Clover. It is just what a spike would become if its axis were shortened; or an umbel, if its pedicels were all shortened until the flowers became sessile. The head of the Buttonbush is naked; but that of the Thistle, of the Dandelion, and the like, is surrounded by empty bracts, which form an *involucre*. Two

particular forms of the spike and the head have received particular names; namely, the *spadix* and the *catkin*.

299. A *Spadix* is a fleshy spike or head, with small and often imperfect flowers, as in the Calla, Indian Turnip (Fig. 173), Sweet Flag, etc. It is commonly surrounded or embraced by a peculiar enveloping leaf, called a *SPATHE*.

300. A *Catkin*, or *ament*, is the name given to the scaly sort of spike of the Birch (Fig. 247) and Alder, the Willow and Poplar, and one sort of flower clusters of the Oak, Hickory, and the like,—the so-called *amentaceous* trees.

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301. *Compound* flower clusters of these kinds are not uncommon.

When the stalks which in the simple umbel are the pedicels of single flowers themselves branch into an umbel, a *compound umbel* is formed. This is the inflorescence of Caraway (Fig. 248), Parsnip, and

almost all of the great family of umbelliferous (umbel-bearing) plants.

The secondary or partial umbels of a compound umbel are

UMBELLETS. When the umbellets are subtended by an involucre, this secondary involucre is called an **INVOLUCEL**.

302. A *compound raceme* is a cluster of racemes racemously arranged, as in *Smilacina racemosa*. A *compound corymb* is a corymb, some branches of which branch again in the same way, as in Mountain Ash. A *compound spike* is a spicately disposed cluster of spikes.

249

303. A **Panicle**, such as that of Oats and many Grasses, is a compound flower cluster of a more or less open sort which branches with apparent irregularity, neither into corymbs nor racemes. Figure 249 represents the simplest panicle. It is, as it were, a raceme of which some of the pedicels have branched so as to bear a few flowers on pedicels of their own, while others remain simple. A *compound panicle* is one that branches in this way again and again.

304. **Determinate Inflorescence** is that in which the flowers are from terminal buds. The simplest case is that of a solitary terminal flower, as in Fig. 250. This stops the growth of the stem; for its terminal bud, becoming a blossom, can no more lengthen in the manner of a leaf bud. Any further growth must be from axillary buds developing into branches. If such branches are leafy shoots, at length terminated by single blossoms, the inflorescence still consists of solitary flowers at the summit of stem and branches. But if the flowering branches bear only bracts in place of ordinary leaves, the result is the kind of flower cluster called

305. A Cyme. — This is commonly a flat-topped or convex flower cluster, like a corymb, except that the blossoms are from terminal buds. Figure 251 illustrates the simplest cyme in a plant with opposite leaves; namely, with three flowers. The middle flower, *a*, terminates the stem; the two others, *bb*, terminate branches, one from the axil of each of the uppermost leaves; and being later than the middle one, the flowering proceeds from the center outward, or is *centrifugal*. This is the opposite of the indeterminate mode, or that where all the flower buds are axillary.

250

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If flowering branches appear from the axils below, the lower ones are the later, so that the order of blossoming continues *centrifugal* or, which is the same thing, *descending*, as in Fig. 253, making a sort of reversed raceme or *false raceme*, — a kind of cluster which is to the true raceme just what the flat cyme is to the corymb.

306. Wherever there are bracts or leaves, buds may be produced from their axils and appear as flowers. Figure 252 represents the case where the branches, *bb*, of Fig. 251, each with a pair of small leaves or bracts about their middle, have branched again, and produced the branchlets and flowers, *cc*, on each side. It is the continued repetition of this which forms the full or compound cyme, such as that of the Hobblebush, Dogwood, and Hydrangea.

307. A **Fascicle** (meaning a bundle), like that of the Sweet William and *Lychnis* of the gardens, is only a cyme with the flowers much crowded together.

308. A **Glomerule** is a cyme still more compacted, so as to imitate a head. It may be known from a true head by the flowers not expanding centripetally; that is, not from the circumference toward the center.

309. **Scorpioid or Helicoid Cymes**, of various sorts, are forms of determinate inflorescence (often puzzling to the student) in which one-half of the ramification fails to appear. So that they may be called *incomplete cymes*. The commoner forms may be understood by comparing a complete cyme, like that of Fig. 252, with Fig. 251, the diagram of a cyme of an opposite-leaved plant, having a series of terminal flowers and the axis continued by the development of a branch in the axil of only one of the leaves at each node. The dotted lines on the left indicate the place of the wanting branches, which if present would convert this *scorpioid cyme* into the complete one of Fig. 252. Figure 254 *a* is a diagram of similar inflorescence with alternate leaves. An axis made up in this way of a succession of branches is termed a *sympodium*.

253. Diagram of a simple cyme in which the axis lengthens, so as to take the form of a raceme.

310. **Mixed Inflorescence** is that in which the two plans are mixed or combined in compound clusters. A *mixed panicle* is one in which, while the primary ramification is of the indeterminate order, the secondary or ultimate is wholly or partly of the determinate order. A contracted or elongated inflorescence of this sort is called a **THYRSUS**. Lilac and Horse-chestnut afford common examples of mixed inflorescence of this sort. When loose and open such flower clusters are called by the general name of *panicles*. The heads of *Compositæ* are centripetal; but the branches or peduncles which bear the heads are usually of centrifugal order.

XIII. LABORATORY STUDIES OF THE FRUIT

The whole purpose of the fruit is embodied in the seed. The portion external to the seed is important in the life history of the plant only as it ministers to the maturing, preservation, transporting, or planting of the germ. The ways in which the character of the exterior parts of the fruit affects the destiny of the seed will be studied after the general structure of fruits has been examined.

The studies of the first Exercise have to do with the parts of the fruit external to the seed; the second Exercise is concerned with the seed itself; and the third, with dissemination.

EXERCISE XXXV. FLORAL ORGANS INVOLVED IN THE FRUIT

Wild Indigo. — Notice the base and the slender termination of the pod. What was this termination in the flower? What still surrounds the pod stalk? Can you discover any marks of other organs, now fallen away? Open the pod: where are the seeds attached? Pod and seeds are the ripened forms of what members of the flower? How many carpels in this fruit? The ripened ovary is termed the *pericarp*.

Violet. — After examining all exterior features, cut a cross section. With the lens, and by trying the seeds with a needle, find the places of attachment. How many *placentæ*? Of how many carpels is the pod composed? From dried and opened specimens determine whether the pod bursts between the carpels or along the carpellary midribs. Of what floral organ does the fruit consist?

Cranberry. — Opposite the stem end is a slight hollow, roughly square, edged and often nearly covered in by four projections. Cut these projections away. Observe the bottom of the depression. At the center is a single scar, marking the position of what member of the flower? Around this, within the crater, notice two circles of scars. What are they? Finally, what is the nature of the four projections first noticed and then cut away? Parts of what organs of the original flower now compose the berry?

Cut the fruit transversely. How many carpels compose it? The size of the cavities in which the seeds lie is striking when compared with the minute size of the seeds themselves. Will the berry float? Try it. Count and record the number of seeds.

Draw: *Wild Indigo*. The pod, with persistent calyx. This sort of fruit is termed a *legume*.

Violet. Cross section, to show the seeds attached ($\times 5$). The dehiscent fruit ($\times 2$). The fruit is termed a *capsule*.

Cranberry. Cross section, showing cavities and attachment of seeds ($\times 2$). The terminal depression showing remains of the flowers ($\times 10$). Soft, fleshy fruits of this sort are termed *berries*.

Checkerberry. — Dissect the fruit. What is the morphological nature of the lower, fleshy part?

Draw a longitudinal section to show all parts — including the seeds in one of the cavities — and their arrangement ($\times 3$).

The Rose hip. — Examine the fruit to discover, if possible, where the floral parts were situated. Cut the hip open. Are seeds seen? Are seeds of Angiosperms produced in an *open* receptacle or cavity, as these seedlike bodies are? Are they seeds or fruits? The hollow, pulpy portion bearing them on its inner surface is an enlarged *receptacle*.

Draw a diagram representing a longitudinal section ($\times 2-3$).

EXERCISE XXXVI. THE SEED

The student is already familiar with the interior of the seed — with embryo and albumen. The integuments need to be looked at more particularly than has been done heretofore.

Squash. — Notice the place at which the seed was broken from its connection with the placenta. It is called the *hilum*. Beside this there is a distinct aperture leading into the interior, the *micropyle*. Cut away the shell. How many seed coats? This is the characteristic number. The outer is the *testa*; the inner, the *tegmen*.

Draw a cross section of the Squash seed (diagrammatic).

Castor Bean. — On one side observe a straight, dark line, running three quarters the length of the seed (the *raphe*). At one end is a very slight elevation, the point at which the coats are organically connected with the kernel; this point is the *chalaza*. At the other end is the hilum, nearly covered by a structure called the *caruncle*.

Bean. — At one side of the hilum is the micropyle, more easily made out if the material has been properly soaked. On the other side of the hilum, running to the end of the bean, is a ridge, more or less indistinct — the *raphe*. Overlying its inner extremity, next the hilum, is a heart-shaped, purple excrescence, called the *strophiole*.

Draw the bean, showing the features indicated ($\times 3$).

Outgrowths of the testa. — By the aid of the hand lens make enlarged drawings of the seeds of Milkweed and of the Trumpet Creeper. Cut the seed of the Cotton Plant in half. Draw the section, so as to show the length of the Cotton fibers relatively to the diameter of the seed proper. What is the use of these outgrowths?

EXERCISE XXXVII. THE FRUIT IN RELATION TO DISSEMINATION

The need of dissemination will be most keenly realized by a rough computation of the number of seeds produced by a single plant, all

of which would have a chance of germinating upon the plot of ground occupied by the parent, unless carried elsewhere. Take as an example the Cranberry, studied in Exercise XXXV. Allow fifty berries to a single bush, and multiply by the number of seeds actually observed in one berry. The resulting product represents the possible number of seedlings upon less than a square yard of ground.

That even one seedling should occupy part of the soil held by the parent plant would evidently be disadvantageous to both. Accordingly, plants exhibit a great variety of devices by which the service of various agencies is secured for the dispersal of the seeds. The means of dissemination may be (1) some feature of the coat of the seed itself, (2) some special character, construction, or outgrowth of the pericarp. The first case has been seen in the Milkweed; the second remains to be studied in more detail.

Bladder Nut. — Examine the bladdery fruit before dehiscence, noting (1) the morphology of the pericarp, (2) the number of carpels, and (3) the relative size of the pericarp and the seeds. Place the fruit on the table. Blow it about. The object of the inflated pericarp becomes apparent.

Draw the fruit, natural size. Indicate in dotted line the position and size of the seed.

Curled Dock. — With a lens examine the three-winged and coarsely veined parts, each bearing at its base a granule resembling a seed. They are persistent sepals, and are closely appressed. Hidden between them is the three-angled *achene* (dry pericarp, containing a single seed). The dispersal apparatus here comes from the calyx. Note how readily the fruit is driven by a mere breath.

Draw the fruit, with one sepal removed to show achene, magnified about eight diameters.

Bur Marigold. — The barbed bristles, well seen with the lens, are morphologically the border of the calyx, the lower part of which is adherent to the pericarp. What is the mode of dissemination?

Draw the fruit, magnified about four diameters.

Witch-hazel. — Notice:—

(1) The pericarp proper, with the old calyx surrounding the lower half. (2) The partial splitting at the tips of unopened fruits. (3) The number of cells (*loculi*) in the opened capsules. (4) The mode of dehiscence. The *loculi* are split open along the median line in each case. This is *loculicidal* dehiscence. (5) The backward curving of the open jaws. (6) The very hard, smooth inner surface of the *loculi*, and the similar surface of the seeds, which indeed makes it rather difficult to hold them securely between finger and thumb. (7) Cut away the calyx and the outer, softer layer of the pericarp. It will be seen that the inner and immediate receptacle of the seeds is a bony and rather thick-walled double case. There was originally one seed in each

compartment. (8) The halves (*valves*) of the seed case are separated nearly to the middle, cohering only by their basal portions. (9) The edges of the inner, bony seed cases curve in somewhat, as if compressed. (10) Try to fit the seeds back into the cases. Are the cases large enough to cover the seeds?

The fruit of Witch-hazel is a projectile apparatus. As the valves open wider and wider, in the process of drying, the seeds are squeezed more and more by the shrinkage of the bony layer and the incurving of the valve edges. At a certain point, the intensity and direction of pressure become such that the seed is shot out with much force — enough force, under the most favorable conditions, to carry the seed to a distance of forty or fifty feet.

Draw whatever is necessary to illustrate your notes on this fruit.

XIV. THE FRUIT

311. Nature of the fruit. — The mature ovary is the Fruit. In the strictest sense the fruit is the seed vessel, technically named the PERICARP. But practically it may include other parts organically connected with the pericarp. The calyx especially, or a part of it, is often incorporated with the ovary, so as to be indistinguishably a portion of the pericarp. The receptacle forms, along with the calyx, the whole bulk of such edible fruits as Apples and Pears. The receptacle is an obvious part in Blackberries (see Fig. 256), and is the whole edible portion in the strawberry.

312. A cluster of distinct carpels may, also, in ripening, be consolidated or compacted, so as practically to be taken for one fruit. Such are Raspberries, Blackberries, etc. Moreover, the ripened product of many flowers may be compacted or grown together so as to form a single compound fruit.

THE KINDS OF FRUITS

313. In respect to composition, fruits may be classified into

Simple, those which result from the ripening of a single pistil, and consist only of the matured ovary, either by itself, as in a Peach (Fig. 255), or with the receptacle and

calyx tube completely incorporated with it, as in the Gooseberry and Pear (Fig. 259).

Aggregate, when a cluster of carpels of the same flower are crowded into a mass; as in Raspberries and Blackberries (Fig. 256).

255. Section of a Peach.

Accessory, when the surroundings or supports of the pistil make up a part of the mass. In an *accessory* fruit such as the Strawberry the great mass is receptacle (Fig. 156).

Multiple or *collective*, when formed from several flowers consolidated into one mass, of which the common receptacle or axis of inflorescence, the floral envelopes, and even the bracts, etc., make a part. A Mulberry (Fig. 257, which superficially much resembles a Blackberry) is of this multiple sort. A Pineapple is another example.

Stone fruits, or *drupaceous* (Fig. 255), the outer part fleshy like a berry, the inner hard or stony, like a nut; and

Dry fruits (Fig. 266), those which have no flesh or pulp.

314. In reference to the splitting apart of the pericarp for the liberation of the seeds, fruits are said to be

Dehiscent, when they open regularly along certain lines. A dehiscent fruit almost always contains many or several seeds, or at least more than one seed (Fig. 267).

Indehiscent, when they do not open at maturity. Fleshy fruits and stone fruits are of course indehiscent. The seed becomes free only through decay or by being fed upon by animals. Of dry fruits also many are indehiscent.

315. The principal kinds of fruits which have received distinctive names are the following :—

256. Aggregate fruit of the Blackberry: consisting of a number of ripened pistils crowded on a fleshy receptacle. At the right, one of the individual fruits (a drupe) further enlarged.

257. Multiple fruit of the Mulberry.

316. The berry, such as the Gooseberry and Currant, the Blueberry and Cranberry (Fig. 258), the Tomato, and the Grape. Here the whole flesh is soft throughout. The Orange is a berry with a leathery rind.

317. The pome, a name applied to the Apple, Pear (Fig. 259), and Quince. These are fleshy fruits, like a berry, but the principal thickness is the enlarged receptacle, only the papery pods arranged like a star in the core really belonging to the carpels.

318. The drupe, or *stone fruit*, of which the Cherry, Plum, and Peach (Fig. 255) are familiar examples. In these the outer part of the thickness of the pericarp becomes fleshy, or softens like a berry, while the inner hardens like a nut. Two portions of the drupe are thus distinguishable, named respectively *exocarp*—the outer, fleshy layer; and the *endocarp*—the innermost layer, the stone.

319. Of dry fruits there is a great diversity of kinds having distinct names.

320. The achene is a small, dry, and indehiscent one-seeded fruit, often so seedlike in appearance that it is popularly taken

260. Achene of Buttercup; at the right, opened to show the seed.

for a naked seed. The fruit of the Buttercup is a good example (Fig. 260). Its nature, as a ripened pistil (in this case a simple carpel), is apparent by its bearing the remains of a style or stigma, or a scar from which this has fallen. It may retain the style and use it in various ways for dissemination (Fig. 261).

321. The fruit of Compositæ (though not of a single carpel) is also an achene. In this case the pericarp is invested by an adherent calyx tube, the limb of which, when it has any, is called the **PAPPUS**. This name was first given to the down like that of the Thistle, but is applied to the limb of the calyx, in whatever form it appears, of the "compound flower." In Lettuce, Dandelion (Fig. 263), and the like, the achene

258. Fruit of the Cranberry.

259. Sections of Pear.

261. Achene of Clematis, the style retained as a plume for purposes of dispersal by winds.

as it matures tapers upwards into a slender beak, like a stalk to the pappus.

262

263

262, 263. Achenes : 262, of a Thistle, provided with a pappus for wind-dissemination; 263, of a Dandelion, the pappus borne on a long beak.

322. A caryopsis, or grain, is like an achene with the seed adhering to the thin pericarp throughout, so that both are incorporated into one body; as in Wheat, Indian Corn.

323. A nut is a dry and indehiscent fruit, commonly one-celled and one-seeded, with a hard, crustaceous, or bony wall, such as the Coconut, Hazelnut, Chestnut, and the Acorn (Fig. 264). Here the involucre, in the form of a cup at the base, is called the **CUPULE**. In the Chestnut, near relative of the Oak, the cupule forms the bur; in the Hazel, another relative, a leafy husk.

324. A samara, or key fruit, is either a nut or an achene, or any

other indehiscent fruit, furnished with a wing, like that of Ash, and Elm (Fig. 265). The Maple fruit is a pair of keys (Fig. 266).

264.

265. Samara
of the Elm.

325. Dehiscent fruits, or pods, are of two classes, viz., those of a simple pistil or carpel, and those of a compound pistil. Two common sorts of the first are named as follows:—

326. The follicle, a fruit of a simple carpel, which dehisces down one side only, *i.e.* by the inner or ventral suture. The fruits of Marsh Marigold (Fig. 267) are of this kind.

266

267

266. Fruit of the Maple.

267. Follicle of the Marsh Marigold.

327. The legume or true pod, such as the Pea pod (Fig. 268), and the fruit of the Leguminous or Pulse family generally, which opens along the dorsal as well as the ventral suture.

268

269

268. A Legume.

269. A Loment

The two pieces into which it splits are called **VALVES**. A **LOMENT** is a legume which is constricted between the seeds, and at length breaks up crosswise into distinct joints, as in Fig. 269.

328. The pods or dehiscent fruits belonging to a compound ovary have several technical names: but they all may be regarded as kinds of

329. The **capsule**, the dry and dehiscent fruit of any compound pistil. The capsule may discharge its seeds through chinks or pores, as in the Poppy, or burst irregularly in some part, as in Lobelia and the Snapdragon; but commonly it splits open (or is *dehiscent*) lengthwise into regular pieces, called **VALVES**.

330. Regular *dehiscence* in a capsule takes place in two ways, which are best illustrated in pods of two or three cells. It is either

271. Septicidal capsule of St. John's-wort.

Loculicidal, or, splitting directly into the *loculi* or cells, that is, down the back (or the dorsal suture) of each cell or carpel, as in Iris (Fig. 270); or

Septicidal, that is, splitting through the partitions or *septa*, as in St. John's-wort (Fig. 271), Rhododendron, etc. This divides the capsule into its component carpels, which then open

by their ventral suture.

331. In loculicidal dehiscence the valves naturally bear the partitions on their middle; in the septicidal, half the partition is borne on the margin of each valve. See the annexed diagrams, Fig. 272. A

272. Diagrams of the various modes of dehiscence: *a*, loculicidal; *b*, septicidal; *c*, *d*, septifragal.

273

274

273, 274. Fruit of one Fig: 273, fruit laid open; 274, a part magnified to show the minute, interior flowers.

variation of either mode occurs when the valves break away from the partitions, these remaining attached in the axis of the fruit. This is called *septifragal* dehiscence.

332. The **syconium**, or **fig fruit** (Fig. 273), is a fleshy axis or summit of stem, hollowed out, and lined within by a multitude of minute flowers, the whole becoming pulpy, and, in the common fig, luscious.

THE SEED

333. Seeds are the final product of the flower, to which all its parts and offices are subservient. Like the ovule from which it originates, a seed consists of coats and kernel.

275. *a*, hilum; *b*, testa; *c*, inner coat; *d*, albumen; *e*, embryo.

334. The seed coats are commonly two, the outer and the inner. Fig. 275 shows the two, in a seed cut through lengthwise. The outer coat is often hard or crustaceous, whence it is called the *testa*, or shell of the seed; the inner is almost always thin and delicate.

335. The shape and the markings, so various in different seeds, depend mostly on the outer coat. Sometimes this fits the kernel closely; sometimes it is expanded into a *wing*, as in the Trumpet Creeper (Fig. 276, *a*), and occasionally this wing is cut up into shreds or tufts, as in the Catalpa (Fig. 276, *b*); or instead of a wing the seed may bear a *coma*, or tuft of long and soft hairs, as in the Milkweed or Silkweed (Fig. 276, *c*). The use of wings or downy tufts is to render the seeds buoyant for dispersion by the winds. This is clear, not only from their evident adaptation to this pur-

276. Seeds fitted by outgrowths of the testa for dispersion by the winds: *a*, Trumpet Creeper; *b*, Catalpa; *c*, Milkweed.

pose, but also from the fact that winged and tufted seeds are found only in fruits that split open at maturity, never in those that remain closed. The coat of some seeds is beset with long hairs or wool. *Cotton*, one of the most important vegetable products, since it forms the principal clothing of the larger part of the human race, consists of the long and woolly hairs which thickly cover the whole surface of the seed. There are also crests or other appendages of various sorts on certain seeds. A few seeds have an additional, but more or less incomplete, covering outside of the real seed coats, called an

336. Aril, or arillus.—The loose and transparent bag which incloses the seed of the White Water Lily (Fig. 277) is of this kind. So is the *mace* of the Nutmeg. The aril is a growth from the extremity of the seed stalk, or from the placenta when there is no seed stalk.

277

A short and thickish appendage or outgrowth around the micropyle in certain seeds is called a **CARUNCLE** (Fig. 278).

The various terms which define the position or direction of the ovule (erect, ascending, etc.) apply equally to the seed: so also the terms anatropous, orthotropous, campylotropous,¹ etc., as already defined, and such terms as

HILUM, or *scar* left where the seed stalk or funiculus has fallen away, or where the seed was attached directly to the placenta if there was no seed stalk.

RAPHE, the line or ridge which runs from the hilum to the chalaza in anatropous and amphitropous seeds.

CHALAZA, the place where the seed coats and the kernel or nucellus are organically connected, — at the hilum in orthotropous and campylotropous seeds, at the extremity of the raphe or tip of the seed in other kinds.

MICROPYLE, answering to the *foramen* or orifice of the ovule.

ECOLOGY OF THE FRUIT AND SEED AS REGARDS DISSEMINATION

337. The word dissemination here signifies the scattering of the seeds. In a vast number of cases not only the seeds, but the entire fruits, are dispersed, the pericarp furnishing the same protection to the seed that it provided during the period of ripening, and furthermore aiding directly by its construction in the transportation or even in the planting of the seed.

338. The need of seed dispersal is plain, both for the parent plant — which should not be crowded by its own offspring — and for the interests of the seedlings themselves. That an advantage is to be won through wide distribution of seed is shown by the fact that the seed or the fruit is, in most species, adapted to the special work of dissemination.

339. The agents of dissemination are wind, water, and animals. But a considerable number of plants are quite independent of external aid, being provided with special mechanisms for throwing their seeds to a distance.

340. Structures to accomplish dissemination through the agency of the winds are exemplified by the wings of the Elm and Maple fruits (Figs. 265, 266), the plume of

¹ For these terms see the section on the ovule, § 280.

the Clematis achene (Fig. 261), and the tufted pappus in the case of the Dandelion (Fig. 263). The wing of the Maple key does not avail to carry the seed very far from the source, on the average, as may be seen if we examine the neighborhood of a Maple tree when the seedlings are coming up in the spring. The seedlings are very numerous near the parent, very few at a distance of two or three times the height of the tree. But one cannot fail to be struck with the successful planting of the seeds. Although not originally covered by the soil, they stand in multitudes, rooted and growing, in spots where the grass was beaten down and matted before the fruits fell. Though bulky, the keys find their way into the grass through the action of the winds in driving the wings this way and that, until the seed ends have been

worked well toward the moist surface of the soil. This example illustrates the fact, of common occurrence, that appendages of the fruit may serve both in dissemination and in placing the seed in the position most likely to secure germination.

341. In connection with this subject, the mechanism of *Erodium* (Fig. 279) for burying the fruit may be mentioned. The elongated extremity of the fruit is hygroscopic; that is, it absorbs vapor of water rapidly in damp weather, and exhales it in dry, the changes being accompanied by twistings and untwistings.

279. Fruit of *Erodium*. On the left a single carpel in damp weather; at the right, several carpels in the calyx, in dry weather.

As the fruit naturally falls with its weightier or seed end toward the earth, these hygroscopic movements, aided by backward-pointing hairs, enable it to work its way through grass or other impediments toward the soil, and finally even partially to bury itself.

342. The appendages of seeds securing dissemination by wind are very similar to those of fruits in many cases. Compare, for instance, the seed of the Trumpet Creeper (Fig. 276, *a*) with the fruit of the Elm (Fig. 265); and the seed of the Milkweed (Fig. 276, *c*), possessing a *coma*, or tuft of hairs, with the pappus-bearing achene of the Thistle (Fig. 262).

343. Water.—The fruits of the Coconut Palm are originally covered with husks impermeable to sea water. They sometimes fall into the ocean, and being carried to distant strands are cast up by the waves and there germinate. In a like manner the achenes of the Arrow-head (*Sagittaria*)—a plant which is common along the margins of ponds—buoyed up by the air-filled cells of the pericarp, are floated to a distance. In a number of species they float for a definite length of time; then, when germination is about to begin, they sink to the bottom.

344. Animals.—The fruits of many plants are thickly set with hooks suited to catch in the fur of animals (Fig. 280). The fruits are thus separated from the plant and carried away, to be subsequently removed by the animals themselves or brushed off accidentally. Nuts hidden away in the ground by squirrels must occasionally be left to grow, either through oversight or on occasion of the death of the depositor. Then again, edible fruits like the Cherry, the Apple, and the berries offer to animals a substantial reward in return for the service of dispersal.

280. The fruit of Agri-mony.

345. Ejection of the seeds is not uncommon. The most familiar example is that of the Jewelweed, or Touch-me-not, the ripe pods of which, when touched, burst and throw the seed in all directions. The bursting is due to the sudden splitting asunder and coiling up of the

several valves, already in a high state of tension, the

281. Fruit of Witch-hazel discharging its seeds.

touch which produces the explosion merely increasing the stress along the lines of dehiscence. The opened valves of the Violet fruit, constricting, cause the forcible expulsion of the seeds one after another. The hard, bony capsules of the Witch-hazel (Fig. 281), contracting, squeeze the smooth,

hard seeds with much force ; and the seeds are shot to a distance of many feet.¹

Supplementary Reading

- 1. Plants that bury their Seeds. Lubbock's "Flowers, Fruits, and Leaves," pp. 85-88.
- 2. The Fruits and Seeds of Plants Parasitic on Trees. Same source, pp. 83, 84.
- 3. Dispersal of various Fruits and Seeds. Same source, Chap. III.
- 4. Dissemination of Plants by Ocean Currents and by Migrating Birds. Darwin's "Origin of Species," Chap. XI, *Dispersal*.

¹ If a bough with the ripe but unopened fruits is hung on the wall of one's room, the force with which the seeds are ejected and the distance to which they fly are likely to be observed.

Distances to which seeds are ejected by several plants are given by Kerner and Oliver ("Natural History of Plants," II, 839) as follows:—

Cardamine impatiens	3 ft.
Viola canina	3 ft.
Geranium palustre	8 ft.
Lupinus digitatus	23 ft.
Acanthus mollis	31 ft.
Hura crepitans	48 ft.
Bauhinia purpurea	51 ft.

XV. LABORATORY STUDIES OF CRYPTOGRAMS

[NOTE:—Many of the following types may be studied without compound microscopes, if good hand lenses or, better, dissecting microscopes, are provided. In the suggestions for study which follow, (simple) following the number of a paragraph indicates that the simple microscope is to be used; similarly, (compound) indicates that a compound microscope is to be used; and (compound or simple) indicates that the simple microscope may be used, but the compound is to be used if available.]

346 (Compound). Nostoc. Make a note of the general character—form, consistency, color, etc.—of the masses in which the plant occurs. Mount a bit of the mass in a drop of water on a glass slide, cover with a cover glass, pressing the latter down gently, and examine first with a low, then with a higher power of the compound microscope.

What constitutes one single individual plant? How are the individuals grouped? What is the color? Are any cells distinguished by size or other character? What holds the cells and chains (colonies) together? Draw one chain by aid of the highest power you have.

347 (Compound). Unicellular Green Algæ: Pleurococcus, or the like. Upon what do the plants provided grow? Examine this substratum with the hand lens, to see if the individual plants causing the green tinge on the surface can be distinguished. Then scrape a bit of the green film into a drop of water on a glass slide, cover, and examine with different powers of the compound microscope, the lowest first. Do you find the plants single? In groups? If in both ways, draw both. Is there anything in the number of plants in a group, or in the position of the members of a group, or any other circumstance, to suggest to you the way in which these plants multiply?

348 (Simple). Spirogyra. Use the simple lens to obtain an idea of the actual size of the plants. Do the filaments branch? Are there cross partitions? Do any parts of the filaments differ markedly from others? How does the color differ from that of *Nostoc*, if at all? What portion of any cell bears the color? What is the arrangement of the color-bearing bands (*chromatophores*)?

349 (Compound). Is there more than one chromatophore in each cell? Draw a short portion of one filament, using a moderate power. Indicate, without drawing all of them, the arrangement of the chromatophores.

350 (Compound). Select a cell (for example a terminal cell) in which the spirals are rather loose. Look for the nucleus, near the center, a colorless body from which colorless strings radiate. If this is not distinguishable, delay search until after the following treatment.

Place a small drop of dilute (30 per cent) eosin glycerine at the edge of the cover glass so that it will run under. If the glycerine reaches the *Spirogyra*, many of the cells will now be found with their contents much distorted. Does it appear that the contents are separable from the walls on all sides? Select a cell slightly affected. Is there a definite layer of substance in which the chromatophores are imbedded? The nucleus, stained by the eosin, will now be readily made out. Draw a cell highly magnified, showing a part of one chromatophore, the nucleus, and the layer of living substance (*protoplasm*) where separated from the wall.

351 (Compound). If material is provided, make drawings of conjugating cells, showing stages in the process. Label the rounded bodies found where conjugation has been effected *zygospores*.

352 (Compound). *Vaucheria*.—Use the hand lens to gain an idea of size and general habit. If the feltlike mass is growing on earth, pick off a little with needles, using care to get rid of soil in the preparation. Mount in water under the compound microscope. Are the filaments septate (partitioned), or not? Focus on the upper surface. What is the shape and size of the chromatophores here? Focus down until the side walls stand out sharply. Do the chromatophores occur only near the walls, or are they scattered throughout the interior of the tubes? Do the filaments branch?

353 (Compound). Do you find lateral club-shaped (not globular) branches, or somewhat swollen tips of filaments, of a very dark green color (*sporangia*)? Are they cut off by partitions (*septa*)?

354 (Compound). Look for short, nearly globular branches, in company with others more slender, lighter green, and somewhat coiled. If any of these can be made out clearly in all parts, draw them (*oögonia* and *antheridia*). If the form and attachment are not clear, turn to the figure given by the teacher, and with its help decide whether the *oögonia* and *antheridia* are found on the material you have. The species studied and that represented in the figure may not be the same, in which case exact similarity of organs will not be expected.

355 (Compound). *Ectocarpus*, exemplifying the **Brown Algæ**.—View with the hand lens, then with higher magnifications. Are the main trunks more than one cell in thickness? The branches? Draw a small, branching portion. Are there any very short branches distinguished by greater thickness? If so, are they more than one cell in thickness, or does each branch consist chiefly of one large terminal cell, or sac, with granular contents? Draw both sorts of branches, if found, labeling the many-celled ones *gametangia*, and the saclike ones *sporangia*.

356 (Simple). *Rockweed*.—Make a life-size drawing from a branching portion, to show the habit of the plant. With the hand

lens examine the thickened tips. Have the minute raised spots openings?

357 (Compound or Simple). With a wet razor make a good many sections, as thin as possible, across the tips where the raised spots are thickest, and mount them in water. Have the cavities seen in the sections, and more or less lined with dark bodies (*oögonia*), any relation to the little prominences before seen? Have the cavities (*conceptacles*) openings? Make a diagram two or more inches in diameter, showing the cavity of a conceptacle as seen in section, with opening if any, and adjacent external surface of the *thallus* (or general body of the plant). Show a few *oögonia* in proper proportion and form, with some of the long filaments that spring from the walls of the conceptacle.

358 (Compound). Examine the *oögonia* with the compound microscope and draw if additional details are found. Look in the same conceptacles (or in others from different plants, according to the teacher's directions) for swollen cells borne on short filaments, much smaller than the *oögonia*, and distinguished by coarsely granular contents and orange color. These are the *antheridia*. If necessary pick one of the sections apart with needles—or merely squeeze it enough under the cover glass to break it up—in order to see how these antheridia are borne. Make a drawing to show this. Also indicate on the diagram before made the relative size and the position of the antheridia in the conceptacle. (But if antheridia and *oögonia* are not found together, use two diagrams.)

359 (Simple). **Polysiphonia**,¹ one of the Red Algæ.—Draw the habit of the plant, enlarged, as seen with the lens. Look for dark round bodies embedded in some of the branches—the *tetrasporangia*. Do they seem to be somewhat eccentrically placed, or are they situated centrally so as to occupy the whole diameter of the branch where they occur? Draw a portion very much enlarged to show the facts.

360 (Compound). Are the filaments of the *thallus* (or plant body) composed of more than single rows of cells? How do the branches end? Into how many separate parts (*tetraspores*) is the contents of each tetrasporangium divided? (It should be said that the tetraspores are so arranged that one of them is always hidden from view.) Draw a tetrasporangium with a short portion of the *thallus* adjoining.

361 (Compound). **Nemalion**, a Red Alga.—Draw a short branching portion to show the filamentous habit. If possible select a piece bearing the small, rounded *antheridia* at the tips. If so directed by the teacher, seek to identify *carpogonia* and *cystocarps* by aid of the figures provided.

¹ Material bearing *tetrasporangia* is to be provided.

362 (Compound). Bacteria.—With a needle transfer to a slide a bit of the scum that gathers on water in which vegetable matter is decaying. Cover with a cover glass and examine with a high power. The Bacteria are glistening white (*i.e.* colorless) bodies of small size often occurring in broad patches of gelatinous matter (the matter which holds the “scum” together) in which they are more or less evenly spaced; or occurring in chains or threads. Some may be spiral in form and exhibit very active motion. Having found the Bacteria, remove the cover glass, spread the scum out thin on the slide, and dry this preparation by holding it at some distance above a flame. When the last bits of the spread scum are about to become dry, remove from the heat and add drops of gentian violet stain.¹ After a moment wash this off with a little water, cover, and reexamine. The various forms, now more plainly seen, are to be drawn.

For suggestions as to the biological study of Bacteria see Appendix.

363 (Compound). Yeast.—Mount in water a small bit of yeast cake, spreading the material out thin, and examine with a high power. Are the yeast plants of uniform size? Have they any peculiarity of form, common to all, or nearly all (*i.e.* are they uniformly spherical, or elliptical, or ovate, etc.)? Have they any common features of internal structure? Having determined these points in your own mind, make a drawing of a typical yeast plant of the species you have, the drawing to be large enough to show easily any internal features.²

364 (Compound). From material that has been growing for a few hours in sweetened water (a teaspoonful of sugar to a half glass of water), study the method of multiplication. Do the buds—the new individuals growing out from the bodies of the old plants—spring from any particular region, as a rule? Draw in outline three stages in the budding process.

365. Is any action of the yeast upon or in the sugar solution to be seen? To test this, drop small pieces of yeast cake into tumblers of (1) sugar solution, (2) water alone. In fifteen minutes or so the result should be observable, and within an hour very marked. What bearing has the action observed upon the utility of yeast plants in bread making? Answer this question in your notes on this experiment.

366 (Simple). Bread Mold (*Rhizopus nigricans*).—Use the hand lens to examine the moldy bread without disturbing it, so as to see

¹ Strong eosin solution may be used, and it leaves the Bacteria with a more lifelike appearance, though not so sharply defined. If the preparation is stained with gentian violet, washed, and thoroughly dried, Canada balsam may be used upon it and the preparation thus be made permanent.

² The teacher should draw upon the board the characteristic form and striations of starch grains to be found in the yeast cake, so that they may not be mistaken for the yeast plants.

how the mold grows. Especially notice the growth on the bottom of the dish where the fungus is spreading away from the bread. Make a much enlarged drawing to show the groups of stalked *sporangia* as seen from the side. Are these groups connected in any way? Are there any special organs for attachment to the substratum? Is the number of sporangia in a group constant? Estimate the height of the sporangial stalks in inches. State the magnification which your drawing represents.

367 (Compound). With a needle carefully remove a bit of the plant, selected from a spot where both white (young) and black (old) fruiting heads (*sporangia*) can be seen, and mount in water, or better in alcohol followed by a drop of water. Use first a low power, afterwards a higher power. Have the threads partitions? What is the color and appearance of the contents? Compare an unopened sporangium with one where the external membrane has given way. What portion of a whole head is occupied by spores? Answer by drawings; show one of the spores separately, more enlarged.

368 (Compound). If material is furnished, draw two or three stages to illustrate zygospore formation.

369 (Compound). **Water Molds: Saprolegniaceæ.** — Upon what is the given plant growing? Remove a bit with forceps and needle to a drop of water on a slide. Examine with the hand lens, to get an idea of the actual size. Then use low and high powers of the microscope. Are the hyphæ of even diameter? Is the protoplasm dense or thin? What is the shape of the ends of the hyphæ? Answer these questions in drawing.

Do you find certain branches filled with denser protoplasm, and somewhat enlarged or club-shaped? Can you find stages leading to this condition? Are the swollen extremities (*zoösporangia*) separated by a partition from the rest of the hyphæ? Find zoösporangia in which the protoplasm seems gathered into many definite masses; others empty, with these masses (*zoöspores*) escaped, but still near by. From what point do the zoöspores escape? Draw an unopened zoösporangium, and one ruptured, together with a mass of the spores.

370 (Compound). Short-stalked, globular organs (slightly resembling the sporangia of Bread Mold) will probably be found in abundance in both old and young stages. Are the youngest ones cut off by a wall? The oldest? What difference in the contents at the two different stages? You may find gradations from one condition to the other. The organs are the *oögonia*, and when mature contain a number of *oöspores*. How many? Have the oöspores walls? If so, are they thicker or thinner than walls (if any) of the zoöspores before noted?

371 (Compound). Look for slender branches with ends applied to the oögonia, and somewhat swollen at the point of contact. In

some cases these branches (*antheridia*) may send tubes into the oögonia. The antheridia may grow from the stalks of the oögonia themselves, or from the main hyphæ close by.

Draw old and young oögonia, with contents, and antheridia (if found).¹

372 (Simple). *Peziza*. Upon what as a substratum does the species of *Peziza* furnished grow? If the *Peziza* is small, use the hand lens in examination. What is the general shape? Is the external surface entirely smooth? Is the color the same on inner and outer surfaces? Represent all features of form in a drawing considerably larger than nature, if necessary.

373 (Compound). Cut sections perpendicular to the inner surface. Mount in water. Do you find, with a high power, elongated sacs containing a definite number of rounded bodies (spores)? Do you find many or few such sacs? (If the sections are not very thin, press the cover glass down cautiously with a needle to spread them out thinner.) How are they situated relatively to one another and to the surface of the plant? They are near which surface, inner or outer? How many spores in each sac, or *ascus*? Draw a diagram of the *Peziza* in section, showing the region of the sacs, and indicate some of the sacs in position. Draw a sac (*ascus*) highly magnified, with spores, and the threads that grow up between the sacs.

374 (Compound). Pulling off with forceps bits of the substratum at the point where the cup of the *Peziza* was attached, and spreading these bits out with needles in water on a slide, you may find the threads of the fungus, which gather nourishment from decayed vegetable matter. These threads together form the *mycelium*; the saucer-shaped or cup-shaped sac-bearing body first examined is the *apothecium*. That layer of the apothecium in which the sacs are found is the *hymenium*. Label drawings according to the terms given.

375 (Simple). *Microsphæra*.² With the lens examine the whitened patches of the fungus-infested leaf. Is the whitening external or internal? To decide this, wet the leaf with a drop of alcohol, and scrape gently with a knife point. The black, rounded bodies are *perithecia*. Indicate by drawing the size of the leaf and of the perithecia. Wet a bit of the fungus with alcohol, and remove with a knife to water on a slide. If the material has been dried, add strong potash solution to the preparation. Is the white film composed of granules or of threads? Examine the perithecia by transmitted light. Have they appendages? Draw a perithecium much magni-

¹ In the same mount more than one kind of Water Mold may be found, the species differing in position and character of oögonia, and in antheridia and sporangia.

² Or any genus of the group *Erysiphææ*; perhaps the commonest form being *Microsphæra alni*, the cause of mildew on Lilac leaves.

field. (But if the compound microscope is to be used, delay drawing until further examination has been made.)

376 (Compound). With a moderate power reëxamine the material noting the composition of the white coating and the details of the perithecia. Draw a perithecium, showing one or two appendages with care, and indicating the rest. Press down the cover glass so as to rupture some of the perithecia. Draw one of the spore-containing organs. In what essential respect, if any, does it differ from the ascus of *Peziza*?

377. Toadstool, illustrative of *Basidiomycetes*. — Draw the habit. Cut smoothly down through the middle of the umbrella, so as to split the stem at the junction with the umbrella. Draw the section of the umbrella and summit of stem as now seen. Label the radial folds *gills* (*lamellæ*); the part from which they are suspended, the *pileus*. Do all the gills extend from the margin of the pileus to the stem or *stipe*? Are the inner ends of the gills attached to the stipe? Draw a diagram of a sector of the umbrella as seen from below, to show arrangement of gills. *

378 (Compound). With a wet razor section a portion of the umbrella so as to get cross sections of the gills. Carefully wash the sections from the razor to a slide, cover, and examine with low and high powers. If small and thin-gilled species are used, sections need not be made; simply mount a piece of the gill flatwise, when the spores will be seen, grouped in a particular way, and at the edge of the piece the manner in which the spores are borne will probably be seen. How many spores are borne upon the same swollen hypha tip (*basidium*)? How are they attached to the basidium? Draw a basidium with spores. Make a diagram of the cross section of a gill, showing where the spores are borne. Label the layer in which the basidia are found *hymenium*.

With needles dissect small pieces of the stipe and pileus, and examine with the high power. Of what microscopic elements is the toadstool made up?

379 (Simple). *Lichen*. — Examine the lichen with the hand lens. Is there stem or leaf, or an appearance of a main axis of growth? Is there indication of green (chlorophyllous) color? Are there structures resembling the spore-bearing portion of any fungus heretofore studied? Draw one of the "fruit" bodies (*apothecia*) as seen from above, much magnified. The deeper-colored layer nearly filling the saucer is the hymenium. Draw the apothecium in outline as seen from the side.

380 (Compound or Simple). Detach an apothecium, place it in a piece of pith split to hold it, and section it as thin as possible with a wet razor. Mount the sections in water, and examine with the lens or a low power of the microscope. Draw the section of the apothec-

cium, with the attached portion of the thallus. Where is the green color distributed? (Show in drawing.) Distinguish small brown bodies (spore sacs) standing in large numbers perpendicularly to the inner surface of the apothecium, and indicate these in the drawing. The layer in which they occur is the hymenium. If possible, examine this with a higher power, and draw an *ascus* (spore sac) with the (how many?) spores. Also determine further the exact location of the green color, and draw the green bodies.

381 (Simple). *Marchantia*: a *Liverwort*. — Draw the outline of a single plant, as seen from above, about twice the natural diameter. Distinguish the growing tip and the base of the plant. Represent the position and outline of any structures produced from the upper surface. Is there a midrib? Examine the upper surface with the hand lens. What do the cup-shaped structures contain? Draw, much magnified, labeling the receptacle *cupule*, and the small bodies within *gemmae*. Are the *gemmae* easily detached? Put a drop of water into one of the cupules and note the behavior of the *gemmae*? (The *gemmae* are best seen on living plants; in other material they may be absent.) What are the purpose and nature of the *gemmae*? By what means are they likely to be disseminated?

382 (Simple). Examine the upper surface of the thallus (plant body) with the lens. Have the minute prominences pores at their summits? It will be well to use also a low power of the compound microscope to settle this question definitely. Do the same prominences occur on the under side of the thallus? By what means is the plant attached to the ground? Draw a little portion of the upper surface as seen by the hand lens, making the drawing large enough to show all discernible details clearly.

383 (Simple). Turn your attention now to certain slender branches of the thallus, ending in umbrellalike portions. Do you find more than one kind, as regards the shape of the "umbrella"? If so, represent one sort in side view, "stalk" and all. Draw both of the "umbrellas" as seen from above. The branch ending in free rays is to be labelled *archegonial branch*, that ending in a lobed disk, *antheridial branch*.

384 (Simple). Select a branch bearing well-matured *sporoquia*. Remove the stalk. Lay the head, under side upward, on the dissecting stage, and study the position of the sporangia. How are they arranged, and to what are they attached? Note the fringed sheaths that partly inclose them. Detach a sporogonium. Draw it to show the form, the method of dehiscence (press the sporogonium slightly), the relative length of the stalk, etc. What does the sporogonium contain besides spores (use a high power)?

385 (Compound). The antheridial heads may be sectioned with comparative ease, and the *antheridia* studied under the teacher's direc-

tion. Good preparations of the *archegonia*, from which the sporogonia originate, are more difficult to make. If time allows, vertical sections of the young archegonial heads may be made by the pupils; or better, the archegonia may be drawn from preparations provided by the teacher. Distinguish the central *egg cell*, the *neck* and *canal*.

386 (Simple). **Moss.**—Select a single plant, in fruit. Draw the habit as seen with the hand lens. Examine with the highest power of the dissecting microscope. Is there distinction of leaf and stem? Are the leaves petioled? Have they midribs? With needles clear away the leaves at the point where the stalk of the spore capsule (*sporogonium*) originates. Does this stalk spring from the end of a shoot of the moss, or is it a branch springing directly from the side of a shoot? Is there any appearance of a joint or any mark around the base of the stalk? Are the shoot and stalk separable?

387 (Simple). Look for a capsule which still bears on its summit a loose cap, the *calyptra*. Draw the capsule, much enlarged. Remove the calyptra. Examine the now exposed end of the capsule with a strong lens. Do you find any appearance of a lid, or cover, by the removal of which the capsule may be opened? Draw the outlines of this part of the capsule, labeling the lid *operculum*. Slight pressure may force the latter off. Teeth standing within the edge of the opening may be seen. Note the quantity and appearance of the spores.

388 (Compound). With the compound microscope examine the *protonema* of the moss, if this is provided, and draw a portion. Look for buds, or beginnings of new leafy shoots.

389 (Simple or Compound). If ready mounted sections of the flower, so called, are provided, the *archegonia* and *antheridia* may be studied under the teacher's direction. At least, the shoot tips bearing these organs should be examined with a lens, and then dissected carefully with needles in a little water under the dissecting lens. By skillfully removing the leaves that form more or less of a rosette around the desired parts, and by further separation if necessary, archegonia and antheridia may be distinctly seen, together with the sterile filaments, or paraphyses, that grow up with them on the end of the stem.

390 (Simple). **Fern.** — 1. *The prothallium.* Place a young prothallium on the stage of the dissecting microscope, without water. Examine rapidly with the lens. Are the upper and under surfaces alike? Is the *prothallium* of equal thickness throughout? By what means is the plant attached to the soil? Add water. If soil particles still adhere, remove carefully with a small wet brush or with needles. The general form reminds you of what cryptogamous plant before studied? In what respects (refer to former drawings)? Which is the younger extremity of the prothallium?

Turn it under side upwards and view by transmitted light. Draw

the outline ($\times 3-5$); mark the margin at the bottom of the chief notch as the *growing point*. Indicate by shading in the proper place any thickened portion, and mark this *cushion*. Show the root hairs, or *rhizoids*.

391 (Compound or Simple). *Antheridia*. Small prothallia should show the antheridia plainly under the simple lens, especially if the (living) material is first treated with aqueous iodine for two or three minutes and then washed. The antheridia are seen as small round, brown bodies. Indicate their position and relative size on the drawing already made. With the compound microscope the general structure of these organs can be made out probably without sectioning, and a drawing may be made.

392 (Compound or Simple). *Archegonia*. Older prothallia may be required. Treat with iodine, as before. With a low power the presence and distribution of the archegonia (appearing as numerous short columns of cells projecting from the cushion) may be made out. In many of the older and over-ripe archegonia a central cell, embedded in the prothallium at the base of the projecting neck, is seen as an opaque, brownish sphere. Indicate the position and number of the archegonia on the diagram before drawn.

The details of structure will require higher powers and sections of the prothallium, either provided already mounted, or made under the teacher's directions.

393 (Simple). 2. *Origin of the spore-bearing plant*. From the material provided find out from what part of the prothallium the leafy shoot springs. Is there a root? and if so, does it originate from the tissue of the prothallium or from the new shoot? Answer these questions in a drawing ($\times 2-4$).

394 (Simple). 3. *The spores*. Examine a "fruiting" leaf of the mature plant. Are the "fruit spots" (*sori*, sing. *sorus*) on the upper or under side? Have they a definite location upon the divisions of the leaf? Indicate the facts in an outline sketch. Pick off a leaf segment and placing it on the dissecting stage under the lens, with needles carefully raise the covering (*indusium*) of a sorus. Estimate the number of spore cases (*sporangia*) found beneath. Have they stalks? If you have no high-power instrument, draw, highly magnified, all the details you can discern with the simple microscope. Much can be made out in this way. Draw (1) the sorus covered by the indusium (if present), (2) the group of sporangia uncovered.

395 (Compound). If high powers are at hand, further examine sporangia and spores, after removing from the leaf with a knife point and mounting in water in the usual way.

396 (Simple). *Selaginella*. — With hand lens examine the arrangement and shapes of the leaves, and draw a short section of the shoot ($\times 3-4$) to show these points. Do the shoots of *Selaginella* grow

upright or more or less prostrate? Has the leaf arrangement any relation to the habit of growth? Look for special leafless, root-bearing branches.

397 (Simple). Do you find the tips of some of the shoots modified (*fruiting spikes*)? The leaves of these spikes differ in what ways from those of the rest of the plant? In their axils are the rounded *sporangia*. On the stage of the dissecting microscope, in a few drops of water, dissect a fruiting spike with needles. Pull off some of the leaves. Do the sporangia come away with them? Make a drawing to show the facts. Let the drawing be large enough to show the form of the sporangium clearly.

398 (Simple or Compound). Crush some of the sporangia; what do they contain? If possible, see these very numerous bodies (spores) with a good power of the compound microscope. Do they resemble anything you have seen in flowering plants?

399 (Simple). Look over the fruiting spikes for sporangia considerably larger than those already seen. Determine from a number of cases whether they occur with the lower or the upper leaves of the spike; on one side of the spike only, or on all sides. Draw one of these sporangia (how many protuberances)? Open it; how many bodies (spores) contained?

Having now seen the two sorts of sporangia, label the one producing small spores, *microsporangium*; the other, *macrosporangium*. Indicate roughly the relative size of small spores (*microspores*) and large spores (*macrospores*) in drawing.

400 (Simple). **Club Moss, *Lycopodium*.**—Sketch the general habit, to show the attitude of the main and branch stems. Are there distinct fruiting spikes in the species studied? If so, are they raised on stalks, or not? Show these points in the habit drawing. Compare herbarium specimens of a few different species with regard to the same features. Does the material furnished show any roots? If so, show them in the habit drawing. Are the leaves petioled? Are they evenly distributed around the stem?

401 (Simple). Dissect under the lens a fruiting spike. Do you find sporangia? How many to each leaf? Draw one of the leaves to show the facts. On which surface of the leaves are the sporangia borne, upper or under? Press one of the sporangia; what does it contain? Look at the bodies emitted with the compound instrument. Have they any resemblance to any bodies produced by Phanerogams? Do you find more than one size of sporangium and of the spores? Would the number of spores in any sporangium be represented in 10's, in 100's, or in 1000's?

402 (Simple). **Horsetail, *Equisetum*.**—Find the leaves. If the main axis bears offshoots of any sort, determine whether these are leaves, or stems, or both. Make a drawing to show the facts, and another of

the cone terminating the fertile shoot. Dissect the cone under the lens. Note the peculiarly modified leaves: how many saclike folds has each? Is the number constant? What is the nature of these "folds" as determined by the contents? Draw a diagrammatic longitudinal section of one of the cone leaves, much enlarged.

403 (Compound). With the compound microscope examine the contents of the sacs. Draw. Allow some of the spores to dry on a slide, and then, while viewing them through the microscope with a low power, breathe out gently so that the moisture from the breath will strike the spores. Describe the action seen, illustrating by diagrams.

XVI. CRYPTOGRAMS

404. The plants to be described in the present chapter are a few chosen from a very great number of forms, making up a series which differs in many important respects from the group of Phanerogams. Cryptogams on the whole are smaller than Phanerogams. It is true that the Ferns (cryptogamous plants) are a conspicuous element of land vegetation almost everywhere, and in the warmer regions attain to the stature of trees; and that Seaweeds, some of them of great size, hold exclusive possession of the littoral rocks and the borders of the ocean bed. But the great majority of cryptogamic forms are too small to attract attention, and many are even too minute to be seen by the naked eye. Although many of the Cryptogams, both great and small, have a very varied life history and a structure that is by no means very easy to understand, yet as a group the Cryptogams are structurally simpler than the Phanerogams.

405. Viewing all cryptogamic plants together, we find that they fall into a kind of series, which, if followed in one direction, leads toward the general type of organization found in Flowering Plants; or, in the other direction, leads toward the simplest microscopic forms. The series is, however, a very imperfect one, broken by many gaps. Next to the Phanerogams stand *Selaginella* (Fig. 353), *Lycopodium* (Fig. 357), and similar plants, with stem, leaf, root, and even structures answering to rudimentary flowers. A little further removed come the true Ferns

(Fig. 345). Still less like Flowering Plants, but closely allied to the Ferns, stand the Mosses and Liverworts (Figs. 340, 334). In the groups named — found at what we speak of as the upper end of the cryptogamic series — the stem-and-leaf type of structure prevails. In the lower groups a contrast in this respect will be noted.

406. Going below the Liverworts — *i.e.* away from the Phanerogams — we come to the Algæ (Seaweeds and the like, Figs. 291, 298), between which and the Liverworts the similarity is not marked. The Algæ include all green (chlorophyllous) plants below the Liverworts, down to the smallest and simplest (Fig. 282). Along with them, and often resembling them in many respects, are the Fungi, of which ordinary molds and toadstools are examples. Fungi lack chlorophyll.

407. In the Algæ and Fungi the plant body is not distinguished as in Flowering Plants and higher Cryptogams into axis or stem, and leaves. It is a simpler structure, and is termed a *thallus*. In the simplest Cryptogams the thallus is the single cell constituting the individual; in higher forms it becomes a filament, membrane, or solid mass. Algæ and Fungi together are termed Thallophytes.

408. The Algæ fall into four grand divisions, conveniently distinguished in most cases by the color. In the lowest group the green due to chlorophyll is more or less modified by the presence of a blue pigment; in the second group the chlorophyll gives its true hue; in the third, green is masked by brown; and in the fourth, a red pigment is usually present to obscure the green more or less effectually. The description of typical Cryptogams will begin with the simplest Algæ.

Throughout the present chapter merely the structures and processes *most commonly found* in the groups selected will be described. Let it be understood that a full account of even the few forms brought forward would involve many qualifying additions to the general statements now made.

BLUE-GREEN ALGÆ

409. On wet walls of stone and on undisturbed moist earth may often be found small, rounded, jellylike masses of a greenish or bluish color. A bit placed under the microscope shows a great number of chains of rounded

282. A chain of Nostoc cells: *h*, heterocyst; *d*, recent divisions.

cells (Fig. 282), embedded in the gelatinous matter. Certain cells of each chain are somewhat larger and lighter colored than the rest. When a chain breaks in pieces, as occasionally happens, separation usually takes place next to one of these enlarged

cells, or *heterocysts*. The fragments finally develop into chains of the original character. The cells increase in number by transverse division (Fig. 282, *d*). Cell division is, in fact, the ordinary process by which the plants of this group multiply.

410. If the substratum on which the plants are growing dries up, the investing mass of gelatinous substance hardens in proportion as it parts with water, and so becomes a protective coating which enables the plant to withstand extreme drought.

411. The plant here described and figured (Nostoc) is representative of the Blue-green Algae in color, in the filamentous arrangement of the cells, in the method of multiplication by transverse fission, and in throwing off mucilaginous matter from the walls to form sheaths and embedding masses. In some species, however, the cells are found in small groups, not filamentous; and in others the gelatinous coating is either very thin or entirely wanting.

412. *Oscillatoria* (Fig. 283) is, like many of the group, often aquatic, either floating freely or gathered in small tufts. The filaments have a characteristic motion of bending slowly from side to side—whence the name *Oscillatoria*. They also possess some means of locomotion, by which they slip along over the substratum, while at the same time slowly revolving upon the longer axes of the filaments.

New filaments arise from short portions (*hormogonia*) with rounded ends (Fig. 283, *h*), when these portions have been set free from the old filaments.

283. Oscillatoria: *a*, part of a filament showing hormogonia (*h*, *h*); *c*, filaments, less magnified.

413. The Blue-green Algæ comprise a large number of species, many of which differ considerably in general habit from the forms just described.

GREEN ALGÆ

414. The Green Algæ (so called from their pure chlorophyll green color) are mainly small aquatic plants, and chiefly inhabit fresh waters; though some of them are sub-aërial. The smallest members are distinguishable only with the microscope; the largest form growths several inches in diameter.¹ The exceedingly numerous species vary widely in structure and mode of life. The few here described will give some idea of the chief types. It should be understood at the outset that only the most important facts of life history are given; and that in many of the forms modes of reproduction, *not here described*, exist.

415. Pleurococcus.—Almost all surfaces that are occasionally wet and are not too much exposed to heat and drying—as shaded sides of tree trunks, rough posts, and rocks—after a time become green by the growth of minute unicellular plants of various kinds. They thrive and multiply in rain and dew, and resist ordinary drying. One of the commonest of these unicellular forms is *Pleurococcus* (Fig. 284). The plant is simply a microscopic

284. *Pleurococcus*.

¹ For example, the familiar Sea Lettuce of the seashore.

sphere. Its only known mode of reproduction is by division. That is, each individual divides by a cross wall, and the two new individuals so produced increase in size. Before they separate they may each again divide; and in fact the plants are commonly found cohering in small colonies (Fig. 284, *B*).

416. Ulothrix.—The fine unbranched filaments of Ulothrix are abundant in fresh water, where they grow attached to stones, sticks, etc. (Fig. 285, *a*). The filaments increase in length by the division and elongation of any or all of the cells. When Ulothrix is about to reproduce, its cells divide internally, so that within each one are produced several cells; but the latter have no cell wall formed about them. When these naked cells escape, by the rupture of the mother cell wall, it is seen that they are

285. Ulothrix: *a*, a young filament; *b*, larger zoöspore; *c*, escape of these spores; *d*, *e*, escape and conjugation of smaller zoöspores. — DODEL-PORT.

provided with hairlike organs called cilia, by means of which they swim energetically about (Fig. 285, *b*, *d*). The motile cells (called, from their animal-like power of locomotion, *zoöspores*) are of two kinds, large and small. The larger have four cilia (Fig. 285, *b*). After a short active period they settle down, lose their cilia, invest themselves with cell walls, and germinate by growing out into new filaments. The smaller zoöspores are provided with but two cilia. After swarming they fuse (Fig. 285, *e*), generally in pairs. This process, wherein *two cells* unite to form the germ of a new plant, is called *conjugation*. The body formed by the conjugation of two *similar* cells is a *zygospore*. In the case of

Ulothrix the zygospore forms a wall about itself, rests for a time, then makes some growth by elongating and enlarging, and finally its contents break up into several zoöspores which are like the larger ones described above and develop in a similar fashion.

417. Spirogyra.—*Spirogyra* may be found floating in unattached masses at the surface of almost any sunny pool or spring in warm weather. It is often known as Frog slime or Frog spittle. Under the microscope a bit of the mass becomes a tangle of beautiful green filaments,

286. *Spirogyra*: *n*, nucleus; *s*, chromatophores.

unbranched, and consisting of elongated cylindrical cells (Fig. 286) placed end to end. In the cells of *Spirogyra* the essential parts of the *typical vegetable cell* are well seen.¹ The wall is lined with a thin layer of living matter (*protoplasm*), embedded in which are several spiral bands of denser composition, the *chromatophores*, or color-bearing organs (*s*), containing the chlorophyll. Near the center of the cell is found the rounded *nucleus* (*n*), from which strands of protoplasm run to the peripheral layer. The remaining space is filled with cell sap—water with dissolved substances.

418. The cells of the filament live in apparent independence of one another, each forming its own food supplies, and every one capable of dividing transversely to form two daughter cells; by which process the plant increases rapidly under favorable conditions.

¹ Refer here to §§ 494–498; a full discussion of the cell should be had at this point. Emphasize the relative unimportance of the wall; the idea of the living unit having the nucleus as the center and conservator of vital activity; the rôle of the nucleus in cell division (briefly); and the occurrence of many cells (represented by nuclei) in a common wall, as in *Vaucheria* next to be described.

419. *Growth* and *reproduction* should now be clearly distinguished. *Growth* is the increase in size of an already existing individual; *reproduction* is the formation of a new individual, or new individuals. In the case of *Pleurococcus* cell division results in the production of two new individuals, which separate sooner or later. In the growing root tip of a Flowering Plant, on the other hand, cell division is merely a step in the formation of more root, and is therefore only a growth process. In the case of *Spirogyra*, if we consider the *whole filament* to be the individual, then division of the several cells is to be regarded as *growth*. But if the *cells* of the filaments are considered to be the individuals, *i.e.* essentially independent organisms, their division must then be regarded as *reproduction*. The two processes here run together, since it is not easy to say how much of the plant may be termed the individual.

287. Conjugation of *Spirogyra*: *zs*, zygospore; *f*, fusion in progress.

420. *Reproduction.* — Under certain conditions, however, the cells of *Spirogyra* take part in a distinctly reproductive process. The cells of a filament send out lateral processes which meet similar processes from cells of another filament (Fig. 287). Cells thus become united in pairs. Openings are then made in the conjoined outgrowths, by which the contents of all the cells on one side pass over into those on the other. The contents of each pair of cells unite to make up a single body, or *zygospore* (*zs*), which becomes invested by a thick wall preparatory to a resting period. In this form the plant endures periods of drought, when the pools

where it grows dry up; and thus it also passes the winter.

421. Here, as in *Ulothrix*, two *similar* cells unite in reproduction. In plants soon to be described the fusing cells differ largely in size and other characteristics.

422. Conjugation of similar unciliated reproductive cells is characteristic of a considerable group of Green Algae. Fresh water preparations very often contain unicellular forms belonging to this group, more or less resembling the species represented in Fig. 288. Sometimes they cohere in chains. Usually they are capable of slow locomotion. They are Desmids.

423. Vaucheria.—The green filaments of *Vaucheria* are large enough to be distinguished by the naked eye. By repeated branching they form upon moist soil matted growths which may be several inches in diameter. The plant also grows submerged in water. The filaments are continuous tubes, ordinarily without cross partitions (*i.e. unseptate*), and are lined with a protoplasmic layer in which numerous nuclei and small rounded chromatophores are held; the main cavity of the tubes being filled with cell sap as in the case of *Spirogyra* cells. In fact the thallus of *Vaucheria* is to a certain degree such as would be produced if the cells of *Spirogyra* were not separated by end walls, the chief differences in this respect being the greater number of nuclei, the shape of the chlorophyll bodies, and the branching habit of *Vaucheria*.

288. Desmids.

289. Zoöspore and zoösporangium of *Vaucheria*.
—MURRAY.

424. Reproduction. — *Zoöspores* are produced in the ends of side branches after these portions have been cut off by septa and thus converted into *zoösporangia*. The whole contents of each zoösporangium escapes by the rupture of the wall at the apex (Fig. 289), and constitutes a single large zoöspore provided with numerous pairs of cilia distributed over its surface. The motile period may last for several hours, after which time the cilia are lost, a wall is formed around the zoöspore, and germination very soon takes place by

the protrusion of one or two tubular filaments, which grow directly to new plants.

425. Zoöspores are apt to be formed when the plant is growing in a submerged situation. In places where it is exposed to the air and moistened only occasionally, as by

290. *Vaucheria*: *A*, the unopened antheridium (*a*) and oogonium (*og*); *B*, the same after fertilization and formation of the oöspore (*os*).—PRINGSHEIM.

the dew, a second method of reproduction prevails. Swellings arise on the thallus, which develop into short, thick branches of peculiar form. When cut off by septa below they become the *oögonia* (Fig. 290, *og*). The contents of the oögonium contracts somewhat to form the *egg cell*, and an opening makes its appearance in the oögonium wall. Near by, short, slender, often coiled branches grow up. Their extremities are cut off to form the *antheridia* (Fig. 290, *a*), from which *antherozoids*, bodies resembling small zoöspores, are

finally liberated. The latter make their way through water to the opening of the oögonium, and one, entering, fuses with the egg cell. The resulting body, or *oöspore*, now surrounds itself with a cell wall and enters a resting state. It is ultimately set free by the rupture of the oögonium wall, and germinates.

426. In *Vaucheria* we have essentially the same reproductive processes as in *Ulothrix*, but now appearing in a much modified form. The single large zoöspore of *Vaucheria*, with its many cilia, performs the same office as the numerous small zoöspores of *Ulothrix*. The production of the oöspore in *Vaucheria* may be likened to the union of reproductive cells in *Ulothrix*, with the important difference that now the fusing cells differ greatly in size, and only one of them is motile.

427. Cells designed for reproductive union are called *gametes*. When they are of unequal size, the larger is termed *egg cell* or simply *egg*; the smaller, if motile, is an *antherozoid*. The egg is said to be *fertilized* by the antherozoid. The body directly resulting from the union of unequal gametes is an *oöspore*.

BROWN ALGÆ

428. The Brown Algæ (Fig. 291) are almost exclusively salt-water plants. They are in most cases attached. In size they range from microscopic, unicellular forms, through the fine filamentous species (Fig. 291, D), to thalloid forms of immense length. "Of these, *Macrocystis pyrifera*

291. Brown Algæ: A, the Sea Colander (much reduced); B, Laminaria (much reduced); C, the Gulf Weed with floats (a); D, Ectocarpus (magnified), s being sporangia.

is noted for its gigantic size: rising obliquely upward to the surface of the water from the sloping sides of elevations in the ocean bed, its floating thallus has a length of 600 to 900 feet. The stalk below is naked, but at the surface, where it streams out horizontally, it bears many long pendent segments, each provided at the base with a

large bladderlike float filled with air.”¹ The Gulf Weed (Fig. 291, C), which collects in such quantities in the so-called Sargasso seas, belongs to this group. On certain coasts it grows as an attached plant. Portions which have been detached and carried off by currents continue to grow and multiply vegetatively as they float in the quieter areas of the ocean.

429. The brownish color of the Brown Algæ is due to a pigment in the cells, which probably aids the chlorophyll present in the work of assimilation.

430. Reproduction. — Reproductive cells are of several sorts in this group. First and simplest are the zoöspores borne in Zoösporangia (Fig. 292, A), found in most

292. A, zoösporangium, and B, gametangium, of *Ectocarpus*; C, gametes (g) and their conjugation (s). — PRINGSHEIM.

members of this group. Their history is like that of the larger zoöspores of *Ulothrix*; that is, they germinate directly after swarming, without fusion.

431. Secondly. We find processes of cell fusion, not unlike those already seen in the reproductive bodies of Green Algæ. We may select three representative cases. (1) In *Ectocarpus* and allied plants, zoöspores (gametes) are produced, which are indistinguishable from the zoöspores intended for direct germination, except that the bodies now in mind arise in sporangia of a different character (Fig. 292, B). They may conjugate in pairs (C), like the small zoöspores of *Ulothrix*. (2) In some forms (*Cutleria*), the fusing zoöspores (gametes) differ in size. The larger come to rest before fusion. This is a step intermediate between the condition in *Ectocarpus* and that next to be described. (3) In the common Rockweed of the shores, the gametes are *egg cells* and *antherozoids*

¹ Strasburger, "Text Book of Botany," p. 330.

(Fig. 297). The egg cells are produced in *oögonia* (Fig. 295), found in cavities or *conceptacles* (Fig. 294), which make their appearance at certain seasons in special portions of the branching thallus (Fig. 293). The antherozoids originate in *antheridia*

293. A Branch of Rock-weed: *f*, a fertile portion.
— THURET.

294. Section of a conceptacle. — THURET.

(Fig. 296), enlarged cells produced on branching filaments. The antheridial filaments grow from the walls of conceptacles, either with the *oögonia*, or in other conceptacles upon separate plants, according to the species of Rockweed considered. At maturity both egg cells and antherozoids escape from the conceptacles and float about. The antherozoids swarm about the naked egg cell energetically (Fig. 297), and one of them finally penetrates and fuses with it. At once a wall begins to form about the fertilized egg, or *oöspore*, which now settles to the bottom, and upon germination gives rise to a new plant.

295. An *oögonium*. — THURET.

296. An antheridial branch; *a*, antheridia.
— THURET.

297. Antherozoids swarming about the egg cell. — THURET.

432. From the series given above (Ectocarpus, Cutleria, Rockweed) it is apparent that the antherozoids in Rockweed are in the nature of reduced zoöspores; while the egg cell also answers to a zoöspore, only in this case the cell is of increased size, and being from the first devoid of cilia, is entirely passive.

RED ALGÆ

433. The Red Algæ (Fig. 298) are, with few exceptions, marine.¹ While many forms may be found in very shallow water, many are found in deep water where, owing to the feeble light, no other algæ can exist. In

298. Red Algæ: *A*, *Delesseria sinuosa*; *B*, the so-called Irish Moss; *C*, a fresh-water species, *Batrachospermum cœrulescens*; *D*, two filaments of the last, showing the cells.

some of the smallest and simplest species the thallus consists of loose branched filaments (Fig. 298, D); in others, as in the Irish Moss (Fig. 298, B), the flattened thallus is divided into narrow segments; while in many others, the

¹ Of fresh-water species. *Batrachospermum*, Fig. 298, C, is very common on stones in brooks.

plant body is very thin and much expanded, and reaches a length of several feet. In most cases the plants are attached by more or less rootlike holdfasts. The often beautiful color is due to the presence of a red pigment, which more or less completely masks the chlorophyll.

434. Reproduction.—A characteristic method of bearing spores is in groups of four (Fig. 299), each group resulting from the division of the contents of an original mother cell. Such spores are termed *tetraspores*. They are bright red bodies without cell walls, and being unprovided with cilia, are dependent upon water currents for dissemination.

435. Reproduction, with fusion of the reproductive cells, may be illustrated by the case of *Nemalion*; this being taken as a simple instance of a process which

in some members of the group becomes highly complicated.

The reproductive cells of *Nemalion* are *pollinoids*, naked spherical cells produced singly in rounded *antheridia* (Fig. 300, *a*), and differing from *antherozoids* only in being unciliated; and *egg cells* formed within elongated cells termed *carpogonia* (Fig. 300, *c*).

The egg occupies the enlarged basal portion of the carpogonium, the hair-like extremity of

which is known as the *trichogyne* (*t*). Several pollinoids, brought by circulation of the water, may adhere to the

299. Tetraspores (*t*) in a filament of *Polysiphonia*.

300. *Nemalion*: *A*, showing the carpogonium (*c*), trichogyne (*t*) with pollinoids near, and antheridia (*a*); *B*, after fertilization, the carpogonium beginning to branch; *C*, the nearly mature spore-bearing body (cystocarp, *cy*). — THURET.

trichogyne; they surround themselves by membranes, and the contents of one of them passes through the trichogyne wall and makes its way to the egg cell. After fertilization the fertilized egg (oöspore), remaining in position, divides and, on all sides, sends out branches (Fig. 300, c), from which separable cells, called *carpospores*, are finally formed. These spores serve the same purpose as the tetraspores, growing directly to new plants.

436. It is to be noted that while in *Vaucheria* and Rockweed the oöspore is set free from the parent plant before germination and grows directly to a new plant, in *Nemalion* the corresponding body (fused egg cell and pollinoid) is not liberated from the carpogonium, but, as we may say, germinates in position. The free spores are produced only *after an interval of growth*.

437. We summarize reproduction in the types of Green, Brown, and Red Algæ as they have here been described, as follows:—

(1) Reproductive cells give rise to new plants *without conjugating*. A single cell, set free from the parent, germinates without having to fuse with another cell. This single cell is a spore: in *Ulothrix* and Brown Algæ, a zoöspore; in Red Algæ, a tetraspore or a carpospore.

(2) Reproductive cells *conjugate* before giving rise to new plants. Two cells unite to make up a body which is the starting point of a new plant. The uniting cells are gametes. Gametes may be: (a) zoöspores (zoögametes), indistinguishable in some cases from the zoöspores which germinate without conjugating; (b) pairs of similar unciliated cells (*Spirogyra*); (c) egg cells and antherozoids or pollinoids (*Vaucheria*, Rockweed, *Nemalion*). The egg cell may be fertilized in position (*Vaucheria*, *Nemalion*), or after liberation (Rockweed). The immediate result of conjugation is a *zygospore* when the uniting cells are alike; an *oöspore*, when they are unlike. The oöspore may be freed from the oögonium before it germinates (*Vaucheria*, Rockweed), in which case the reproduction is described as *oösporic*; or may develop in position (*Nemalion*), carpospores being the indirect result, in which case the reproduction is said to be *carposporic*. In *Vaucheria* and Rockweed the germination of the oöspore gives a new plant; we may properly, therefore, think of the structure resulting from the fertilization of the egg in *Nemalion* (namely, the branches of the carpogonium and the carpospores while forming) as a new plant parasitic upon the parent.

(3) Reproduction *without conjugation* serves for rapid propagation; and at the same time for dispersion, since the spores are often motile, and when unciliated float easily in the water.

(4) *Reproduction with conjugation*,¹ in the Algæ and other low plants, is often associated with exposure of the plant to adverse conditions, such as the approach of winter or drought or the old age of the plant. It seems to be a mode of reinvigorating the species at the moment when the production of a new plant is to be provided for. It is clearly of the same nature as the fertilization of the egg cell in the ovule of the Flowering Plants.

Reproduction with conjugation (sexual reproduction) in the Thallophytes is of three types, as indicated above; viz., 1) zygosporic, 2) oösporic, 3) carposporic. An important system of classification of both Algæ and Fungi (in which essentially the same reproductive processes occur as in Algæ) is founded upon these types.

FUNGI

438. Fungi may conveniently be defined as Thallophytes lacking chlorophyll. In structure and life habit many of them closely resemble certain Algæ. In some instances the resemblance is so striking that we may with assurance regard the fungal forms, in these cases, as having been derived from Algæ, chlorophyll having been lost through the adoption of a parasitic or saprophytic mode of life. Parallel cases in Flowering Plants are furnished by the Dodder (a parasite, Fig. 32) and the Indian Pipe (a saprophyte, § 59).

439. Many of the species are unicellular and very minute. When of more than one cell, the plant body is generally filamentous. Even in the compact, fleshy forms, like the Toadstools, the solid structures are built up of an immense number of essentially independent threads. The vegetative filaments of Fungi are termed *hyphæ*; and the plant body composed of hyphæ (aside from special spore-bearing parts) is the *mycelium*.

440. The number of species of Fungi is very great, and the types are extremely various. A few common forms will be described in order, thereby, to present several of the most important groups.

¹The last two methods of reproduction are also termed the *asexual* and the *sexual* modes, respectively.

Bacteria

441. The Bacteria (Fig. 301) include the smallest of all living organisms. Even the highest powers of the microscope fail to show much of their inner structure ; so that at present very little is known of their relationship to other groups. Our knowledge is confined to their external forms, methods of multiplication, and modes of life, with their effects, good and bad ; but this knowledge is of the highest practical importance, since the Bacteria affect the lives of other living beings, including man, in very direct ways.

442. Size. A common spherical form is $\frac{1}{500000}$ inch in diameter ; the rod-shaped germ of consumption is from three to nine times as long as this ; many species, however,

are considerably larger. *Form.* The principal forms are (1) spherical, (2) straight cylindrical, (3) spiral.

Movements. Many Bacteria exhibit very lively movements. Locomotion is usually accomplished by means of extremely fine cilia (Fig. 301). *Multiplication* commonly takes place by fission. Each individual divides into two parts, by transverse division, each part becoming a new individual.

Under favorable conditions — abundance of food and considerable warmth — the Bacteria may double in numbers about every half hour. In this way enormous multitudes may result even from one original individual in a comparatively short time.

Low temperatures retard growth and division : hence the utility of ice in preserving foods in warm weather. Under certain conditions Bacteria pass into a spore condition, in which they become highly resistant to destruction by heat or drying. In a dry

301. Bacteria, highly magnified: *a*, the germ of typhoid fever, stained to show the cilia; *b*, a spiral ciliated form; *c*, a rod-shaped form, in chains; *d*, a spherical form. — *a*, *b*, from ENGLER and PRANTL.

state the spores of some species may live for years. They are not necessarily killed by boiling. Only repeated or greatly prolonged boiling will sterilize liquids, *i.e.* free them from all Bacteria; though a single boiling will kill all active Bacteria present. *Prevalence.* Bacteria are present in considerable numbers in ordinary air and in most fresh waters. They are very abundant in most soils. They abound in many milk supplies and are present in butter, cheese, and other foods. *Subsistence.* Bacteria are (1) saprophytic and (2) parasitic. The parasitic species may cause deadly diseases in animals (including man).

443. *Effects.* Bacteria bring about chemical changes in the substances in which they live. Such changes are: the decay of the dead bodies of animals and plants; the fermentation (souring) of milk; the "ripening" of cream and of cheese; and the conversion of the alcohol in cider into the acid of vinegar. In the manufacture of butter, cheese, and vinegar, therefore, Bacteria play an important part. Other instances of their usefulness in the arts might be given.

Among diseases known to be due to Bacteria are influenza, erysipelas, scarlet fever, typhoid fever, consumption, leprosy, lockjaw, and cholera. The principal source of harm is the production of virulent poisons in the blood. In spite, however, of the dangerous character of the parasitic species, the Bacteria are on the whole a highly beneficial group of organisms. The dissolution of dead organic bodies, and the enrichment and preparation of soils for the uses of higher plants, effected by Bacteria, are very important services.

Yeasts

444. If one examines microscopically a small portion of yeast cake sold for raising bread, he finds (along with starch grains from the potato used in making the cake) numbers of small, colorless, unicellular plants, broadly elliptical or somewhat ovate in outline, and of various

sizes (Fig. 302). Though very small plants, the Yeasts are larger than most Bacteria, averaging perhaps $\frac{1}{32000}$ inch in length. Each cell consists of wall and protoplasmic body, generally including refractive granules and a large sap cavity.

302. Yeast plants: 1 and 2 represent successive stages in the process of budding.

Reproduction. — New individuals are formed not by division into two equal parts, as in the Bacteria, but by a process of “budding.” The cell wall is pushed out at some point in a small rounded swelling, which receives protoplasmic contents from the parent cell.

It increases in size and is finally cut off by a new cell wall; though it may long remain attached to the parent cell. Before its separation it may itself bud in one or more directions, and thus irregular colonial growths arise. Yeasts may multiply very rapidly, an entire new generation appearing in a couple of hours.

There are many different sorts of Yeast. The usefulness of all Yeasts, however, depends upon their power of decomposing certain sugars, with the resultant formation of alcohol and carbonic acid gas (that is, their power of exciting alcoholic fermentation). In beer and wine making, alcohol is the product sought; in bread raising, on the contrary, carbonic acid gas is the useful product, its bubbles giving the bread its lightness.

Bread Mold (*Rhizopus*)

445. If fresh moist bread is placed in a tightly closed dish in a warm place, within a few days a thick growth of fine white mold will probably make its appearance, unless special precautions have been taken to prevent such a result. That the plant may be secured without failure by such means of course demonstrates the prevalence of its minute spores in the air, or in the dust which has settled on the bread or on the dishes used. If we were to

follow a spore to its destination and observe its development, we should find that after soaking up some of the juices of the bread it germinates by putting out a transparent hypha (Fig. 306). The hypha grows by further absorption of food matter, increases rapidly in length,

303. Bread Mold: *S*, a sporangium; *r*, rootlike organs.

branches repeatedly, and thus ultimately develops into a complex mycelium running over the bread and sending hyphæ into the interior. All portions of this mycelium may be in communication internally, for there are no cross walls, or septa. In this respect *Rhizopus* is like *Vaucheria*.

446. Reproduction.—Special erect filaments are soon sent up, at the summits of which white globular sporangia

304. *A*, young sporangium; *B*, section of a mature sporangium; *C*, sporangium after rupture of the exterior membrane (*w*).

305. A spore of Bread Mold, more highly magnified.

are formed (Figs. 303, 304). At maturity both turn black. The numerous spores are ovate bodies (Fig. 305), covered with cell walls which protect them from

the chief danger which besets all very small organisms exposed in the air, namely, drying. Where the Fungus spreads away from the bread along the bottom of the dish, it is seen that the sporangial stalks arise in groups at points where the hyphæ touch the dish, at which points also rootlike organs appear (whence the name *Rhizopus*, *root footed*). The whole has very much the habit of a Strawberry plant propagating by runners (Fig. 303).

306. Germination of the spore.

307. Conjugation of *Rhizopus*: A, B, C, D, successive stages in the production of the zygospore.

447. Under certain conditions short lateral branches spring out near one another from neighboring hyphæ and grow until their tips are in contact (Fig. 307). The end parts of the branches become cut off by septa. They are the *gametes*, which fuse after the walls have been absorbed at the point of contact. The result is the formation of a thick-walled resting spore, or *zygospore* (Fig. 307, z).

Water Molds (*Saprolegniaceæ*)

448. The best way to secure material for the study of these plants is to bring in a large handful of decaying leaves from some pond hole or bog where water stands, throw them into a jar of water, and after them throw in either dead insects or succulent shoots of seedlings killed by heat. Upon these food materials the spores of the Water Molds from the dead leaves will fasten and ger-

minate. The short floating filaments, often much stouter than those of the Bread Mold, may be distinguished by the naked eye. Under the microscope they are seen to compose an unseptate branching mycelium, which penetrates the object upon which it grows.

449. Reproduction. — The more or less swollen ends of some branches are seen to be filled with dense protoplasm and to be cut off by septa to form the *zoösporangia* (Fig. 308, A). The contents finally breaks up into numerous rounded bodies which finally escape from a terminal opening in the zoösporangium. These bodies, the *zoöspores*, in some species are motile from the time they are set free; in other species just after ejection they surround themselves by a delicate cell wall, from which they soon escape and swim away, soon to germinate.

450. Resting oöspores are formed from egg cells, produced in spherical *oögonia* (Fig. 308, D), fertilized from *antheridial tubes* (Fig. 309), which penetrate the oögonial wall in order to reach the egg cells. After fertilization the oöspore surrounds itself with a thick wall.

308. Water Mold: A, zoösporangium; B, escaped zoöspores, before becoming motile; C, zoöspores in the active stage; D, oögonia and antheridia (a). The lower oögonium contains an unfertilized egg cell (e), and two young oöspores (o); the upper shows four mature oöspores (sp).

451. This process differs from oöspore formation in *Vaucheria* chiefly in the usual presence of several egg cells in each oögonium, and in the conduction of the fertilizing cells (or nuclei) to the egg cells by means of tubes. In *Vaucheria*, it will be remembered, the fertilizing cells are antherozoids. Frequently in Water Molds there is this further peculiarity, that *without fertilization* egg cells become oöspores capable of germination.

309. Fertilization of Water Mold:
a, antheridial tube.

452. It is from resting oöspores in the dead leaves that the plant is obtained for study, as recommended above. The oöspores on germinating shortly give rise to zoöspores (Fig. 310), and these infect the dead flies, etc., thrown into the water.

310. Germination of the oöspore:
a, zoösporangium; s, zoöspores.
—DE BARY.

Sac Fungi (Ascomycetes)

453. The name Sac Fungi or Ascomycetes (*ascus*, sac, and *mycetes*, fungi) is given from the fact that spores are borne in more or less oval, club-shaped, or elongated sacs at the ends of hyphae (Fig. 313). The sacs may be present in large numbers and are generally grouped in special structures, or "fructifications," built up from the mycelium around the sac-bearing hyphae. The following common forms will serve to familiarize the student with prevailing types of fructification, for it is by the forms of these structures that the different Sac Fungi are chiefly distinguished.

454. Peziza. — Common species of *Peziza* are most readily found growing on rotting logs and sticks, though many spring from the soil. The mycelium of septate threads spreads through the substratum for absorption of decaying organic matter. The fructification, known as *apothecium*, is in many species saucer-shaped (Fig. 311), in others

bowl-shaped, or even club-shaped. The largest have apothecia several inches across, but the commoner kinds

311. *Peziza* on wood.

312. Section of apothecium;
h, hymenium.

are a quarter inch or less in diameter. The interior of the saucer is lined by a layer (*hymenium*, Fig. 312) made up of spore sacs (Fig. 313) and sterile filaments that grow up between them. When ripe, the (eight) spores escape by the rupture of the sac (*ascus*). On germinating, the spores give rise to mycelia, the apothecia not appearing for a considerable time.

313. A part of the hymenium, greatly magnified: a, an ascus; f, a sterile filament.

455. Microsphaera Alni, one of the **Powdery Mildews**, is parasitic, often on the leaves of Lilac (Fig. 314). The mycelium

spreads over the surface of the leaf and sends haustoria (sucking hyphæ) into the interior. In the earlier part of the season simple erect filaments arise, at the ends of which spores are formed (somewhat as in *Penicillium*). Later, fructifica-

314. Lilac leaf, infected by *Microsphaera*.

tions are produced on the leaf surface, appearing to the naked eye as minute rounded black bodies. These are the *perithecia* (Fig. 315) which inclose the spore sacs. The perithecia bear radial appendages.

315. A perithecium broken open to show the asci.

456. *Aspergillus*, a very common fine mold on dry bread, cake, cheese, preserved fruits, etc., should be mentioned here, since, though it is really an Ascomycete, it would not be recognized as such at one stage of its existence. On first appearing upon

the given substratum the mycelium sends up great numbers of erect branches ending in globular heads, from

316. Section of the sporophore of *Aspergillus*.—KNY.

which are produced spores in chains radially arranged (Fig. 316). At a later stage of its history the mycelium gives rise to small rounded fructifications inclosing the characteristic spore sacs of an Ascomycete. In like manner other members of this group are known to pass through two stages of development differing in the method of spore bearing. *Penicillium*, a very common blue mold (Fig.

317. Fruit of *Aspergillus*, with asci (a).—KNY.

318), is an example.

457. The Rusts.—Many Fungi undergo remarkable transformations in the course of their life history. This is very marked in the case of the Rusts, of which the common Rust of Wheat (*Puccinia graminis*) may be taken for description. It infests the leaves and stems of Wheat,

318 Sporophore of *Penicillium*.

Rye, Oats, and various other grasses. The first appearance of this Fungus in the spring that one is at all likely to see, however, is not upon a grass, but on the leaves of the common Barberry, in the form of thickened red patches. On the under side of these areas, embedded in the leaf tissues, are then found the so-called cluster cups, or fructifications (Fig. 319),

320. A stalk of grass with spores of *Puccinia* breaking through the epidermis in dark patches.

filled with chains of rounded spores. New spores are formed at the base of the chains while the terminal ones fall off and are

carried by the winds to the Wheat (or other grass). The mycelium produced from these spores penetrates the body of the new host, where it increases largely, working damage to the Wheat, and forming masses of spores for the further

spread of the disease. The spores produced on the Wheat are different both in shape and in the manner in which they are borne from the spores of the cluster-cup stage on Barberry. Moreover, on Wheat the spores are of two sorts (Fig. 321): (1) unicellular *uredospores*, prevailing until late summer or fall, the office of which is to spread the Rust by immediate germination on being blown

319. Section through a cluster cup of *Puccinia* in the leaf of Barberry.

321. Uredospores and a teliospore (*t*) of *Puccinia*. — DE BARY.

to uninfected plants; (2) two-celled *teleutospores*, characteristic of the latter part of the season, thick-walled, and fitted to survive the winter. While still remaining on the dead stalks of the grain in the following spring, the teleutospores germinate. Each cell puts out a short filament (Fig. 322); and on the sides of these filaments small spores called *sporidia* are formed. Finally, by these sporidia the Barberry leaves are infected, and the life cycle is brought to the point at which this description was begun.

322. Germination of the teleutospore (*t*); *s*, *s*, the sporidia.
—DE BARY.

458. *Puccinia graminis* is one of many Fungi adapted to different hosts at different periods of their life history, and failing to develop if the proper hosts are not met with at the particular stages when they are required. The sporidia of this Rust germinate only on Barberry;

while the cluster-cup spores and uredospores of the *same* *Fungus* refuse to develop except on certain grasses (Wheat, Oats, Rye, etc.).

Basidiomycetes

459. The Basidiomycetes include the Toadstools and Puffballs and their relatives. The mycelia usually live saprophytically in soil, leaf mold, decaying wood, etc.¹ The fructifications which arise may be simple layers of tissue, coating the surface of the substratum, as in the whitish or brownish incrusting growths found everywhere on the under sides of rotting sticks; but in the majority of cases they are stalked structures.

In the common Toadstool (Fig. 323) the stalk (*stipes*, *s*) supports a cap (*pileus*, *p*) from which depend radial gills (*lamellæ*, *l*). Upon the surfaces of these gills the sporiferous

¹ Some Basidiomycetes are parasitic; for example, the Fungus which causes on Azalea and allied plants the growths known as "May Apples."

layer (*hymenium*) lies. Figure 325 shows part of the cross section of a gill. The spores (*s*) are borne, usually in fours,

323. Fructification of a toadstool (*Amanita phalloides*): *p*, pileus, or cap; *l*, lamellæ, or gills.

on enlarged hypha tips called *basidia* (*B*). This character — namely, bearing spores on basidia — has given the group (*Basidiomycetes*) its name.

324. A part of the mycelium.

460. Other types of fructification. —

The Basidiomycetes furnish the collector a great variety of curious and interesting forms. A little search in almost any woods will bring some of them to light. The hymenial layer is variously disposed. In some incrusting forms mentioned above (*Corticium*) it is simple (not folded); in *Clavaria* (Fig.

326) it covers the coral-like branches; in *Hydnum* (Fig. 327) the hy-

325. Section of a gill, highly magnified: *B*, basidia; *S*, spores.

326. *Clavaria*. 327. *Hydnum*. 328. *Polyporus*: *p*, pores of the under surface.

LICHENS (Figs. 329, 330)

461. Lichens form gray or yellowish patches on rocks and trees, festoons on the branches, and incrusting sheets and spongy mats on barren soil. They are commonly known as "Moss" — a wholly wrong name, as will be seen when

329. A lichen (*Physcia stellaris*):
a, apothecia. 330. *Usnea barbata*,

we come to the real Mosses. A section through a Lichen thallus (Fig. 331) shows large numbers of green cells having much the appearance of such unicellular Algæ as *Pleurococcus* and *Nostoc*, held in the meshes of a tissue made up of filaments resembling Fungus hyphæ. These appearances represent the truth of the matter. Lichens are composite growths in which certain unicellular Algæ and certain Fungi take part. Figure 332 shows how this union begins. The spore of a Fungus has fallen near a cell of *Pleurococcus*. The young mycelium is already applied to the Alga, which has divided. Further development consists in the

331. Section of a lichen thallus.

332. First stages in the formation of the lichen thallus. — BORNET.

extension and branching of the mycelium, and the multiplication of the algal cells; the construction, by these means, of a thallus having certain distinguishing peculiarities of structure, according to the

kind of Fungus and the kind of Alga concerned; and finally, the production of a spore-bearing body. In many Lichens this fructification is an apothecium (Fig. 329, *a*) very like that of *Peziza*, with a hymenium containing spore sacs or *asci* (Fig. 333). Most of the Lichen Fungi are Sac Fungi. They are parasitic upon the Algæ and cannot exist without them. The Algæ, however, are known to be able to exist perfectly well without the Fungi.¹

333. Section of an apothecium.

¹ Symbiosis (as the word is understood among English-speaking botanists) is the living together of unlike organisms for mutual advantage. Many botanists regard Lichens as examples of symbiotic accommodation.

LIVERWORTS AND MOSSES (BRYOPHYTES)

462. The account of Chlorophyllous plants was interrupted at the end of the section on Red Seaweeds. A series of colorless forms (Fungi) was then introduced, in general structure and often in detail closely resembling Algæ. We return to chlorophyll-bearing plants at a point where the ascending line of vegetable life leaves the waters to become henceforward very largely terrestrial.

463. The words "line" and "series" are not to be understood in too restricted a sense. For example, in Algæ several seeming lines of progressive development, running more or less side by side, are to be discerned; and the same may be said of any large group of plants. Moreover the "line" or "series" is never continuous,—is in fact merely a succession of considerably separated groups, through which run certain general principles of structure. In the grand series beginning with unicellular Algæ and ending with Flowering Plants, many breaks occur. That is, at certain points new features appear in the plant body, not matched by anything in any known lower form. It is not to be imagined that the whole organization is new—that the break in the series is absolute. The nature of the cells upon which the whole character of all vegetable life depends is always the same, and certain reproductive processes are always essentially the same. By the interruption of the series, we mean that in considering the origin of certain plants we are unable to find anything which we can regard as their near ancestry in the lower grades. This is the condition in the Liverworts. We may suppose they sprung from an algal stock; for the plant body is an expanded thallus, the habitat is often damp earth or even water, and reproduction is brought about through fertilization of an egg cell by antherozoids, as in many Algæ. But there is nothing by which we can fix the Liverworts as near relatives of any particular one of the existing algal groups.¹

464. *Marchantia* (Fig. 334), one of the commonest of the Liverworts, is found growing prostrate upon the ground in damp situations. The ordinary length is an inch or two. The thallus forks frequently, and the branches grow forward while the oldest portion of the thallus continually dies away; so that finally the branches

¹ By some authorities the Liverworts have been regarded as related to the Stoneworts (*Characeæ*) or the like; by others to be descendants of Algæ resembling *Colcochæte*, the Water Shield.

become separate individuals. The plant is attached to the ground by absorptive hairs, or *rhizoids*. Above, the sur-

334. *Marchantia*: *A*, thallus with rhizoids (*r*), cupules (*c*), and archegonial branch (*b*); *B*, section of archegonium, the fertilized egg (*e*) having divided once; *C*, disk of fruiting branch cut to show sporogonia (*m*, *n*, *o*); *D*, opened sporogonium with enveloping sheath (*pe*), and remains of old archegonium (*ar*).

face is seen on close inspection to be divided into small, slightly raised areas, each with a pore at the summit. The pore leads into a chamber (Fig. 335), from the floor of which rise short filaments or rows of richly chlorophyllous cells — the chief assimilatory tissue. This arrangement has the same effect as that of the loose tissues in the leaf of Flowering Plants (see Fig. 382), where pores (*stomates*) give free passage to gases, while the epidermal covering retains moisture.

335. Section in upper part of thallus to show pore (*p*) and assimilating cells (*ac*).

465. Reproduction. — Upon the upper surface, over the axes of growth, or midribs, small cup-shaped structures called *cupules* (Fig. 334, A, *c*) are found. From the bottom of each, several small lens-shaped bodies, composed of a considerable number of cells, arise; they are known as *gemmae* (literally *buds*). When set free and scattered by rains and running water they develop directly into new plants. This is *vegetative propagation* much resembling the propagation of Lilies by bulblets and various other Flowering Plants by offsets. Gemmae serve the same purpose as zoöspores in the Algæ, namely, rapid multiplication.

466. A second reproductive process is now to be described, in which gametes much like the equivalent bod-

ies in Algæ take part. In late spring and in early summer erect, more

or less umbrellalike, branches are found. They are of two kinds. In one case (*antheridial branches*, Fig. 336) the termination is a disk with scalloped margin. In the other the stalks end in a disk from which fingerlike rays project (Fig. 334); these are the *archegonial branches*. In

depressions of the scalloped disks stand the short-stalked antheridia.

The large cell of the antheridium (Fig. 338) becomes divided into a great number of smaller cells, in each of which a single antherozoid is formed. The antherozoids are like those of Rock-

337. Section of the disk; a, antheridia.

336. Antheridial branch.

338. Antheridium: antherozoids (az), highly magnified.

— SACHS.

weed—and like the zoöspores of many Algæ—in having two cilia for locomotion.

467. The archegonial branches bear on the under side at the base of the rays rows of flask-shaped organs called *archegonia* (Fig. 334, B). In the archegonium an *egg cell* (*e*) is situated at the center of the enlarged basal part. When ready for fertilization the egg may be reached through the canal in the slender portion, or neck, of the archegonium. When the dew is on the plants the antherozoids make their way to the archegonial branches (which at the season of fertilization are not much grown), and swarm to the mouth of the archegonia. One of them passes through the canal and fuses with the egg cell.

468. In most cases of oösporic reproduction in Algæ and Fungi, it will be remembered, the oöspore falls from the parent plant before it germinates. In Nematium, however, fertilization of the egg gives rise to a structure organically united to the original plant; this structure ultimately bears spores (carpospores), serving to disseminate the species. Marchantia is like Nematium in the noteworthy fact that the oöspore *germinates in position*, and gives rise to spores *only after an interval of growth upon the parent plant*. For after fertilization the oöspore divides into two, then into four, then into eight parts, and so on. The mass of cells thus originating grows and finally forms a stalked spore capsule (Fig. 334, C, D), or *sporogonium*. The foot of the sporogonium is embedded in the tissue at the base of the old archegonium (*ar*).

469. The *spores* are numerous, free, rounded or somewhat angular, walled cells. When the capsule bursts, one sees that it contains a great number of fine threads mixed with the spores. They have the property of twisting and untwisting with changes of atmospheric moisture, and so serve to give the spores to the winds from time to time. From the spores new plants develop.

470. The archegonium is a structure that is found in no plant lower than the Liverworts. As we go upward,

however, the archegonium appears in all the cryptogamic forms, and even in the Gymnosperms among Flowering Plants. In Liverworts and all plants higher in the vegetable series the fertilized egg cell germinates *in position*, and develops to a spore-bearing body.

471. Other Liverworts.—Some of the Liverworts are simpler than *Marchantia*. The archegonia and antheridia are borne by the thallus

339. A foliose Liverwort.

without the formation of special erect branches. The structure of the sporogonium (spore-bearing body) differs widely in other members of the group also. Many

of the species—*e.g.* many small forms found on tree trunks—show a distinction of stem and leaf (Fig. 339). Between thalloid and leafy forms gradations are found. The essential structure of archegonium and antheridium is the same throughout the group.

472. Mosses are closely related to the Liverworts. The foliose (leafy) Liverworts might indeed at a casual glance be mistaken for Mosses. In the latter, however, the leaves are generally arranged radially about the stem (Fig. 340); while in the foliose Liverworts, as seen from Fig. 339, the leaves are so disposed that the whole shoot has a flattened character in accordance with the creeping habit.

473. The Mosses live in very diverse situations. Some common species grow wholly submerged in running water like *Algæ*. Again, many common species inhabit extremely dry places, like the bare face of rocks, where there is no soil but dust and *débris* collected by the Mosses themselves, and where the plants can

340. A Moss shoot after the production of a sporogonium: s, spore capsule; o, operculum; c, calyptra.

have water only when dew or rain falls. Other kinds live in the crevices of bark on tree trunks; others on soil. The *Sphagnum* Mosses live in bogs, of which they sometimes form the chief vegetation. Peat from these bogs (used for fuel in some countries) is to a considerable extent made up of the dead stems and leaves of these Mosses.

474. *Reproduction* is essentially the same in Mosses as in Liverworts. On the end

342. Group of antheridia: (*a*) and sterile filaments (*f*) on the end of a Moss stem.

of the stem, usually, at the proper season *archegonia* (Fig. 341) are found. *Antheridia* (Fig. 342) arise in a similar position; but in most species the two kinds of organs occur on different shoots. The

antherozoid is motile by means of two cilia, and reaches the archegonium and finally the egg cell when the plants are wet. Fertilization results, as in Liverworts, in the production of a (usually long-stalked) sporogonium (Fig. 340). The upper part of the old archegonium may be carried up on the growing sporogonium as a cap (*calyptra*, *c*). The spore capsule opens for liberation of the spores by the displacement of a lid (*operculum*, *o*) in most Mosses.

475. When the spore germinates it gives rise, not to the Moss shoot directly, but to a many-branched filamentous

341. Archegonium of a Moss: *e*, egg cell; *n*, neck; *l*, lid (opening before fertilization).

— SACHS.

343. Protonema of Moss: *b*, bud of Moss shoot. — FRANK.

growth called the *protonema*, which spreads over the soil and resembles a filamentous Green Alga. Finally shoots appear as buds on the protonema (Fig. 343).

476. It will be noticed that in the Bryophytes (Liverworts and Mosses) the fertilization of the egg cell does not, as in most Algae, produce an oöspore which separates from the parent and develops into a new and distinct plant. The fertilized egg remains in position in the archegonium and gives rise to the spore-producing organ, or sporogonium.

FERNS AND FERN ALLIES (PTERIDOPHYTES)

477. Most of the Ferns and Fern allies of to-day are comparatively small plants, frequently with a creeping habit; some grow partly or wholly submerged; while several small species are floating plants. All this is in strong contrast with conditions in former geological times. In the Coal period Tree Ferns (now confined to the

344. A tropical Tree Fern.
— KERNER.

tropics) were widely distributed. Certain relatives of the modern slender, creeping Club Mosses (Fig. 357) were trees from 60 to 80 feet in height. Similarly some Equisetumlike plants, now represented mainly by species from 1 to 4 or 5 feet tall (Fig. 358) were tolerably stout trees 30 feet high. Forests largely composed of these Cryptogams formed the immense coal deposits of that period.

478. Ferns are still numerous, and in some places are predominant features of the vegetation. In the tropics they are especially abundant and large (Fig. 344). In most common species the stem is a creeping rhizome (Fig. 345), wholly or partly buried, so that all that one sees is the foliage rising from the ground. Ferns

have true roots,—unlike Mosses and Liverworts, which are attached only by hairs, or rhizoids.

345. Rhizome and leaves of the Rock Fern.

346. Under side of a segment of Fern leaf, showing sori.

347. Section of sorus: s, sporangia; i, indusium; b, blade of the leaf. — WOSSIDLO.

348. A sporangium.

479. *Spores* are borne in small sporangia (Fig. 348), clustered in groups on the under sides of the leaves (Fig. 347). Each cluster, or “fruit spot” (*sorus*), is in many species shielded by a membrane (*indusium*, *i*). At maturity, and on the occasion of certain conditions of moisture in the atmosphere, the sporangium splits at one side. The top is slowly thrown far back, and then suddenly resumes its former place. The spores are ejected by the violence of the motion.

480. The *germination* of the spore results in the formation of a small, thin, heart-shaped body called the *prothallium* (Fig. 349), in shape and habit of growth much resembling a small thalloid Liverwort. Prothallia of common species are from a quarter to a half inch in diameter, and may

349. Fern prothallium: ar, archegonia; an, antheridia.

be found on bare, moist earth under Ferns; or, better, in greenhouses. They are attached to the soil by rhizoids, most of which spring from a median thickening, the *cushion*. On the under surface, mainly nearer the more pointed end of the prothallium, hemispherical *antheridia* are borne (Fig. 350, *B*), in which the spiral, ciliated *antherozoids* (Fig. 350, *C*) have their origin. *Archegonia* (Fig. 350, *A*) may be found on the same prothallia, nearer

the notched (younger) extremity. In some species, however, antheridia and archegonia are always borne on different prothallia; though the spores from which the two sorts of prothallia arise are indistinguishable.

350. *A*, the archegonium with egg (*e*), and canal (*c*); *B*, antheridium; *C*, antherozoid, very highly magnified.—STRASBURGER.

481. *Fertilization* of the egg cell takes place when the prothallia are wet with dew or rain, by the

entrance of an antherozoid into the archegonium and the conjugation of antherozoid and egg cell.

482. The *result* is the division of the egg and the formation of an embryonic Fern plant (Fig. 351), in which the beginnings of leaf, stem, and root can soon be made out. Commonly only one of the several archegonia which may be fertilized gives rise to a perfected Fern plant. After the establishment of the latter, the prothallium dies.

483. The entire life history of the Fern thus comprises two stages, that of the prothallium (bearing archegonia and antheridia), and that of the leafy, spore-bearing plant. It will be recalled that in some of the lowest Algae (e.g. *Vaucheria*) the same individual plant gives rise to *spores*

351. Prothallium with young spore-bearing plant.

(zoöspores) germinating without fusion, and *gametes* destined to conjugate. In Ferns it is plainly seen that the two sorts of reproductive cells (spores and gametes) are not borne at the same period, but at very different stages of the life cycle. The two stages regularly alternate. This phenomenon is known as the *Alternation of Generations*. That form (stage or generation) of the plant that bears gametes (egg cell, antherozoid) is called the *gametophyte*; in Ferns the prothallium is the gametophyte. That form (stage or generation) which bears spores is the *sporophyte*; in Ferns the leafy plant is the sporophyte.

352. Section through a very young Fern plant: *s*, stem; *l*, leaf; *r*, root; *p*, the prothallium; *a*, *a*, remains of archegonium. — HOFMEISTER.

484. The Fern prothallium corresponds to the thallus of a Liverwort and the protonema and shoot of a Moss; for these structures all bear archegonia and antheridia. The final result of fertilization in Liverworts and Mosses is a sporogonium, *i.e.* a spore-bearing body. The final result of fertilization in Ferns is also a spore-bearing body—the Fern “plant.” Sporogonium and Fern “plant” have the same origin; they are therefore of the same nature: both are sporophytes. The sporophyte of Liverworts and Mosses (the sporogonium) has no root, but is, so to speak, parasitic on the parent plant, or gametophyte. The sporophyte of Ferns has a root, as well as leaves, and after the very first is self-supporting.¹

485. *Selaginella* (Fig. 353) is usually a creeping plant (a common species is ascending), with leaves *dorsiventrally* arranged; *i.e.* so placed that the shoot shows an upper and an under side. Special branches are often given off below, from which roots are sent out. The sporangia spring from

¹ Alternation of generations is not confined to Bryophytes and Pteridophytes, though in the Pteridophytes it is easier to see than elsewhere in the vegetable kingdom. It is foreshadowed in the Thallophytes and occurs in all plants above them.

leaf axils in the terminal "fruiting spikes" (Fig. 354). They are of two kinds as concerns contents, and often as

353. *Selaginella*.

concerns size and color. The larger (*macrosporangia*, *ma*, Fig. 354) each contain four large spores, or *macrospores*; the smaller (*microsporangia*, *mi*) contain large numbers of very much smaller *microspores*. Macrosporangia are found only in lower axils, or else only in axils on one side of the spike. Leaves with which sporangia occur, as here, are termed sporophylls.

354. Fruiting spike of *Selaginella* (*f*), and the same in section magnified: *ma*, macrosporangium; *mi*, microsporangium.
— GOEBEL.

486. In the after development of the spores *Selaginella* departs in a remarkable man-

355. Section of microspore: *s*, cells in which antherozoids originate; *p*, prothallial cell.

nner from the Ferns. The spores of Ferns give rise to distinct structures (prothallia) upon which archegonia and antheridia are produced. In *Selaginella* the germination of the spore goes no farther than the formation of a number of cells *within the original spore walls*. Moreover, the nature of these internal formations is different in the two kinds

of *Selaginella* spores. In the microspore these cells, filling the whole interior, compose an antheridium, with only the slightest rudiment of a prothallium; and within this antheridial body are formed antherozoids. In the macrospore a reduced prothallium appears. This finally increases sufficiently to burst open the spore at one end (Fig. 356); and on the exposed surface several archegonia develop. Fertilization takes place after the spores have fallen to the ground, when water is present to allow the antherozoids to make their way to the archegonia. Then, as in Ferns, an embryonic plant is formed, which soon develops stem, root, and leaves.

356. The macrospore with prothallium (*p*) bearing archegonia at the time of fertilization.

— CAMPBELL.

487. Two points are to be particularly noted with regard to the reproduction of *Selaginella*:

(1) Spores are of two kinds as regards (*a*) origin, (*b*) size, (*c*) ultimate development. For they originate in different kinds of sporangia, are very unequal in size, and give rise to antheridia and archegonia, respectively. This condition is foreshadowed in the Ferns, of which some species have *two sorts of prothallia* (§ 480). Here (in *Selaginella*) the differentiation extends to the spores and sporangia.

(2) The gametophyte (prothallial structure) is reduced so much that it is held in the original spore walls, and has lost all independence, possessing neither chlorophyll nor rhizoids.

488. Other Pteridophytes which one will frequently see are *Lycopodium*, the Club Moss, and *Equisetum*, the Scouring Rush or Horsetail.

489. *Lycopodium* (Fig. 357), to be met with in woods and old pastures and in partly shaded situations, resembles *Selaginella* in general habit, except that the leaves are usually arranged radially. The rhizome runs close to the ground or in the soil, and sends up erect branches. Spo-

rangia, all of one sort, are borne in leaf axils (s, Fig. 357). The sporangial leaves are usually grouped apart in a "fruiting" spike. Spores are of one kind, and give rise to prothallia which in many species are fleshy, tuberculate bodies, leading a more or less subterranean existence. Fertilization and the growth of the sporophyte have much the same history as in Ferns.

357. *Lycopodium*: *f*, fruiting portion; *s*, sporangium in axil of a sporophyll.

One of the commonest species is to be found along railroad banks. The northern species are, in general, a foot or so tall, though in the tropics *Equisetum giganteum*, a slender, clambering species, reaches a height of thirty feet.

491. The upright shoots spring from a running base. The stem is clothed at the nodes by short sheaths of conjoined scaly leaves. When branches arise they spring from the nodes and display the same arrangement of reduced foliage (Fig. 358).

492. The terminal portion of fertile shoots is converted into a spore-bearing region (*f*), in which the leaves are peculiarly modified (Fig. 358, *B*, *C*). They are peltate in form, and bear on the under (or inner) side pocketlike *sporangia* projecting toward the stem. The *spores* are very numerous. Each one is provided with two narrow strips of membrane (called *elaters*, Fig. 358, *D*), fastened to the spore at their middle points, the four extremities

490. *Equisetum*, the Horsetail, or Scouring Rush (Fig. 358), grows preferably in sandy soil, and often in moist situations. One of the commonest species is to be found along railroad banks. The northern species are, in general, a foot or so tall, though in the tropics *Equisetum giganteum*, a slender,

extending like arms when dry, but curling up suddenly when moistened by water or damp air. If a lot of the dry spores under the microscope is gently breathed upon, it is seen that the elaters almost instantly curl; and in doing so the elaters of neighboring spores become entangled, so that the hitherto dust-like heap becomes a coherent fluffy mass. This entanglement of the spores is of importance in the economy of the plant, from the fact that the prothallia to which they give rise are of two kinds. One kind bears archegonia alone, the other only antheridia. If archegonial and antheridial prothallia were separated, evidently fertilization of the egg cells by the antherozoids could not take place, and new *Equisetum* plants would not be produced. The prothallium and its organs are so much like corresponding structures in Ferns that no separate description need be given here.

358. *Equisetum*: A, a shoot bearing a fruiting cone (*f*); B, axis and sporophylls of the cone; C, sectional view of a sporophyll; D, a spore.

Relationship of Cryptogams and Phanerogams.—Suppose in the macrosporangium of *Selaginella* only one macrospore were to mature; that this macrospore were to remain permanently in the sporangium; that the prothallium were to be still further reduced, so as not to burst the macrospore wall; that the microspore should be brought to the macrosporangium, and put out a tube, which, penetrating into the macrospore, should conduct the antherozoids to the archegonia; and that the resulting *Selaginella* plant should develop and form its first pair of leaves quite within the macrospore,—then we should have an arrangement very like what actually exists in ovule, pollen, and seed in Flowering Plants. The embryo sac of Phanerogams is regarded as a macrospore remaining in its sporangium (nucellus of ovule, the integuments representing the indusia of some Pteridophytes). The several nuclei of the sac probably represent cells of a reduced prothallium, the egg cell standing for the egg cell of an arche-

gonium. In the embryo sac of Gymnosperms (Conifers, etc.) a definite prothallial tissue is formed with rudimentary archegonia at the summit.

The pollen grain of Phanerogams corresponds to the microspore of Selaginella. At the time of fertilization there are three or more cells in the pollen grain and tube. These cells—like those in the developed microspore of Selaginella—are regarded as prothallial in character, two of them (those which pass through the pollen tube to the embryo sac) being equivalent to antherozoids. In some Gymnosperms the fertilizing bodies from the pollen are motile, like the antherozoids of Pteridophytes.

Thus the gametophyte of Flowering Plants is wholly within embryo sac and pollen grain. In Liverworts the gametophyte (vegetative thallus) is larger than the sporophyte (sporogonium). In Ferns the proportions of the alternating generations are reversed, the gametophyte being much the smaller. In Flowering Plants reduction of gametophyte and increase of sporophyte have been carried to an extreme. The carpels and stamens of Phanerogams are the spore-bearing leaves, ovules (or their nucelli) and pollen sacs being sporangia; carpels and stamens are therefore often termed *sporophylls*.

XVII. THE MINUTE ANATOMY OF FLOWERING PLANTS

493. Cellular structure.—Attention has already been called, incidentally, in several places, to the fact that plants are made up of definite members of small size, called cells. All new cells are formed from preëxisting cells. Commonly this comes about by division: the original cell divides to form two or more, each of which may increase by independent growth, and in turn give rise by division to new cells. The very first cell of the embryo has a different origin, however. In fertilization, a nucleus from the pollen tube, entering the embryo sac of the ovule, fuses with a nucleus there found (see Fig. 164). As the result of this union the initial cell of the new plant is formed within the embryo sac. All future increase proceeds by division and independent growth.

494. The cell, then, is the unit of plant structure.—It is the unit also of plant activity. Whatever activities the plant as a whole manifests—such as growth, move-

ment, absorption of food material, assimilation — these activities are carried on by the coöperation of the cells composing the plant. This being the case, it is important to know something of the structure of the typical vegetable cell.

495. Structure of the cell. — In illustration of the typical vegetable cell, we might select cells from the apex of a growing stem or root, or from a leaf rudiment, or from the young, growing fruit. Thin sections cut from any of these regions would show, under the com-

pound micro-

scope, the

cells as sev-

eral angled,

thin - walled

components of the tissue

(Fig. 359).

359. Sectional view of young cells from the root tip.

360. Stinging hair of a Nettle. In the large terminal cell the circulation of protoplasm is indicated by arrows.

496. The living substance of the cell is protoplasm. It has been described as being of a jellylike consistency. A better illustration of the semifluid, yet cohesive, properties of protoplasm is afforded by the raw white of egg. The fluidity varies in different portions of the protoplasmic body of the cell, some parts being relatively firm, others containing a very large percentage of water, and being, therefore, capable of more or less rapid movement in circulating currents. In some cells in which the nucleus is suspended near the center by threads of protoplasm (Fig. 360), the currents may be seen in the threads, passing toward and away from the nucleus. Two opposite currents may often be observed in

the same thread. In cells like the largest one of Fig. 362 the whole body of protoplasm, except that part

directly in contact with the walls, may be in slow rotation, dragging with it the nucleus.¹

497. The term protoplasm includes all the living constituents of the cell. "The word *protoplasm* is a morphological term. . . . Protoplasm is not a single chemical substance, however complex in composition, but is composed of a large number of different chemical substances, which we have to picture to ourselves as most minute particles, united together to form a wonderfully complex structure. . . . In this mixture of substances, the wonderful vital phenomena may very frequently be observed (contractility, irritability, etc.)."²

Of the protoplasmic cell contents we have to distinguish a rounded central body, the *nucleus* (Figs. 359, 362, *n*), in

many young cells occupying a considerable portion of the cell space; and the general mass, aside from the nucleus, called the *cytoplasm*.

The nucleus is denser than the cytoplasm. It is made up of definite parts, differing in chemical constitution, definitely arranged. Although actually of extremely small size, the nucleus is a highly organized body. It is the controlling part of the cell. It is the first part to divide when new cells are to be formed, and in division passes through a complicated series of changes (Fig. 361), by

which equal shares in all the essential constituents of the

361. Nuclear and cell division: *A, B, C*, successive stages; *n*, region of the nucleus; *c*, cytoplasm; *d, d*, beginnings of daughter nuclei. In *C*, the original cell has become divided internally into two, each with a large nucleus (*n*).

— GUIGNARD.

¹ Stamen hairs of *Tradescantia*, cells of the leaf of *Elodea canadensis* or of *Vallisneria spiralis*, and cells of Stonewort (*Chara*), are objects in which movements of protoplasm may be studied. See Goodale, Ch. VI.; Strasburger, p. 244.

² O. Hertwig, "The Cell," p. 13.

parent nucleus are assured to the two resulting nuclei. Only after the nucleus of a cell has finished its division, is the surrounding cytoplasm separated into two portions. The production of two cells from one is completed by the formation of a new transverse wall.

498. Many cells possess, in addition to the nucleus, protoplasmic organs performing special offices in the general work of the cell. Cells from the interior of the leaf, for example Fig. 382, contain numerous rounded or lens-shaped bodies, lying in the cytoplasm near the walls. These bodies, colored green by the chlorophyll pigment which they contain, are the *chlorophyll granules* or *chloroplastids*. They give plants their characteristic green color. They are active in carbon assimilation. Similar cell organs, with red or yellow pigment instead of green, give color to fruits and flowers. They are called *chromoplastids*.

A thin external layer of the cytoplasm next the cell wall may be distinguished by its superior clearness and the absence of granulation.

It is very probable that this

362

really constitutes a sort of membrane, possessing a closeness of structure and tenacity above that of the rest of the cytoplasm. The remainder of the cytoplasm is highly granular in appearance, owing chiefly to the varying density of the protoplasm itself. Except in their earliest stages active cells contain interspaces, or *vacuoles*, filled with water and dissolved substances (Fig. 362). One large vacuole may fill the greater part of the cell, the protoplasm forming a layer next the wall. The watery contents of the vacuole or

vacuoles is the *cell sap*. It is sometimes colored. The red and yellow colors of healthy leaves are generally due to colored cell sap in some of the cells, masking the green of the chlorophyll granules. Bright colors of fruits and flowers also are generally due partly to colored cell sap. The cell sap may contain sugar in storage, as it does in the root of the sugar beet and in the stem of the sugar cane.

Certain substances belonging to the class of *formed matters* (non-protoplasmic) are of such frequent occurrence and are produced in masses of such size in the cell that they should be briefly described.

363. Starch cells from Potato tuber.

499. Starch.—Starch is the form in which elaborated plant food is most commonly stored. It is laid down in the cells of storage organs, *e.g.* tubers, in rounded granules (Fig. 363). When these are considerably magnified they are seen to be stratified, in evidence of

the mode of deposition of the starch in successive layers. If the granules are closely packed together, they may become angular instead of rounded.

500. Protein¹ granules and crystals.—The external storage cells of wheat grains afford examples of protein granules (Fig. 364). The contents of these cells make up the so-called gluten of

364. Transverse section near the outside of a Wheat grain: *a*, the husk (pericarp, integuments); *b*, cells with protein granules; *c*, starch cells.—TSCHIRCH.

¹ Protein is the name given to organic substance, whether of animal or of vegetable origin, containing nitrogen and a small proportion of other

wheat, which is, or should be, a highly nutritious element of wheat flour. In the cells of the potato tuber are to be found examples of proteid matter formed into cubical crystals. These granules and crystals are storage forms of protein.

501. Crystals of calcium compounds — calcic carbonate and oxalate — are of very common occurrence (Fig. 365). These are generally considered to be waste products of the chemical changes going on in the cells.¹ Other substances also occur in crystalline form, but less frequently.

502. The account here given of the typical vegetable cell, as regards protoplasmic structures and cell contents, is of course brief and incomplete; it is meant to be suggestive of the extent of the subject. The nature of the cell has been, and will long continue to be, the object of the investigations of numerous workers.

503. Certain cells of certain plants regularly contain more than one nucleus each. And in not a few of the lower cryptogams great numbers of nuclei exist within a common wall. The many-branched plant body may in such cases consist of one continuous chamber without internal division walls. Each nucleus represents a single cell, but there is no corresponding division of the cytoplasm.

504. The cell wall. — Early investigators assigned to the cell wall the chief importance; but we now know that life resides in the protoplasm, and that the wall is of secondary importance. In many of the lower plants the contents of certain reproductive cells break from their walls, and swim freely forth (Fig. 285). Only after a

365. Cells containing needle-like crystals (raphides) of calcium oxalate.

matters in addition to the carbon, hydrogen, and oxygen which compose starch and sugar. Proteid substances enter directly, and as such, into the composition of protoplasm.

¹ It is quite possible that calcium oxalate is a storage form of food.

period of active locomotion do they settle down and become invested with a membrane. This fact, among others, shows the essential independence of protoplasm in cells, and the subordinate rôle of the wall.

The wall is a product of the protoplasm. New walls are formed by the conversion of a portion of the protoplasm into the substance of the wall. In

366. Wood fibers in longitudinal section: *a*, part of the wall showing face view of pits; *b*, the pits in section.

young cells, and many old cells, this substance is *cellulose*, chemically resembling starch. It is a regular occurrence that in certain of the cells of the plant body, the protoplasm becomes at length wholly converted into wall, when, of course, the life of these particular cells is at an end. In the later phases of this process, the depositions may take a form differing chemically from cellulose. We have, for instance, in wood cells, lignified walls; in cork cells, walls containing a fatty substance called *suberin*. Modified walls of these sorts have physical properties differing from those of cellulose. For example, the suberized walls of cork resist the entrance of water, whereas the cellulose of pith and the lignified walls of wood take water into their pores readily.

Walls are seldom, or never, evenly thickened when the depositions are considerable, but certain areas remain thin, even after the completion of the thickening process. Or the greater part of the cell wall may fail to thicken, and then the depositions take the form of raised markings on the interior of the walls. Examples are the annular and spiral ducts (Fig. 371).

505. Changes in the shape of the cell.—The cells of the growing tips of the stem and root, and young and actively dividing cells elsewhere, are, in general, nearly isodiametrical. Subsequently, many of these cells become greatly

changed in shape. Cells of the external layer are in many instances flattened, in accordance with their protective function. Cells of strengthening and conducting tissues, on the other hand, are frequently greatly elongated. In the conducting tissues, elongated cells placed end to end in rows become united into tubes or *ducts*, the end walls being absorbed, wholly or in part, to allow the passage of liquids.

506. Several of the principal modifications of cells should now be described. We may begin with wood fibers.

507. Wood, whether occurring in so-called woody stems, or in succulent herbaceous stems, consists largely of fibrous cells, associated, in most cases, with ducts, or vessels. The fibrous cells are of a great variety of form and appearance in different plants; but those which are termed, in rather an indefinite way, *wood fibers*, are pointed cells, several times longer than broad, having thickened and lignified walls, and characteristically showing in these walls numerous pits, *i.e.* spots where the walls have remained thin or become perforated in such a way as to allow communication between the cells (Fig. 366).

367. Bast fibers.—
TSCHIRCH.

508. Bast fibers.—These are found in strands in the bark. They are generally of considerable length, compared with their diameters. Their walls are generally much thickened, so that the internal space, or *lumen*, is small, as seen in cross section (Fig. 367). Bast fibers give strength to the inner, stringy bark of the Basswood, the Grapevine, the Leatherwood, and so on. They constitute the fiber of Flax, from which linen fabric is woven.

509. Collenchyma.—The name collenchyma is given to masses of cylindrical or prismatic cells, having walls thickened at the corners in a peculiar manner (Figs. 368,

369). These walls, when seen in cross section, have a

368. Cross section of collenchyma.

distinctive glistening appearance. Collenchyma — tissue composed of such *collenchymatous* cells — is one kind of strengthening tissue. It is to be found near the surface of herbaceous stems, of

petioles, and of leaves, along the midribs.

510. Grit cells, or *sclerotic cells*, with very much thickened hard walls, are exemplified in the rind and external flesh of the pear, where they occur in groups. The walls are traversed by canals, of the same nature as the pits spoken of above (Fig. 370).

370. Grit cells from a pear.

Shells of nuts also give good illustrations of cells with walls similarly thickened, and affording protection by consequent firmness.

369. Longitudinal section of collenchyma. The lens-shaped bodies are chlorophyll granules.

511. Cell union, or fusion, is

illustrated in the case of many ducts, in which it is impossible to distinguish the original cells, placed end to end. The ducts of the wood are tubes giving unbroken communication between the absorbent roots and the leaves. The walls may remain relatively thin; in this case they are braced internally by rings or spiral thickenings (Fig. 371). The ducts take their names from their markings, being designated as annular, spiral, or pitted ducts, etc.

371. Spiral duct.

512. Milk tubes, or, in more technical language, *latex tubes*, holding the milky juice of Poppies, Dandelions, and allied plants, are formed from originally distinct cells by the breaking down of intervening walls

(Fig. 372). The cell fusions may take place mainly in longitudinal directions, giving the semblance of jointed tubes, or in all directions, producing a dense network. In the Milkweeds and the Euphorbias the milky juice (*latex*) is held in elongated, branching, tubular sacs originating as single cells in the embryo, and growing with the growth of the plant until they have pushed their way into every part of the plant body. The latex itself is a mixture of a considerable variety of substances; sometimes some of the ingredients are poisonous, as, for example, morphia, the active principle of opium, found in the latex of the Poppy.

372. Latex tubes (*l*).

—TSCHIRCH.

513. Tissues.—The word *tissue* has been frequently used above without exact definition, yet probably without misapprehension. Technically the term *tissue* means a mass or collection of cells of the same kind. Any number of cells of a certain kind constitute a particular kind of tissue. Thus collenchyma, a particular kind of tissue, was described above.

514. Fibrovascular bundles are so called from the fact that they are made up largely of fibrous cells and vessels (ducts). In a translucent herbaceous stem like that of the Balsam, the bundles may be seen without dissection, as strands lying not far beneath the surface, traversing the entire length of the stem, and giving off branches to the leaves. In the cross section of such a stem these bundles would be seen as several—perhaps five—areas more opaque than the surrounding parenchyma, arranged approximately in a circle (compare Fig. 376). Upon examination with a proper power of the microscope each bundle would be seen to consist of three parts (Fig. 373). The inner of these consists largely of wood fibers and ducts.

It is called the *xylem* or wood portion. The outer contains more rounded cells, but typically possesses bast

373. Fibrovascular bundle of a Dicotyledon: *ph*, phloëm; *c*, cambium; *d*, duct, and *f*, fibers of the xylem.

fibers in groups, and scattered tubes. It is called the *phloëm*. Between xylem and phloem is a region occupied by thin-walled formative tissue, from which, by cell division, growth, and modification, all the elements of both xylem and phloëm are derived. It is called the *cambium*. The cambium, during the active growth of the stem, continuously forms xylem on one side, phloëm on the other.

The outside of the xylem is thus the newest, while the innermost parts of phloëm are the newest. In old, woody stems, where the number of bundles is increased, and they are crowded together, the cambiums of the several bundles are continuous around the stem, forming a thin sheath outside the wood. It is at the cambium that the bark of twigs, especially in spring when growth is most active, may easily be separated from the wood. The phloëm is then, of course, removed with the bark, of which it forms the inner part.

515. Fibrovascular bundles of the sort described increase in thickness from year to year, if the plant is a perennial. They are found in dicotyledons. The characteristic bundle of the monocotyledons lacks the cambium (Fig. 374). The xylem also is much reduced. Each

374. Monocotyledonous fibrovascular bundle: *ph*, phloëm; *d*, duct (xylem); *p*, pith cell.

bundle is surrounded by a sheath of thick-walled lignified tissue, to which it largely owes its tensile strength. Once formed from the general formative tissue of the stem, the bundle shows no further growth, no annual increase of xylem and phloëm.

STRUCTURE OF STEMS

516. On one or the other of two types the stems of phanerogamous plants are constructed. In one, the wood is made up of separate bundles, scattered here and there throughout the whole diameter of the stem. In the other, the wood is all collected to form a layer between a central cellular part which has none in it, the *pith*, and an outer cellular part, the *bark*.

517. An Asparagus shoot and a Cornstalk for herbs, and a Rattan for a woody kind, represent the first. To it belong all monocotyledons. A Beanstalk and the stem of any common shrub or tree represent the second; and to it belong all plants with dicotyledonous or polycotyledonous embryo. The first has been called, not very properly, *endogenous*, which means inside growing; the second, properly enough, *exogenous*, or outside growing.

518. Endogenous stems, those of monocotyledons, attain their greatest size and most characteristic development in Palms and Dragon trees. A typical endogenous stem has no clear distinction of pith, bark, and wood, concentrically arranged, no silver grain, no annual layers, no bark that peels off clean from the wood.

519. Exogenous stems, those of plants coming from dicotyledonous and also polycotyledonous embryos, have a structure which is familiar in the wood of our ordinary trees and shrubs. It is the same in an herba-

375. Structure of a Cornstalk, in transverse and longitudinal section. The dots on the cross section represent cut ends of the woody bundles.

ceous shoot as in a Maple stem of the first year's growth (Fig. 376), except that the woody layer is commonly thinner, or perhaps reduced to a circle of bundles. The wood

376. Diagram of a cross section of a very young exogenous stem, showing six fibro-vascular bundles. 377. Same later, with bundles increased to twelve. 378. Still later, the wood of the bundles in the form of wedges filling the space, separated only by thin lines, or medullary rays, running from pith to bark.

all forms in a cylinder — in cross section a ring — around a central cellular part, dividing the cellular core within, the pith, from a cellular bark without. As the wood bundles increase in number and in size, they press upon each other and become wedge-shaped in the cross section; and they continue to grow from the outside, next the bark, so that they become very thin wedges. Between the wedges are still thinner plates (in cross section lines) of much compressed cellular tissue, called *medullary rays*, which connect the pith with the bark. The plan of a one-year-old woody stem of this kind is exhibited in the diagrams.

379. Cross section of wood : s, s, spring wood; f, fall wood.

520. When such a stem grows on from year to year, it adds annually a layer of wood outside the preceding one, between that and the bark (Fig. 379). This is exogenous growth, or outside growing, as the name denotes.

521. Some new bark is formed every year, as well as new wood, the former inside, as the latter is outside of that of the year preceding.

522. The Bark of a year-old stem consists of three parts, more or less distinct, namely, — beginning next the wood, —

1. **The liber, or fibrous bark**, the inner bark (Fig. 380, 1). This contains the bast fibers, the walls of which are commonly lignified, and other elements, as already briefly described. In woody stems, whenever a new layer of wood is formed, some new liber or inner bark is also formed outside of it.

2. **The green or middle Bark** (Fig. 380, 2). This consists mainly of rounded parenchyma cells, containing chlorophyll granules like the cells of the leaf. The green bark of twigs functions as assimilating tissue in the same way as the leaf parenchyma.

3. **The corky layer or outer bark** (Fig. 380, 3), consisting of empty, angular cells, closely coherent, the walls of which are *suberized*, or chemically altered in such a manner as to be impermeable to water. It is this which gives to the stems or twigs of shrubs and trees the aspect and the color peculiar to each, — light gray in the Ash, purple in the Red Maple, red in several Dogwoods, etc.

Sometimes the corky layer grows and forms new layers inside the old for years, as in the Cork Oak, which produces the cork of commerce, the Sweet Gum Tree, and the White and the Paper Birch. This growth proceeds from a formative layer, called the cork cambium, lying on the inner boundary of the cork. The old cork, being dead and therefore incapable of

380. Cross section through bark into the wood of a Lilac twig: *e*, epidermis; *c*, cork; *p*, collenchyma; *g*, green rounded cells; *f*, bast fibers; *ca*, cambium; *w*, wood; 1, 2, 3, inner, middle, and outer bark.

growth, is stretched, and finally rent by the continual enlargement of the wood within; it is weathered and worn, and thrown off in fragments, in some trees rapidly, in others more slowly, so that the bark of old trunks may acquire great thickness. Similarly in Honeysuckles and Grapevines, the layers of the inner bark or liber loosen and die, and come off in strips when only a year or two old.

523. The epidermis, consisting of a single layer of close-fitting, tabular cells, with outer walls much thickened and coated with a layer of matter impermeable by water, persists only for the first year or two. It is found, therefore, in the case of stems, only on herbaceous plants, and on the twigs and young parts of perennials, as a rule.

ANATOMY OF LEAVES

524. In the framework of leaves — ribs, veins, and veinlets — all the usual elements of vascular tissue are represented. The midrib, for instance, possesses a typical fibro-vascular bundle, with phloëm and xylem portions, derived from the branching of the fibro-vascular system of the stem. In the veinlets, however, the conducting elements become reduced to simple series of hollow cells and fibers. The woody framework serves not only to strengthen the leaves, but also to bring in sap and to distribute it throughout every part.

525. The living cells of the leaf, making up the green pulp, are of various forms, usually loosely arranged, so as to give copious intercellular spaces or air passages communicating throughout the whole interior (Figs. 381, 382). The green color is given by the chlorophyll grains, seen through the transparent walls of the cells and through the translucent epidermis of the leaf.

In ordinary leaves, having an upper and under surface, the green cells form two distinct strata, of different arrangement. Those of the upper stratum are oblong or cylindrical, and stand endwise to the surface of the leaf, usually

rather close together, leaving scanty vacant spaces; those of the lower are commonly irregular in shape, most of them with their long diameter parallel to the face of the leaf, and are very loosely arranged, leaving many and wide air chambers. The green color of the lower is therefore

381. Magnified section of a leaf of White Lily, to exhibit the cellular structure, both of upper and lower stratum, the air passages of the lower, and the epidermis in section; also a little of the lower face, with some of its stomates.

diluted, and paler than that of the upper face of the leaf. The upper part of the leaf is so constructed as to bear the direct action of the sunshine; the lower so as to afford freer circulation of air, and to facilitate the escape of moisture. It communicates more freely than the upper with the external air by means of pores in the epidermis.

526. The upper cylindrical cells are known as the *palisade* cells. The lower, irregular, or sometimes slightly branching cells make up the *spongy parenchyma*, so called.

527. The epidermis is usually composed of a single layer of more or less flattened cells, devoid of chlorophyll, and mostly of irregular outline (Figs. 382, 383).

The walls of the epidermis are commonly thickened externally by the addition of a layer of a waterproof substance. This layer is easily distinguished in the cross section from the original exterior walls of the cells. It is termed the *cuticle*. The several walls of each epidermal cell are impregnated with the same waxy or fatty

matters which give the cuticle its resistance to water. These walls are said to be cutinized.

528. The pores of the epidermis are called *stomates* or *stomata* (i.e. mouths). Each stomate (*stoma*) is guarded, so to speak, by two cells of peculiar conformation, called *guard cells* (Figs. 382, 383, *g*).

382. Section of a leaf: *e*, epidermis; *c*, assimilating cells containing chlorophyll granules; *p*, intercellular passages; *g*, *g*, guard cells of stomate.

383. Surface view of epidermis of the leaf: *e*, ordinary epidermal cell; *g*, guard cell. — TSCHIRCH.

The guard cells, unlike the rest of the epidermis, contain chlorophyll. They are so constructed that as the quantity of water they contain varies the slit between them is either opened wider, or narrowed, — or, it may be, quite closed. The guard cells are closed together when flaccid on account of the wilting of the leaf.

Stomates are found on most of the green surfaces of the plant, but most abundantly on the leaf. Here they are generally more numerous on the under side.

384. Trichomes (*h*, *h*) of the leaf. — SACHS.

529. **Trichomes** are outgrowths of the epidermis, consisting in the simplest cases of single cells, but in many cases of several cells in a more or less

complicated arrangement. Several different kinds may spring even from the same leaf (Fig. 384). Stinging hairs (Fig. 360) and hairs with bitter secretions are an important means of defense to many plants.

530. The anatomy of the root resembles, in a general way, that of the stem. There is a central conducting and strengthening strand of wood. In the older roots of perennial exogenous plants this becomes a cylinder of wood surrounded by a cambium zone, from which wood is formed annually just as in the stem. The cortex of the older parts of many roots is bounded externally by several layers of cork cells, preventing the passage of water into or out of the root. Formation of new tissue for growth in length takes place at the growing point (Fig. 28, *g*) under the root cap. New lateral roots originate from cells lying near the wood, and push their way through the cortex to the surface. They arise in longitudinal rows.

XVIII. A BRIEF OUTLINE OF VEGETABLE PHYSIOLOGY¹

531. Vegetable physiology deals with the processes by which the life of plants is carried on. Such processes are the absorption of materials; the transfer of raw and elaborated food matters from one part of the plant body to another; the conversion of inorganic matters into organic substance; the storage of elaborated products; respiration and the consumption of food for the production of vital energy; growth; and movement.

532. Constituents of the plant body.—The chief constituent, as concerns quantity, is water, since even in woody parts the solid portions amount at most only to fifty per cent of the total weight, and in herbaceous parts to but twenty or thirty per cent.

533. We may distinguish three ways in which water is useful to the plant: (1) it furnishes part of the raw material out of which

¹ A number of experiments in vegetable physiology and some information as to the general function of plants have already been given in this book. The present chapter is added for the purpose of gathering together in coherent form the results of these previous studies. As discussions of the most important matters will be held in the class room, following experimentation in the laboratory, the chapter may be used for reference rather than for ordinary assignment in lessons.

substances like starch and cellulose are formed; (2) it is the solvent in which all the vital chemical changes, like assimilation, are carried on; (3) its presence is an important factor in preserving the rigidity of the plant body. The first of these offices has been touched upon in the brief statement of assimilation made in the chapter on the Leaf. The second need not be further dwelt upon. The third may now be more fully considered, since it concerns a first essential to the existence of the plant, namely:—

534. The stability of the plant body.—By stability is meant the power of the plant to keep its form,—the power, if it is an erect plant, of keeping itself erect and outspread in proper position in all its parts. It is a matter of common observation that plants suffering from drought wilt and droop, sometimes even fall flat to the ground. Wilted plants have partly or wholly lost their stability.

535. Stability is secured in part by the properties of the tissues themselves; the thick-walled, strengthening fibers are so disposed in the stem as to secure the greatest rigidity. But in herbaceous and succulent organs, firmness depends oftentimes as much, or more, upon the condition of the living cells in regard to their supply of water. When one of these cells has a full supply of water, the expansive substances held in solution by the cell sap (for example, sugar and acids) are enabled to distend the cell to its full limits.¹ The cell is then said to be *turgid*.

In such a condition it resists the distorting stresses brought upon it by the pulls of neighboring cells. And when all the cells of a tissue are fully turgid, they resist, collectively, all distorting stresses. That member of the plant body which is well watered, therefore, retains its form and proper attitude.

536. The turgidity of cellular tissues gives rise to tensions between different masses of tissue lying side by side in the plant body. A good illustration of these tissue tensions is furnished by the succulent stalk of a Rhubarb leaf. Let a portion of the fresh stalk be cut squarely

¹ Dissolved substances have an expansive force, comparable in a general way to the expansive force of gases. Sugar dissolved in cell sap presses against the protoplasm that holds it in, just as hydrogen presses against the walls of a balloon. The cell, in such a case, has a constant tendency to expand. If water is at hand that can come in to occupy the additional space to be made by expansion, then the cell expands until the outward push of the solutions equals the resistance of the cell wall to being stretched. The entrance of water, therefore, is the result of the expansive tendency of the cell sap solutions. Water does not cause the swelling, only allows it. Absorption of water by such action is called osmotic absorption.

For a clear statement of the theory of osmotic pressure, see Ostwald's "Solutions," Eng. trans. The theory, however, has received important additions since the work named was published.

off at the ends, and its length be exactly measured. Let the stringy external sheath then be stripped off, and at once let both the central cellular column and one or two of the external strips be measured. It will be found that the pith has considerably lengthened, while the fibrous strips are somewhat shorter than the piece of leaf stalk originally measured. Before separation, then, the pith must have been compressed, the external tissues stretched. Tissue tensions add rigidity to stems, petioles, etc. Variations in tissue tensions give rise to curvatures of organs, such as the bending of the stem toward the light.

537. Solid components of the plant body.—By solid components is meant here all the matter left when water has been entirely driven off by heat at somewhat above the boiling temperature of water. This includes cell walls, dried living substance (protoplasm), starch, sugar, and other formed matters in the cells, and small amounts of mineral matters ordinarily held in solution in the juices of the plant or deposited in the tissues in crystalline form.

538. Amongst these, the organic constituents are composed almost solely of the four chemical elements—carbon, hydrogen, oxygen, and nitrogen. Organic matters belonging to the class carbohydrates—as sugar, starch, cellulose—and fats, include in their composition only the first three of these elements; they lack nitrogen. Nitrogenous organic compounds—as those that make up protoplasm—contain all the four elements named, and in addition, usually a small amount of sulphur and phosphorus.

539. The nature of the mineral matters held in the plant is found when the dried plant has been burned and the ash has been chemically analyzed. In burning, carbon and hydrogen are united with oxygen from the atmosphere and pass away in a gaseous form. Organic components of the plant body are therefore broken up. The ash that is left is entirely inorganic. In such ash, from various plants, has been found a large part of all the known chemical elements, including even the rarer metals. Most of these elements occur accidentally, being absorbed with soil water. But certain of the chemical elements are absolutely necessary to the healthy growth of every green plant. These are six in number; viz., sulphur, phosphorus, potassium, calcium, magnesium, iron.

540. Source of the elements.—Thus there are, including the four elements before named as chiefly making up organic substance, in all ten elements which must be furnished the growing plant. Each of these is received by the plant in a combined form. Carbon comes from the atmosphere, combined with oxygen, as carbonic acid gas. All the other needful substances come from the soil. Hydrogen and oxygen come together, as water. Nitrogen is brought in under the form of a soluble nitrate, or one of the ammonia salts, in the absorbed

soil water. Sulphur, phosphorus, potassium, *etc.*, are obtained in the form of salts from the soil.

541. As regards the number of elements supplied, the root is therefore the chief organ of absorption; the leaf absorbs only carbonic acid gas.¹ Absorption at the root may be considered under two heads: absorption of water, and absorption of nutrient salts.

542. Absorption of water.—The manner in which the root sends out root hairs, which become applied to the soil particles for the purpose of absorption, has been described in an earlier chapter. What force acts to draw water into the root hairs is not known with certainty. It is believed by most physiologists to be the osmotic force of the root hair cells (see page 230, footnote).

543. Aside from the scarcity or abundance of water in the soil, the chief external circumstance affecting the rate of absorption is that of temperature. Warmth increases absorptive activity, while cold decreases, or even prohibits it. Sachs found that at a temperature of from 38° to 41° F. absorption of water ceased, in spite of the fact that the soil was saturated.

544. Absorption of nutrient salts.—The salts needed for perfect nutrition may be swept into the plant in the absorption current. In case the salts are bound by adhesive force to the soil particles, they must first be loosened by the action of acids excreted by the root hairs. When they exist in free solution in the soil water, or have been brought into this condition by the secretions, they may pass into the root hair quite independently of any current, by the process known as *diffusion*. The dissolved particles of the salt wander throughout the body of water in which they find themselves, through the root-hair walls, and so on through the tissues of the plant body, unless they meet membranes possessing pores too minute to allow of their entrance. Those salts that are most used by the active cells and are therefore scarcest in the general sap of the plant, diffuse from the soil into the plant more rapidly than those that are little used and that therefore tend to become concentrated in the sap. Each kind of plant, according to its nature, by internally appropriating more or less of this or that salt, thus controls the absorption of the different soil salts at the root. Some kinds of plants tend to exhaust one constituent of the soil, some kinds another constituent. Plants are therefore said to show *selective absorption* of nutrient salts.

545. The transfer of water through the root and stem to the leaf is accomplished by a number of forces. In the case of deciduous trees

¹ Like all other parts of the plant, the leaf absorbs oxygen for respiration. But we are here considering the raw materials from which food is formed.

in spring, before the leaves appear, the sap may press up into the trunk and on toward the buds with considerable force. Or again, if in an herbaceous plant evaporation of water from the leaves is checked, the sap may press into the leaves so strongly that drops exude from the leaf tips or from the marginal teeth — usually in those cases from definite water pores. The drops seen at the tips of grass blades after a warm, damp night, are of this sort. In all these cases the rise of water in the plant is due to what is termed *root pressure*.

546. The phenomenon of root pressure may be observed when the stem of a plant, such as the Sunflower, is cut off near the ground. After a time water (sap) begins to run from the cut. If now an effort is made to stop the outflow, a considerable force must be used before the pressure of the sap — the so-called root pressure — is neutralized. Hales, the earliest of exact physiological botanists, who, about 1731, made some measurements of the root pressure of the Grapevine, found it to be equal to the downward pressure of a column of water forty-three feet high. A pressure of sap, equal to the pressure of eighty-five feet of water, has been observed in a Birch. Root pressure falls to nothing, however, when the loss of water at the leaf is going on with any rapidity. Root pressure, therefore, cannot continuously supply the leaves with the water they need.

547. The ascent of water in the stem has been the subject of many investigations and much discussion. The path followed by the current is the cavities of the ducts and fibers of the wood. The force working to raise the water in these cavities is not, to any considerable extent, capillarity, as was once supposed. The ultimate cause is doubtless the evaporation of water from the leaves; but how this works to raise water through the stem is still a disputed question.

548. Evaporation of water from the shoot; transpiration.—Land plants are perpetually giving off water vapor from their parts above ground, in greater or smaller quantities according to external circumstances or internal peculiarities. Even in winter the twigs of trees transpire a little. In desert plants transpiration is reduced to almost nothing in the dry season.

549. Leaves are the especial organs of transpiration in ordinary cases. Though their surfaces are covered with an epidermis that prevents too great loss of water, the pores or *stomates* allow a regulated escape of vapor which is of great importance to the plant. The intercellular passages of the spongy tissue furnish communication between the leaf cells, saturated with water, and the atmosphere without. As long as the stomates remain open, therefore, vapor given off by the moist walls of the cells escapes from the leaf. When the stomates close from any cause, the exit of vapor is checked. Even then, however, some evaporation takes place through the cuticle, which is imperfectly waterproof in most plants.

550. The amount of water lost by transpiration varies very greatly with the character of the plant and the conditions under which it is placed. The early experimenter Hales, by weighing, determined the loss from a potted Sunflower plant, three feet and a half high, to be on the average one pound four ounces every twelve hours. From this some idea may be formed of the very large weight of water transpired by a full-grown tree on a warm day. It has been estimated that the amount of aqueous vapor given off by an acre of Beech forest between June 1 and December 1 is between 1000 and 1500 tons.

551. The object of the transpiratory activity is the acquirement of nutrient salts from the soil and their transportation to the leaves, where they are left by the evaporation of the water.

552. The rate of transpiration is regulated in part by the action of the stomates. When the guard cells of a stomate are turgid the slit between them stands wide open. If the guard cells become flaccid, either through undue wilting of the leaf or from any other cause, the stomatal opening becomes narrowed or closed. The guard cells are sensitive to the influence of light; in bright sunshine the stomates stand wider open than in diffused light, and they close on dark, stormy days even in summer. Artificial darkness closes them — more quickly in the afternoon than in the morning. At night the majority of plants close their stomates, but not so as to prohibit all transpiration. The stomatal cells are sensitive also to dryness. A draught of dry air causes them to close, even though the leaves show no signs of wilting.

553. Aside from stomatic regulation, the rate of transpiration for any given plant depends largely upon the external circumstances of heat, light, dampness, or dryness of the atmosphere and supply of water at the root. Heat furnishes the energy for all evaporation; consequently, rise of temperature in the leaf accelerates transpiration. Light also has a stimulating effect. Dampness of the air around the leaf, on the contrary, retards transpiration, just as it checks ordinary evaporation. And of course dryness of the soil acts finally to reduce the amount of transpiration.

554. Assimilation of carbon. — Carbon is the most important of the elements going to make up the solid parts of the plant body. How great a proportion of the framework it forms is seen when wood is subjected to great heat in the absence of air. Everything volatile is then driven off; but the form remains, even the microscopic details of structure being preserved by the carbon of the charcoal. Carbon constitutes, by weight, about one-half of the dry substance of ordinary plants.

555. Carbon dioxide, the source of this important element, enters the leaf through the stomates, passes along the intercellular spaces of the spongy tissue, becomes dissolved in the water that saturates

the walls of the cells, and then diffuses throughout the green tissue. Its goal is the chlorophyll granules.¹ Here, in sunlight, its particles are torn apart, and the carbon atoms are combined with the atoms of hydrogen and oxygen derived from the decomposition of water, to form a carbohydrate. This carbohydrate, if not starch, is shortly turned to starch as a rule, appearing as minute granules in the chloroplastids sometimes within five minutes after exposure of the plant to light. These granules increase in size while assimilation continues; but when assimilation ceases, as at night, the starch begins to be dissolved, and is finally conveyed away in the form of a soluble carbohydrate. Assimilation of carbon by aid of light is termed *photo-synthetic assimilation*.

556. The conditions that must be fulfilled before assimilation will take place are these: Carbonic acid gas must be present in the atmosphere, there must be light and a certain amount of heat, and the chloroplastids must contain chlorophyll.

557. The atmosphere normally contains about .04 of one per cent of carbonic acid gas, by weight. Increasing this proportion hastens the rate of assimilation slightly; but if the gas is increased two hundred fold, the formation of starch becomes only four or five times greater. Ordinary variations in the amount of carbon dioxide would, therefore, not perceptibly aid assimilation.

558. Light furnishes the energy of assimilation. Of the different components of white light, the red, orange, and yellow rays are the most effective.

559. Liberation of oxygen.—In the act of assimilation, when carbon is taken into the material of the plant, the oxygen of the carbon dioxide is given off. In the case of water plants this may be seen. Let a cut branch of such a plant be exposed to light under water. Bubbles of oxygen will be seen escaping from the cut end. The rapidity with which these bubbles are given off may be taken as a convenient measure of the activity of assimilation in the given plant under the given circumstances. If, for example, the plant is exposed to one sort or one intensity of light for a period, and the number of bubbles rising from it per minute is found, the conditions as to light may then be varied, and the number of bubbles per minute ascertained anew; compared with the former result, the later count will show whether the assimilative activity of the plant is greater, or less, under the new conditions.²

560. The action by which substances like starch and protein granules, insoluble in the sap, are converted into soluble compounds is digestion. In digestion, starch is changed to sugar. In the latter

¹ See Fig. 382, Chap. XVII.

² See Goodale, "Physiological Botany," p. 305, for more explicit directions. The experiments are most interesting.

form the newly made plant food in the cells of the leaf can pass out through the petiole to the stem, and travel to points of active growth, or to storage cells. Digestion is accomplished by means of the so-called *ferments*, or *enzymes*, of which diastase is a common example. The enzymes are not consumed in the process; their mere presence seems to be enough to induce digestion. Diastase is extracted from germinating seeds (*e.g.* barley). If a solution is applied to a bit of starch on a glass slide under the microscope, the disintegration of the starch granules may be observed.¹

561. The formation of albuminous substances.—Assimilation is only the first step toward the formation of living substance, or protoplasm. The albuminous substances which compose protoplasm differ from the carbohydrates produced by assimilation, in containing a considerable proportion of nitrogen often with some sulphur and phosphorus. It is in the formation of these nitrogenous, or albuminous, matters that the nutrient mineral salts are put to use. Where this final step in the production of proteid matter is taken is not definitely known. It may be that it is in the green tissue of the leaf, or it may be at all growing points.

562. The transfer of organic substance, whether of carbohydrates or of nitrogenous compounds, is largely accomplished by the diffusion of solutions of these substances. Albuminous matters not diffusible, as well as solutions, are carried by the so-called sieve tubes in the bark, when the transfer takes place in a dicotyledonous stem.² This is the route by which nourishment designed for the root system is brought from the leaves. If a ring of bark is removed from the trunk of a tree, the bark above the cut grows and swells out, because of the arrest and accumulation of nourishment in transit toward the root.

563. Storage.—Such a part of the elaborated food as is not at once needed for growth passes into the store of reserve material.

564. Living cells perform the office of storage. In stems and roots these cells would be those of the bark, the medullary rays, and the living pith. In tubers and other special organs of storage, the storage cells are particularly numerous and often of large size.

565. Carbohydrates are stored most commonly in the form of starch, but also in the form of sugar. Reserve cellulose is another storage condition of the carbohydrates; in this case, the walls of the storage cells become greatly thickened by the depositions. Food may be stored in the form of oil and fat; also in protein granules and crystals.

566. Respiration.—All plants, like all animals, take in oxygen. As plants are less active than animals, they need less oxygen; and

¹ See *Enzymes*, Strasburger, p. 203.

² In the phloem of the fibrovascular bundles. For *sieve tubes* see Goodale, p. 91.

they have no special organs of respiration comparable to the lungs of animals. Yet special contrivances exist which facilitate the passage of oxygen from the atmosphere to every part of the plant. Intercellular passages penetrating the tissues communicate externally with the stomates, and with larger pores in the bark, called *lenticels*. Lenticels are slight outgrowths of the cork, in which the cells lie loosely upon one another, and over which the epidermis is broken away. They may be seen upon almost any twig. The intercellular spaces of water plants are particularly large in order to convey to submerged parts the oxygen taken in through the stomates of the leaf; or at least in order to retain the oxygen given off by assimilating cells. Oxygen also travels through the tissues dissolved in the liquids of the cells, by ordinary diffusion. In solution it enters the cell where it is needed.

567. All living cells require oxygen. The effect of excluding oxygen may best be seen in those cells¹ in which the protoplasm streams,—that is, circulates in the cell more or less rapidly (Fig. 360). If arrangements are made to supply some other gas—as carbon dioxide—to the cell while the circulation of the protoplasm is being watched under the microscope, the movement is seen to lessen within a few seconds after oxygen is driven off, and shortly to stop altogether. If, after not too long a time, oxygen is once more admitted, the streaming of the protoplasm begins again. But if the suspense is too long, the protoplasm will be found to be dead.

568. In respiration, the oxygen absorbed by the protoplasm slowly oxidizes it. There is, in other words, a slow burning. Of course the protoplasm is slowly destroyed, and has to be renewed through nutrition. The result of oxidation, however, is the generation of heat and other forms of energy, which enable the cells to do their work. The process is essentially like that by which energy is “set free” in the burning of coal for the driving of an engine. All engines, whether organic or inorganic, consume fuel.

569. By the oxidizing process carbonic acid gas is formed. This gas is easy to detect experimentally,² and when given off by the plant furnishes the best evidence that respiration is going on. Plants respire continuously, as long as they live. But in daytime respiration is not easy to show, since the carbon dioxide given up by the respiring cells is taken in by the assimilatory tissues. At night or in darkness, on the other hand, respiration is clearly indicated by the escape of the telltale gas.

¹ Such as the new root hairs of some aquatics, the cells of the leaf of the fresh-water Eelgrass, and cells of the alga called *Chara*, and young crichomes of many plants.

² See Experiment 12, p. 66.

570. "The contrast between assimilation and respiration¹ is very marked: one is substantially the opposite of the other. The following tabular view displays the essential differences between them:—

CARBON ASSIMILATION	RESPIRATION
Takes place only in cells containing chlorophyll.	Takes place in all active cells.
Requires light.	Can proceed in darkness.
Carbonic acid absorbed, oxygen set free.	Oxygen absorbed, carbonic acid set free.
Carbohydrates formed.	Carbohydrates consumed.
[Energy is stored.]	[Energy is brought into use.]
The plant gains in dry weight.	The plant loses dry weight."

571. Resting periods.—The dormant condition of seeds and buds has already been described. In the periods of suspended animation respiration is reduced to its lowest limits. Some seeds may be kept for years without loss of vitality. We must suppose that all the while the protoplasm is to a very slight extent active, and that feeble respiration is going on.

572. Growth.—Were we to trace the inner and outer changes that lead to the formation of a complete leaf,—taking the leaf as an example of the organs in general,—we should find the following course of events. First a slight prominence is to be seen close to the tip of the stem. This elevation is caused by the rapid multiplication of the cells at the point where the new leaf is to appear. All the cells at this point are capable of dividing; the tissue is said to be embryonic. Of course division is accompanied by the increase in size of the cells produced. As the protuberance grows, it soon shows some signs of external shaping. Lobes appear, if the mature leaf is to be lobed or compound. But the whole mass of cells remains embryonic in character, and the cells are still relatively small, until the new organ has been formed and shaped into something like a miniature of its mature condition. Then another phase of growth sets in. Few new cells, or none, are made, but all the cells begin to elongate and enlarge. As a result the whole leaf expands, and it may do so very rapidly. This phase—the *phase of elongation in growth*—is seen in the swift expansion of foliage from winter buds in spring. Finally, as full size is being attained, a third phase appears. The cells of the leaf individually take on their characteristic forms, by final changes in shape and in the nature of the cell walls.

573. Three phases are thus to be made out in the growth of any organ: (1) the formative, or embryonic phase; (2) the phase of elongation; and (3) the phase of internal development. But it is not to be

¹ From Goodale's "Physiological Botany," p. 356.

supposed that one phase ceases altogether before another begins. We distinguish the phases in a general way.

574. Grand period of growth. — If the elongation of a short section of a very young growing part, as for instance a section very near the tip of a growing root, is marked off and measured from time to time through several days, it will be found that at first the rate of elongation in the given section is low, then gradually increases to a grand maximum, and finally declines until growth disappears. The whole time of growth of an organ, characterized by such a general rise and ultimate fall of the rate of growth, is termed the *grand period of growth*. Within this there are minor variations, chief among which are the daily fluctuations.

575. Daily fluctuations. — If the length of a growing stem were to be measured at frequent intervals during the twenty-four hours, it would be found that elongation does not go on uniformly. It is periodic, being less rapid in the daytime than at night. The diurnal minimum is usually reached sometime in the afternoon; the maximum, commonly after midnight. This is due to the nature of the plants themselves, not directly to the working of external causes. For if a well-nourished growing plant is kept for several days in the dark, the periodic changes in growth rate still continue. All this has, however, been induced in plant nature, in the past, by alternation of day and night.

576. The chief external influences affecting growth are temperature and light.

577. Temperature. — Favorable temperatures vary greatly, according to the plant in question. Thus, in northern latitudes and on high mountains certain species are found growing vigorously in early spring, even through a covering of snow, at a temperature very slightly above freezing; while most plants of warm climates altogether cease to grow at a temperature several degrees higher. For many common plants the most favorable (*optimum*) temperature is between 70° and 85° F.

578. Light. — In general, light acts against growth. Too great light may quite prevent growth. In nature, accordingly, the rate of elongation increases during the night, especially after midnight, and decreases during most of the day.

579. Movement. — Transfer of substances in the plant, as of water or food substances, and circulation of living protoplasm in cells have been mentioned. In the descriptive chapters movements of particular organs have been noted in detail, as the movements of roots of seedlings, stems, leaves, tendrils, tentacles, and floral organs. These activities have now to be briefly considered together.

580. Most movements of bending are due to unequal growth on different sides of the organs in question. Curvatures of mature organs, like bending of pulvini of leaves, and sudden movements like

those of tentacles, some stamens, and leaves of the Sensitive Plant are due to alterations in tissue tensions independent of growth.

581. Movements may be due: (1) to internal causes, or (2) to external influences. The first are *spontaneous*, the second *induced*.

582. Spontaneous growth movements. — Darwin showed that the tips of growing parts of plants — stems, leaves, roots — perpetually move in irregular elliptical curves. Since the motion is one of bowing toward all points of the compass in turn, he called it *circumnutation*.

583. Induced growth movements. — These are much the more striking. The exciting causes (*stimuli*) are chiefly: gravity, light, moisture, mechanical contact, and variations of light and heat.

584. Gravity. — It has been observed from actual experiment in the laboratory that roots of seedlings turn toward the center of the earth, while the plumule turns toward the zenith. All turnings under influence of gravitative force are manifestations of *Geotropism*. The root is said to be positively, the shoot negatively, *geotropic*.

585. Light. — Plants turn, as we say, instinctively toward the light. If one could observe the root, however, it would be found to turn away from light. These actions are instances of *Heliotropism*. The shoot is, in general, positively *heliotropic*, the root negatively *heliotropic*.

586. Moisture. — The root seeking moisture displays *Hydrotropism*.

587. Contact. — When the revolving end of a tendril or a twining stem strikes an object of support, growth on the touched side is retarded. The effect of this stimulus is, therefore, to make the tendril or stem encircle the support.

588. Variations of light and heat modify the rate of growth on opposite sides of leaves. If the upper surface of blade and petiole grows faster than the lower, the whole leaf is depressed; if the lower side grows faster, the leaf is raised. Movements of this sort are especially noticeable in floral leaves. In warm sunshine, for example, the leaves of the Dandelion head unfold for the visits of insects; but when, in the afternoon, the light and warmth fall off somewhat, the bracts and corollas of the inflorescence close up tightly. In other cases the effects of illumination are just the reverse, for the flowers open at night, when the nightfliers that pollinate them are abroad.

589. Movements due to change of turgidity. — These have been described in the chapter on the leaf (sleep movements, behavior of the Sensitive Plant, action of insectivorous leaves). Such movements, due to changes of turgidity (apart from growth), are confined to leaves (vegetative and floral); and they result from the sudden escape of water from the swollen tissues of the pulvillus or other motile organ, into the internal ducts or intercellular spaces.

590. Irritability. — All the movements and changes of movement referred to in §§ 583-589, occasioned by external exciting causes (stimuli), are manifestations of the *irritability* inherent in protoplasm.

APPENDIX

I. PHANEROGAMIC LABORATORY STUDIES¹

Laboratory outfit.— Each pupil needs a **simple microscope**. This may be an inexpensive lens, or combination of lenses, mounted over a glass stage, and supplied with light from below by a mirror. Dissecting microscopes of this sort, of various degrees of excellence, are offered by dealers. (Bausch & Lomb, *manufacturers*, Rochester, N.Y.; Queen & Co., *manufacturers*, Philadelphia; Franklin Educational Company, and L. E. Knott Apparatus Company, Boston; Cambridge Botanical Supply Company, Cambridge, Mass.; and others.) Those forms in which the lens is easily removed from the holder, so as to be used as a hand lens, have a decided advantage in examining material that is not readily manipulated on the stage. Lenses that screw into the holder, or frame, are not easily got out for hand use. The best that the school can afford in the way of a dissecting microscope is not too good. On the other hand, even a cheap lens, unmounted, will help one to learn much.

The outfit for each pupil comprises also a pair of **dissecting needles** (which may be homemade, from No. 10 cambric needles and pine handles); a *well-sharpened knife* or scalpel; and a pair of **steel forceps** with slender, roughened points. At hand should be a glass of **water** and a small bottle of **iodine solution** (see Exercise II., 2, p. 246). The laboratory should have **glass slides** and **cover glasses**, and one or two sharp **razors**, with means of keeping the latter in good cutting condition.

The experiments call for various utensils which need not be mentioned here.

Notebooks should be of good size (about 8×10 inches), so bound as to lie flat when open on the table, and made of a good quality of paper. J. H. Schaffner, of Ohio State University (Columbus), has described (*Jour. Appl. Micros.*, June, 1900) what appears to be a convenient notebook. Covers, sheets for notes, and sheets for drawings are separate, of the same size, and punched alike. The whole is held together by shoestrings. Dr. Ganong also has designed a notebook. It may be had of the Cambridge Botanical Supply Company. The paper on which drawings are to be made should be a rag paper, at

¹For Cryptogamic studies, see II., p. 258. Additional implements are there described.

least as good as the grade known as ledger $17 \times 22 - 32$. The J. L. Hammett Company (educational supply), Boston, can furnish books of this paper, 8×10 , 100 pages, with flexible covers, at 40 cents each, more or less, if ordered in lots. I mention this to give some notion of the probable cost of such books.

The Laboratory Studies have been written with a view to the use of the dissecting microscope, or hand lens, solely. But it is evident that one or two **compound microscopes** may be the means of adding greatly to the interest of the pupils. Demonstrations of the minute structure of the higher plants, in the course of the study of the chapter on that subject, demand the compound instrument. How far one may profitably go into the study of cellular structure depends upon circumstances, such as the age of the pupils and the time at their disposal. Personally, I believe that, especially if the teacher has used the compound microscope much, he will be likely to underestimate the difficulties of gaining true impressions of the structure as it exists in three dimensions, from sections necessarily showing but one plane at a time.

Material. — The material for study, when not named and described in the exercises themselves, is specified in the Appendix.

Material in stock. — Dried and pressed specimens, supplementary to the laboratory and the text, should be mounted on stiff board of convenient size. Herbarium paper is too flexible and too large for handling around. The collecting instinct is strong, and the successive classes in botany may be called upon to build up such a collection as is desired, in the case of schools in or near the open country. Valuable suggestions as to collecting and mounting illustrative material is given by Dr. Ganong in the "Teaching Botanist."

Material not dried may be preserved in formaline (formaldehyde) of 4%. As sold, this preservative is of 40%. It is cheaper, when dilute, than alcohol, but the fumes are disagreeable and harmful, so that material to be worked over should be *well soaked and freed from formaline*. Alcohol is the best preservative. Fifty per cent may be strong enough to keep material for general morphological work; but 70% is better.

Study and drawing. — The aim of laboratory work in botany is to win an insight into the life of plants as revealed in structure, or as manifested by living plants under observation in the experiments. Structure is the record of past and present natural history. It repays thoughtful consideration. The simple drawing of the material presented is by no means an adequate method of dealing with it. It is common to see students draw assiduously and well, while passing on from one subject to the next, with little or no comprehension of the meaning of the forms. It is not unusual to see careful drawings, on which much time has been put, which illustrate accidental, abnormal,

or inconsequential features merely. Such drawing is, of course, a waste of time. The corrective is such study of the material as will insure an understanding of its meaning before the drawing is begun. When the essential points have been grasped, they are fixed in the memory by drawing.

It is true that drawing is a help in studying objects; for the strict heed one must pay to their forms in order to represent them exactly leads to the discovery of facts that would otherwise escape notice. The work of the pencil serves as a score by which we keep account of the degree to which the eye has exhausted the details of the object. The practice of drawing thus acts as a means of increasing the power of attention to the manifold separable aspects of anything we wish to examine, — that is, the analytical power. Yet, in general, in order that the drawing may be done intelligently, a certain amount of preliminary study is necessary. This requires time; but the time so spent is likely to be well employed.

The attempt has been made in this book, by brief discussions preceding the exercises and by suggestive questions, to direct the pupil's mind toward the quarter where the most essential points are to be looked for in many cases. When questions are asked they are intended to be answered, sooner or later, in the written notes of study.

For the record of laboratory work should consist of notes illustrated by properly labeled drawings. The notes should be as full as is consistent with time limitations.

In examining the material, even when the desired observations may be fairly well made with the naked eye, pupils should be reminded to make free use of the hand lens, or the microscope lens used as such. Very many things are thus rendered striking and memorable that otherwise would fail of making much impression. For example, the delicacy of the veining of the cotyledons of *Ricinus* in the embryo is far better seen by aid of the lens than with the eye alone, though the cotyledons themselves are well above the microscopic range. And this delicate veining suggests more forcibly than the mere external form of the embryo how highly organized and perfected the young plant already is.

Drawings should be in outline with little or no shading as a rule. Every line should be distinct and definite, and represent an exact observation made upon the object. General impressions are not sought. Artistic "effects" are out of place in scientific drawings. Every part should be labelled.

Experiments. — The best general manual of experiments in vegetable physiology is probably that of Detmer ("Practical Plant Physiology"), translated by Moor, published by The Macmillan Company, New York, 1898. List price, \$3.00. From this source the teacher will gain ideas for additions to the experiments suggested in this

book; and, further, will there find clear and authoritative statements of physiological theory. The book is more than a manual of experimental procedure.

Experiments sometimes fail to convince the pupil of the truth which it is sought to illustrate. Doubts should not be put aside or left unsatisfied when it is possible that some further test—which, oftentimes, the pupil himself is able to suggest—may settle the question without recourse to the statements of the authorities. A little experimenting along an original line, that is, a line original as far as the pupil is concerned, is often of very great value: it awakens and stimulates the scientific spirit strongly in some cases.

Books of reference.—The following will be useful to the teacher who wishes to extend, by reading, a scanty knowledge of botany: "Gray's Structural Botany"; American Book Company, New York. "Goodale's Physiological Botany"; American Book Company, New York. Strasburger (and others), "Text-book of Botany," translated by Porter; The Macmillan Company, New York.

This list might, of course, be indefinitely extended.

Ganong's "The Teaching Botanist" is a manual for the teacher, containing outlines of a course of study, pedagogical suggestions, a list of books of reference, etc., etc.; the book is highly recommended to teachers in secondary schools. Published by Macmillan, New York.

Chapter I.—In approaching a series of studies on a given topic we may adopt either of two courses. First, we may, without delay or preliminary consideration, proceed to the actual study of the material, leaving all general views aside until the laboratory work has been completed and the summarization is to be made. Or, secondly, we may seek to gain at least some general idea of the direction and aim of our investigations before they are actually begun. If the teacher chooses the former method he will pass over the questions asked at the beginning of Chapter I., and will not necessarily emphasize the headings of the several exercises. If the second method is pursued, then the teacher will talk over the proposed work on the subject of seeds with the class before the first exercise. It will probably be found that amongst them the pupils already know a good deal of the natural history of seeds. And this knowledge may be made the basis of interesting suggestions of study. There may be a doubt on the part of some pupils as to whether the seed has a complete plant in it. This may then be left for investigation. But all will doubtless admit that the seed contains at least the starting-point of a new plant, if no more. Assuming this, the idea of the resting state (see text on Seeds, Chapter II.) may perhaps be hinted at. This conception, together with the idea of the feebleness of the young plantlet at the start as opposed to the dangers and difficulties that surround it, and

the need of rapid development, may suggest certain of the structural features which might be expected in the seed. Questions at least may be raised, growing out of the general conceptions already formed from incidental observation, which will unify and illuminate the whole series of studies on the seed.

Because I have found that this second method, that of approaching laboratory work with an idea to work out, adds to interest and intelligent appreciation, I have prefaced the chapter with several questions which it is the aim of the exercises to answer. While the teacher may make use of them by requiring the pupils to read them in advance, it would be much better to draw from the class the principles of the subject, using a recitation period for the purpose, and formulating some general scheme of work to cover the subject of seeds and their germination. Of course under the guidance of the teacher the resulting outline will assume the general form in which the laboratory studies have been cast by the writer, providing Chapter I. is to be used for laboratory directions to the pupil.

I would suggest that, similarly, at the beginning of each of the chapters of laboratory studies, time enough be taken to gain an outlook over the whole of the field about to be entered. In the preparatory conferences interesting points may sometimes be introduced by illustrative material, even in cases where closer, more detailed study is later to be given to similar material.

Exercise I. — Castor Bean. Material from seedsmen. The Castor Bean should not be eaten, as it contains poisonous principles which may do harm. Let the seeds be boiled in water for five minutes for softening, after removing a little of the testa to allow the water to penetrate. — **White Lupine.** *Lupinus albus*, of the seedsmen. Soak 1 day in water. — **Indian Corn.** The flat-fruited Southern or Western variety of Indian Corn, soaked for a day or two. For the sprouted condition sow in soil, damp sawdust, wet sphagnum, or between sheets of wet blotting paper, after soaking in water. Allow from a week to 10 days. If the proper stage of development is reached before the class is ready for the study, keep the material back by placing in a cool room (above 32° Fahr.). In estimating the time required to grow material for class use, one should remember that, in general, moderately high temperatures (70°–80°) accelerate, while low temperatures retard, germination and growth.

A teacher writes: "In the summer I boil some corn on the ear. I carefully remove the kernels and preserve them in about 60% alcohol. They can be used at any time."

In the directions for drawing, the numbers in parentheses indicate *magnification in diameters*.

Exercise II. — 1. Soak the Four-o'clock seeds 1 day. The Sunflower and the Peanut are suggested as having large exalbuminous

seeds. The exalbuminous seed of the Norway Maple is interesting on account of the very small store of food in the embryo. The "grain" of Indian Corn, the "seeds" of Four-o'clock and Sunflower, the "peanut" (including shell), and the key of the Maple are fruits. This fact need not be brought forward, as the distinction between fruit and seed will be made plain in the chapter on fruit. In the case of the Peanut the question will arise, how much is a single seed? Refer to the like case of peas in a Pea pod. — 2. The iodine used may be prepared by dissolving the crystals in alcohol, or, better, in a strong aqueous solution of iodide of potassium, which may be had from supply companies and probably from druggists. In testing for starch, if the iodine is too strong, the characteristic blue tint will be obscured. Use the reagent diluted. In the Castor Bean, Flax, and Cotton, a considerable part of the food takes the form of oil. In this connection it will be well to present facts concerning the uses of oily seeds, and of seeds in general. Or, better, the subject may be assigned, as a whole or in parts, to one or more pupils for special reports. In the Date, the reserve matter is in the form of "reserve cellulose."

A test for proteid matters in seeds may be made as follows: Crush the kernel of the given seed on a glass slide. Add a few drops of concentrated nitric acid, and allow to act for a few minutes. If proteid matter is present in quantity, a yellow or orange color appears, which becomes more intense after the acid has been washed off and strong ammonia water added. Contrast the color reaction in the kernel of Sunflower seed with that in pulp of Potato, when treated with nitric acid and ammonia; also again when treated with iodine. The compound microscope may be used in tests with iodine, and for detection of oil.

Exercise III. — Experiment 1. This may well be a demonstration largely prepared by the teacher. The Beans should be ready after 2 days' soaking. The department of physics or of chemistry will supply some sort of simple hydrogen generator. One may be made of flask, cork, and glass tubing, in the way described by elementary chemistries. Fill the generator flask pretty well up with the acid solution, in order to have as little air in the generator as possible. (For the physiology of seeds and germination, see Goodale's "Physiological Botany," Ch. XV.) — **Experiment 2.** Several pupils may work together on such experiments as this. The gas given off by the sprouting Corn is the same as that from the human lungs, namely carbonic acid gas. Respiration is the same in both plants and animals, as regards the intake (oxygen) and the exhaled product (carbon dioxide). (See "Respiration" Goodale, p. 367.) — **Experiment 3.** The thermometer used should be graduated in half degrees or finer; or, at least, the degree divisions should be long. Subdivisions of the spaces may with care be estimated down to tenths by the eye. Of course, the

rise of temperature found in this experiment is the direct result of the respiratory activity (oxidation) detected in Experiment 2. This experiment also is suitable for a group of three or four students.

Exercise IV.—For pupils in groups. Of course this exercise may be extended somewhat, at the option of the teacher—perhaps as supplementary work for fast working and interested individuals. It is likely that several different temperatures may be obtained in different parts of the building. And if steam heat is used, it may be possible to arrange matters so that minimum, maximum, and optimum temperatures of germination can be approximately determined.

Exercise V.—For the facts and theory of the response of growing parts to various external stimuli, see the text-books under Geotropism, Heliotropism, etc.: Goodale, pp. 392–396, Strasburger's "Text-book of Botany" (Porter), 1898, pp. 251 *et seq.*

Exercise VI.—**Experiment 6.** For an account of the green coloring matter (chlorophyll) see Goodale, pp. 286 *et seq.* It would be interesting to compare the behavior of Pine seedlings with those of common garden plants in respect to the development of chlorophyll in darkness. It may take a month to get the pine started.

When the results of the experiments on germination are in, the teacher will, of course, discuss the teachings of the experiments with the class, making them points of departure for the giving of a greater or less amount of related information. **The time taken by the seeds mentioned to germinate** and come to the various desired stages of development will depend on the temperature of the room. The following data will give some idea of the time required. **Squash**, 1 inch deep, came up in 6 days in a warmish place. **Onion**, $\frac{1}{4}$ in. deep, was looping up well in 9 days in warmth. **White Lupine**, $1\frac{1}{2}$ in. deep, came up in 7 days in a rather cool place. The plants were erect and had spread leaves in 14 days. **Pea**, 1 in. deep, was coming up freely in 6 days. **Morning Glory** was up and had cotyledons spread in 5 days. The seeds may be sown at intervals during two weeks or so in boxes of soil or wet sphagnum. Several pots may be sown to show the manner in which the young plants come out of the ground.

Supplementary Topics.—1. This will require the compound microscope. *Spiranthes cernua*, or Maiden's Tress, is markedly polyembryonic. The embryos are produced without fertilization. (See *Rhodora*, December, 1900.) The embryos are seen at a glance, the seed-coats being transparent. *Spiranthes cernua* blooms in September and October. Mount seeds first in alcohol.—2. The Larch and Spruce seeds named germinate readily in 10 or 12 days.

Chapter III.—Discuss the subject of winter buds. Some such line of thought as the following is suggested: Why do trees like the Maple, Elm, etc., lose their leaves in winter? (Two reasons, at least. For *xerophytic conditions* in winter, see p. 65.) When does preparation

for the new leaves, to replace the fallen ones, begin? Of what advantage would it be to have the new ones ready for unfolding at the first moment of warm spring weather? If leaf rudiments were formed in the fall, what arrangements would be made for their protection? A number of different devices for shielding the tender young leaves or leaf rudiments will probably come to mind. Later, in the laboratory, it will be seen whether in nature these devices have, in effect, been realized. A cursory examination of twigs bearing buds may be made in class at the time of this discussion.

Exercise VII. — Illustration 3. Alternatives are the Hobblebush (*Viburnum lantanoides*), *V. Lantana*, *V. cotinifolium*, *V. furcatum*, and the Butternut (*Juglans cinerea*).

Exercise IX. — Illustration 2. "Dutchman's Pipevine" (*Aristolochia Siphon*).

Exercise X. may be a written exercise to be handed in.

Exercise XI. — The development of buds is a very interesting subject for study. The chief difficulty is to get buds to grow well indoors. Many buds refuse to develop at all in the early winter, but make some growth later in the year. If the subject is taken up in the spring, material may be got from the trees, and cut branches may be forced. A damp atmosphere favors development. In March I have forced Lilac, Rose, and Am. Larch to unfold enough for study, in 8 days; *Acer platanoides* (Norway Maple) — excellent example of scale development — in about 20 days; and Buttonwood (*Platanus occidentalis*) in 14 days. The latter gives a good illustration of the stipular nature of some bud scales, as its scales grow.

Exercise XIII. — The White or Silver Maple and the Rock or Sugar Maple, both illustrate the superior development of the horizontal buds and branchlets. The material should be selected for the purpose. Sometimes the vertical shoots will be decidedly the stronger; such examples would be interesting.

Chapter V. Exercise XIV. — The Shepherd's Purse is a common weed, widely distributed, appearing very early in spring in yards and by roadsides. Its root is much better for general morphology than the fleshy roots of vegetables. Dandelion is fairly good. If root hairs do not show well, grow a few seeds of any kind in sand, and call especial attention to their manner of clinging to the sand, even when the plantlet is pulled up.

Exercise XV. — The Trumpet Flower (*Tecoma radicans*) is best. English Ivy (*Hedera Helix*) may be used.

Exercise XVI. — Sweet Potato is suggested. Carrot includes shortened stem. Dahlia will serve.

Supplementary Subjects. — 1. Material may probably be obtained from some greenhouse. The function of the roots is commonly misunderstood. Vapor of water is not condensed by them, except as dew.

(See *Rhodora*, March and April, 1900; *American Gardening*, March 17 and 24, 1900.)—2. The material is best preserved in alcohol.—3. Many herbaceous, geophilous plants show contraction. Examples must be sought in the teacher's own locality.—4. Grow seedlings in barely moist sphagnum, in which saturated pieces of sponge are buried. First sprout the seeds in water. Place them above and at one side of the sponge or sponges, at varying distances and in different directions. This experiment is suggested by Dr. R. H. True.—5. With a fine brush and India ink mark across the tip of the growing primary root of a lately sprouted Bean, at intervals of 1 mm., for a distance of 1.5 cm. Put the seedling into a thistle tube, or glass funnel, with the root running down into the tube. Over it place wet cotton, and cover the top of thistle tube or funnel. Rest this apparatus in the mouth of a jar or other receptacle containing a little water, the supporting jar or bottle to be closed after the tube or funnel is admitted, so that the water will not be lost by evaporation. In 24 hours, note the region where elongation has taken place: measure the spaces. Repeat this observation after 24 hours more.—6. Place a young *Tropæolum* plant under a bell jar, and leave for a day or two in a fairly warm place. Drops of sap are seen on the margin of the leaf. These are forced up by "root pressure." (See Goodale, pp. 264-268, also Chapter XVIII. of this book.)

Chapter VII. Exercise XVIII.—Balsam (*Impatiens*) is better than Begonia, though the latter is commoner in cultivation. Young shoots of the Pipevine (*Aristolochia Siphon*) may be got at the proper season and preserved for use. The Asparagus meant is the garden species, the young shoots of which may be had from the market and preserved. Indian Corn is equally good, or better. Permanently mounted cross sections of both stems may be used. If the pupils cut their own, the scalpels must be very sharp, and should be wet when cutting.

Exercise XIX.—This exercise may be omitted at the discretion of the teacher. If taken, the block of wood may be of Oak, about 1½ inch in each dimension, cut so that two faces are at right angles to the grain, two are vertical-radial, and two vertical-tangential in the tree. The surfaces should be accurately cut in the given planes, and smoothly finished.

Exercise XX.—The Balsam is the best stem for this exercise; it may be had from greenhouses, or grown in the schoolroom from seed. Other growing plants may be used. A solution of red ink may be used, but is inferior to eosin (from supply companies). One ounce eosin will color three quarts of water.

Exercise XXI.—**Experiment 9.** The more freely the plant used is growing, the better for this experiment. "*Nasturtium*" = *Tropæolum*. On geotropism see Goodale and Strasburger, as before cited.—**Experiment 10.** Other growing flower scapes may be found. The

APPENDIX

Dandelion will answer, if young. Shepherd's Purse I have found especially sensitive to light. Discuss geotropism and heliotropism with class after these experiments.

Exercise XXII. — Illustration 1. Grass rhizomes will do. Iris is excellent, as it shows how the plant is propagated by lateral as well as terminal buds. Useful examples of rhizomes will be found in any piece of woods, under or in the leaf mold. Subterranean stems (*Uvularia*, *Smilacina*, *Polygonatum*, *Sanguinaria*, etc.) are particularly interesting. Keep in alcohol, rather than dry. For comparison with rhizomes introduce such a caudex as Plantain. Also subterranean things like *Trillium*, Jack-in-the-pulpit (beware of tasting). — **Potato tuber.** Artichoke (from seedsmen or the market) may be substituted with advantage. New potatoes from the garden have scales; others may not have. — **Houseleek.** May be ordered several months in advance from commercial growers. As an alternative, Strawberry (pressed or alcoholic) is suggested. — **Asparagus.** From florists: the large decorative species known as *Asparagus Sprengeri* is the best. — **Crocus.** From seedsmen, at about 1 cent each. *Gladiolus* and *Montbretia* are as good but cost about 2 cents each. — **Flowering Quince.** The common Thorn, or the Honey Locust (*Gleditsia*) may be used. — **Boston Ivy.** Or the Grape; in which case the tendrils coil, without disks. The Virginia Creeper (*Ampelopsis quinquefolia*) is figured in the text; otherwise it would do for the present study. In all these cases the tendril is, originally, the termination of the main stem, but is finally turned aside by the growth of a lateral bud, which carries on the growth of the vine. The effect is to make the tendril seem to spring laterally, from opposite a leaf. The *twisting* of tendrils involves an interesting question. (See the text.) Why the *double* twist, often seen? Hold both ends of a string fast then twist it by rolling at its middle; is the twist of entire string single or double?

Chapter IX. Exercise XXIII. — Experiment 11. *Tropaeolum* is meant. Several pupils may work together. Chlorophyll is extracted more rapidly by alcohol in a test tube immersed in hot water. Then, to swell starch grains, boil the bleached leaf in water. For carbon assimilation, or photosynthesis, see Goodale, Ch. X., also the concluding chapter in this book. For the liberation of oxygen as a measure of assimilation, and directions for a most valuable experiment (easy to perform if material is available), see Goodale, p. 305.

In connection with the given experiments on assimilation in the leaf, the observation of starch may be made if compound microscopes are to be had. Use starch from potato, and perhaps from the pea also. Starch being insoluble in water, the question arises how the food which takes the form of starch can pass from one part of the plant to another through the membranes of the plant body. (See *Digestion*, § 560.) Observe digestion with the compound microscope.

Use potato starch. Apply a solution of $\frac{1}{8}$ teaspoonful diastase (druggists or supply companies) in 1 teaspoonful water — a few drops on a slide. Observe, after 15 minutes, the erosion and disintegration of many of the grains.

Experiment 12. Respiration takes place in all living members of the plant. (See the final chapter of the text, this book.) — **Experiment 13.** A Geranium (*Pelargonium*), a Sunflower seedling, or a Fuchsia, is easily got. The experiments on transpiration (which subject see in Goodale, Strasburger, and this book) are easily extended, so as to test the effect of a number of conditions. (See Ganong for further suggestions.) Convenient balances are the "Harvard trip scales" (apparatus dealers). The sheet rubber is a grade or two heavier than that used by dentists.

Experiments 13, 14, 15, and 16 are all on the same activity of the leaf, transpiration. It will be well to have only one or two preparations of each experiment, and have all the experiments going on at once, prepared simultaneously by different groups of pupils. The essential features of manipulation are seen at sight, and the results are obvious, so that the whole class may take notes from apparatus prepared by two or three pupils solely. The importance of transpiration in drawing water from the soil, and with water the nutrient soil salts, should be discussed when the results are all in. Stomatal regulation may be brought up in connection with the results of Experiments 15 and 16, in which it is seen that the vapor escapes from the under surface largely. — **Experiment 17.** Young potted Tropæolums, a month or two old. On heliotropism, or turning occasioned by light, see Goodale, p. 392, or Strasburger, p. 251. The chapter on physiology, in this book, may be referred to. — **Experiment 18.** Seedlings of *Mimosa pudica* may be grown to suitable size in 3 or 4 weeks. Seeds from seedsmen. Oxalis seeds also from seedsmen, or plants from growers. On "sleep" movements, see Goodale, p. 409, and Strasburger, p. 270. The irritability of plants is a most interesting subject of study.

Exercise XXIV. — Of greenhouse material, Hibiscus or Abutilon is very good for all points in this exercise. Geranium (*Pelargonium*) and German Ivy (*Senecio scandens*) have stipules. The veining does not show so well. Of outdoor things, Apple and Quince have stipules. Selections of the best leaves to illustrate types of venation, compounding, etc., should be made in the summer, and the leaves pressed. But for Exercise XXIV. fresh material is needed.

Exercises XXVI. and XXVII. — The assortment of leaves given the pupil will include parallel- and net-veined examples; and of the latter, some pinnate, some palmate. Several examples of each category should be provided. Let some be lobed, divided, etc., so as to suggest the origin of compounding. Pinnately lobed, palmately lobed forms,

etc., suggest corresponding compound forms. This is meant to be an exercise in systematic grouping on lines of possible evolution of leaf forms. Can transitional forms between pinnate and palmate be found? The material will be selected by the teacher from the flora of the particular locality.

Exercise XXVIII.—**Onion.** Onion “sets” from the seedsman; inexpensive.—**Acacia.** This is interesting in connection with the natural conditions under which the phyllodineous Acacias grow. Pressed material may be used, derived, of course, from some greenhouse. Phyllodia with leaflets may be found on some species, even in the adult condition (*e.g.* *A. melanoxylon*). See *phyllodes*, Ch. X.

Chapter X. The special uses of the leaf, treated in §§ 146–153, may with great advantage be illustrated by living material. Seeds of *Cobaea macrostemma* may be bought and the plant raised in the schoolroom, if the temperature is favorable. *Drosera binata* may perhaps be obtained from florists or from a botanic garden. *D. rotundifolia* rests in winter. A Wardian case will keep *Droseras*, *Sarracenias*, and *Dionæas* in good condition for observation.

Chapter XI. Exercises XXIX–XXXII.—*Scilla siberica* is good for these exercises. Order in the fall, for spring use, from florists. Cost small. Tulips can be had from Christmas onward. At wholesale from commercial growers they cost about 2 cents each, though more at times. Hyacinths, not so good, 5–10 cents a spike, November to May. The above are mentioned as available for city schools. *Scilla* is common everywhere in gardens in early spring. Bulbs, \$1 per 100. Of wild material for the first flower studied, Dogtooth Violet (*Erythronium*) and *Trillium* are also good. The *Liliaceæ*, in general, are excellent.

Exercise XXXIII.—The principles of anthotaxy had best be taken up in the course of the general study of the flower, for the sake of economy of material, rather than as the subject of a separate study. For the benefit of city schools, some information as to kinds, prices, etc., of flowers may be proffered. Azaleas, Christmas to Easter, cheap. Swainsonia (leguminous, racemose), all year, 50 cents dozen spikes. Candytuft (cruciferous, racemose), all year, 25 cents dozen spikes. Nasturtium, all year, 25 cents dozen. Begonia (cymose, unisexual), any time, cheap. Primula, 25 cents pot. Bouvardia (umbellate), 25 cents dozen heads, all year. *Crassula quadrifida*, compound cymose. *Oxalis*, good, cymose. Eupatorium, Stevia, and *Chrysanthemum frutescens*, composite heads. The above are suggested in case winter material must be used. Buy of wholesale dealers, or growers.

Exercise XXXIV.—The material must be gathered at the flowering season of the tree chosen (Larch, Spruce, Fir, Pine), in spring, and preserved in alcohol, unless used at once. The fresh, fertile cone (here for convenience called a “flower,” but also spoken of as an inflorescence) is very beautiful in form and color.

Further work on the flower will be directed toward illustration of the principles of floral structure and biology, given in the following chapter of text. The extent and exact character of this study are left to the discretion of the teacher in view of the material obtainable.

Systematic Botany.—With regard to the study of Systematic Botany, when this forms a part of the school course, the following suggestions may prove helpful.

In many schools it has been the custom to require each pupil to determine or 'analyze' a certain number of plants, perhaps a hundred or more. While this exercise has value, it may be doubted whether the pupil ordinarily receives from it information or training commensurate with the time it requires. Through the recognition in recent years of a greater and greater number of species the accurate identification of plants has become a matter so technical as to require a degree of attention and precision rarely possessed by elementary pupils. Nevertheless, the teacher should spare no effort to impart by direct instruction or incidental suggestions as clear an idea as possible of the general classification and relationships of the plants studied in the laboratory. Experience shows that pupils grasp without difficulty the more obvious features which distinguish the larger families. Thus it requires but a few moments to show that nearly all grasslike plants may be divided into three great families, the true grasses with round stems and split leaf sheaths, the sedges with triangular stems, and the rushes with regular 6-parted flowers. Copious illustrative material (readily obtained even by city teachers) should be given to the pupils to exercise their discriminative powers after or during any such instruction as this. Similarly, it requires but a few moments to show how most of the remaining monocotyledons may be divided into *Liliaceæ* with superior ovary and six stamens, *Amarylloidaceæ* with inferior ovary and six stamens, *Iridaceæ* with inferior ovary and three stamens, and *Orchidaceæ* with inferior ovary and one or two stamens. In like manner the leading families of dicotyledons will be found to possess such characteristic features as the peculiar inflorescence of the *Umbelliferae*, the dense heads of the *Compositæ*, the square stems, opposite leaves, and aromatic qualities of the *Labiatae*, or sheathing stipules of the *Polygonaceæ*. Indeed a very few exercises, in which the pupil is encouraged to sort for himself, along such simple lines as these, great piles of mixed flowering plants (including the commonest dooryard weeds), will enable him to determine at sight the twelve to twenty more important families, which include four fifths of the flowering plants he is likely to meet in after life. A similar discrimination of plants in fields and woods should, whenever practicable, supplement laboratory exercises. The pupil will, naturally, make many mistakes at first, being inclined, perhaps, to place a *Potentilla* in the *Ranunculaceæ*, a *Datura* in the *Convolvulaceæ*, or even a clover in the *Com-*

positæ; but such errors may be turned to good account by a tactful teacher, since they lead very naturally to the consideration of important floral differences.

When a general knowledge of plant families has been obtained, the pupil's attention may well be directed to such large and well-marked genera as *Lilium*, *Ranunculus*, *Delphinium*, *Lepidium*, *Prunus*, and the like, and he should be led to contrast these with others of the same families. Similarly, species of two or three simple genera should be considered as such.

After this introduction to classification, the use of keys and the manual will be readily grasped by pupils who are to pursue the subject further, and it may be suggested to teachers that greater enthusiasm in the study of local flora can be stimulated if the subject is optional than if it is made obligatory. Special care should be exercised to direct the attention of the pupil to those plants which, owing to their inconspicuous flowers, are likely to be overlooked or thought too difficult for study. Many small flowers, such as those of *Mollugo*, *Acer*, *Galium*, etc., will be found relatively simple and instructive, while those of the far more showy *Fringed Polygala*, *Lady's Slipper*, *Canna*, and the like, are, from their irregularity, perplexing and discouraging to the beginner. The successful examination of the flower of a plantain, rush, or grass, obtained in the neighborhood of the schoolhouse will train the pupil's powers of observation far more effectively than the dissection of many showy greenhouse flowers.

The teacher's success in this work will be in a general way proportionate to his own knowledge of plants, their names, and relationships. He is, therefore, urged to acquaint himself so far as possible with the plants of his region by the use of the manual. While a knowledge of his local flora will help him greatly, an ignorance of the names and affinities of common plants will expose him to frequent mortifying experiences when questioned by his pupils and others.

The importance of a school herbarium, even if it be small and comprise but a few hundred of the commonest plants, can scarcely be overestimated. Explicit directions for the collecting, labeling, and caring for the herbarium specimens will be found in Gray's "Structural Botany," pp. 370-381, or W. W. Bailey's "Botanizing" (Preston & Rounds Co., Providence). Until the teacher has gained some experience in identifying species, he will do well to send to some large botanical establishment for determination, duplicates of such plants as he is placing in the herbarium. There are several botanical establishments (for example the Gray Herbarium of Harvard University, Cambridge, Mass.) where well-prepared dried specimens of native plants will ordinarily be identified free of charge, provided the specimens may be retained. Each specimen must show, in the case of small species, the whole plant, of larger ones, 10 or 12 inches of stem bearing

leaves and flowers or fruit. Each must also be accompanied by a label stating the place and date of collection and the name of the collector. The labels should, furthermore, bear distinctive numbers by means of which the specialist, who examines the specimens, can report to the teacher their scientific names in such a manner that they can be readily applied to the duplicating specimens which the teacher has retained under the same numbers.

Chapter XIII. — Fruits make most interesting material for comparative studies. Preface the laboratory work by a classroom discussion.

Exercise XXXV. — **Wild Indigo.** Any leguminous pod is suitable. Wild Indigo (*Baptisia tinctoria*) is common on dry, sandy soil. Even Pea pods and Bean pods will do. A teacher offers the following suggestion. "By collecting pods just as they are about to open, and preserving in formaline, one may keep them indefinitely. When the class is ready for the study of seed dispersal, the pods may be taken from the liquid, when they will open just as naturally as in the fall." — **Violet.** Alcoholic material, if fruit is out of season. — **Checkerberry.** The fleshy part is calyx and receptacle. — **Rose Hip.** The cup is hollowed receptacle. The "seeds" are the several achenes.

Exercise XXXVI. — **Outgrowth of the Testa.** Put the Milkweed and Trumpet Creeper seeds in glass "sample" tubes or small vials, and seal them up for class study.

Exercise XXXVII. — **Illustration 1.** *Staphylea*. — **Illustration 2.** *Rumex crispus*, though any *Rumex* will do. — **Illustration 3.** *Bidens*, known as "Beggar's Ticks." The subject of this exercise is one that may well be studied further, either in the laboratory from materials which the fields supply in greatest variety, or in the field itself.

If the course in botany begins in the fall and extends throughout the year, the fruits studied in the field, or at least collected for study by the pupils, will in an interesting way introduce the work on seeds.

II. CRYPTOGRAMIC LABORATORY STUDIES

The following additional utensils and reagents will be needed:—

Compound microscopes.—Many of the studies in Cryptogams may be profitably carried out with good hand lenses, supplemented by the figures of the descriptive text. But compound instruments will, of course, be provided when possible. Even a single instrument will be a great gain. The aim should be to have one for each pupil in the laboratory division. The following makes are recommended as trustworthy; there are others: Bausch & Lomb (Rochester, N. Y., New York, Chicago); Leitz (William Krafft, 411 West 59th St., New York); Reichert (Richards & Co., 46 Park Place, New York); Zeiss (of dealers, *e.g.* Franklin Educational Co., Boston, and Eimer & Amend, New York).

Two eye pieces (2-inch and 1-inch) and two objectives ($\frac{2}{3}$ and $\frac{1}{4}$ inch), with *double nose piece*, should be had, at least. For many details in the arrangement of the laboratory and equipment, the teacher should see some laboratory where these matters have been worked out. For the theory and use of the microscope, see "The Microscope," Gage, Comstock Pub. Co., Ithaca, N. Y. Practical rules for pupils are given by Peabody (see under Bacteria, p. 257).

Razors, flat on one side, are needed if pupils make sections themselves; together with **strops** for sharpening (get a barber to hone razors), **pith** for holding objects sectioned, and cheap camel's-hair **brushes** for removing sections from razor to slide.

Alcohol (commercial, diluted one half) may be kept on the table in 2-ounce bottles with pipettes fitted into the corks. Bottles for **potash**, **glycerine**, and **iodine**, are made with ground glass stoppers drawn out into droppers (1-ounce "dropping bottles" of dealers), for 15–20 cents each. Put two 1-inch pieces of stick potash into bottle, and fill up with water. Use glycerine one third strength, and tinge with eosin. Prepare aqueous iodine as before directed (with KI).

Plants for study.—Material may be bought of supply companies (Cambridge Botanical Supply Co., Cambridge, Mass.; Geo. M. Gray, Wood's Holl, Mass.; Ithaca Botanical Supply Co., Ithaca, N. Y.). Slides may be bought of dealers in microscopical accessories. Material collected by the teacher is best preserved in 70 % alcohol. When the habitats of plants recommended for study are not mentioned in the descriptive text, they are given below, together with the times for collecting, the dates given being applicable to New England.

Books.—Strasburger's text-book will give the main facts on Cryptogams. Bennett and Murray's "Handbook of Cryptogamic Botany" (Longmans, Green & Co., New York, \$5.00) gives fuller details. On Algæ, see George Murray's "Introduction to the Study of

Seaweeds." For a full treatment of Fungi, see De Bary's "Comparative Morphology and Biology of the Fungi, Mycetozoa, and Bacteria" (Clarendon Press, 1887). For names of many common fleshy Fungi, refer to W. H. Gibson's "Our Edible Toadstools and Mushrooms" (Harper Bros.); for Lichens, to Schneider's "Guide to the Lichens" (Bradlee Whidden, Boston); for Mosses, to A. J. Grout's "Mosses with a Hand Lens" (Grout, 360 Lenox Road, Brooklyn, N. Y.); for Ferns, Lycopodiums, etc., Gray's "Manual."

346. *Nostoc*. — Alternative, *Oscillatoria*, found on surface of mud where covered with (especially foul) water, also on the surface of pools, also as a slippery coating on rocks in rapidly flowing streams. Easier to find than *Nostoc*. The former (as well as *Nostoc*) often in greenhouses. It is an open question whether the cell or the chain is the "individual."

347. *Pleurococcus*. — See descriptive text.

348. *Spirogyra*. — Conjugating material may be sought in late April and May. Examine with the lens floating masses turning yellowish. — The cells treated with glycerine are *plasmolyzed*, when the protoplasmic contents is driven away from the walls. Emphasize the separability of wall and protoplasm.

352. *Vaucheria*. — On pots in greenhouses. It is said that material showing both kinds of reproduction mentioned in text, may be obtained by throwing mats of the plant into jars half full of water about six weeks before use, and placing the jar in strong light.

355. *Ectocarpus*. — Sporangia may be found *intercalated in the filaments*, as well as at the ends of branches. Gametangia = pleurilocular sporangia.

356. *Rockweed (Pucus)*. — Abundant on rocks between tide marks; in "fruit" more or less throughout the year. At its best, perhaps, in summer and autumn. Break open the fruiting portions and examine with hand lens. — Wet the razor with alcohol. Make many sections before removing any from razor, then, on the slide, select the thinnest for study.

359. *Polysiphonia* may be found epiphytic on *Ascophyllum*. The latter is the dark (almost black) Rockweed, with thick narrow fronds without midrib, in which are elongated, bean-shaped bladders. In buying *Polysiphonia* specify tetraspores.

361. *Nemalion*. — The fronds are made up of essentially independent filaments. — *Batrachospermum* may be used as alternative. It grows on stones in running brooks. The carpogonia and antheridia are found early in the season (April).

362. *Bacteria*. — This subject is of the highest practical importance, and, if possible, should be treated with considerable fullness. Dwell on the relation of cleanliness, in household and person, to health. The laboratory studies should, if possible, be extended in some such

lines as those drawn by J. E. Peabody in "Laboratory Exercises in Anatomy and Physiology" (Holt & Co., New York; 60 cents). The study of Bacteria given by Peabody is highly to be recommended. By all means see also *Journal of Applied Microscopy* for February, 1891 (Vol. IV., p. 1164).

363. **Yeast.** — Use *fresh* yeast cake.

366. **Rhizopus.** — Use *fresh, moist* bread. Let each pupil place a piece 1 inch square or so on the bottom of a plain tumbler, or, better, a small crystallizing dish, covering to keep moist, two or three days in advance of use. — For zygospores — hard to get in *Rhizopus* — *Sporodinia* may be used. It is found growing as yellowish, smoky tufts of mold on fleshy fungi in woods. Zygospores may be found on the under side of the pileus of the fleshy fungus. Preserve in alcohol.

369. **Saprolegniaceæ.** — Allow from four days to a week, according to temperature, for the molds to develop. Or, better, throw in some of the killed seedlings (Tomato, or other small things) and insects on several successive days, beginning a week in advance of use. Zoösporangia are more abundant on young material. The zoöspores swim away at once in some species, and will not be found near by in a quiescent state.

372. **Peziza**, on logs and sticks in woods in summer.

375. **Microsphaera alni**, in late summer and in September. Press the leaves. *Uncinula*, another fungus of the same group, is common on Willow leaves; another form is on the under side of Horse-chestnut leaves (August, September). — The asci are essentially like those of *Peziza*.

377. **Toadstool.** — Fresh horse dung in bowls, under cake covers (to keep moist), will give *Coprinus* in about two weeks. Make several lots to be sure of material. Various molds will come up before *Coprinus*. Wash these down by sprinkling with water after a week. Take the young heads of *Coprinus* before they open out, in order to section across gills. Or get other material in summer and keep in alcohol.

379. **Lichen.** — *Physcia stellaris*, or any expanded form found on tree trunks. For comparison of habit show such a form as *Cladonia cristatella*, common in pastures, distinguished by bright scarlet apothecia. If time and microscopes permit, study the structure of the thallus further. What are the "green bodies," and what is the nature of the other elements?

381. **Marchantia.** — In fruit (spores) in early summer. *Lunularia*, known by its crescent-shaped cupules, will serve for the living habit and the gemmæ of this kind of Liverwort. It is common in green-houses.

386. **Moss.** — *Polytrichum commune* may be found in good condition (sex organs) in May. The fertile shoots are known by the flowerlike

arrangement of the leaves at the summit. The sporogonia are mature later. Preserve in alcohol, if necessary. Other mosses (*e.g. Mnium*) will serve. The protonema may be found in greenhouses and on soil where moss is growing.

390. Fern. — Prothallia are easiest got in greenhouses. They may best be grown (by the florist) on potsherds. The smaller prothallia are likely to have antheridia alone. For the spores, use preferably some *Aspidium*, taken when the sori are youngish. If necessary preserve this material in alcohol. In the Maidenhair Fern the sori are covered by the recurved leaf margin — not an indusium. — If smallish prothallia, which have not been wet for some time, are placed in a drop of water on a slide, the antherozoids are likely to be seen; use a low power of the compound microscope.

396. Selaginella, from greenhouses, in fruit in early spring (some species at other times). *S. rupestris* is found in dry situations (as bare hilltops) at the edge of ledges in poor soil. It looks at a distance like a stiff, coarse moss.

400. Lycopodium is the “ground pine” used for Christmas decorations. In fruit in late summer.

402. Equisetum arvense is common on railroad banks, the fertile shoots appearing in early May, the vegetative shoots later.

INDEX AND GLOSSARY

- Abortive. Imperfectly developed. 128.
 Absorption, by root, 232; selective, 232.
 Acaulescent. Stemless, or apparently so. 56.
 Accumbent (cotyledon). Having the edges against the radicle.
 Achene. A small, dry, hard, 1-celled, 1-seeded, indehiscent fruit. 149.
 Acicular. Slender, needle-shaped.
 Actinomorphic, 123.
 Aculeate. Prickly, beset with prickles.
 Acuminate. Tapering at the end. 94.
 Acute. Terminating in a sharp or well-defined angle. 94.
 Adaptation, types of, 64.
 Adnate. United, as the inferior ovary with the calyx tube. Adnate anther, one attached for its whole length to the inner or outer face of the filament. 135.
 Adnation, 115.
 Adventive. Recently or imperfectly naturalized.
 Estivation. Arrangement of parts of perianth in bud. 135.
 Alate. Winged.
 Albumen, 18.
 Albuminous seeds, 18.
 Albuminous substances, formation of, 236.
 Algae, blue-green. 170; brown, 177; green, 171; red, 180; unicellular, 157.
 Alternate. Not opposite to each other, as sepals and petals, or as leaves on stem. 90.
 Alternation of generations, 207.
 Alveolate. Honeycombed; having angular depressions separated by thin partitions.
 Ament. A catkin, or peculiar scaly unisexual spike. 141.
 Amphitropous (ovule or seed). Half inverted and straight, with the hilum lateral. 138.
 Amplexicaul. Clasping the stem.
 Anastomosing. Connecting by cross veins and forming a network.
 Anatomy of phanerogams (ch. xvii.), 212.
 Anatroous (ovule). Inverted and straight, with micropyle next the hilum. 138.
 Androecium, 109.
 Androgynous (inflorescence). Composed of both staminate and pistillate flowers.
 Angiospermous. Having seeds borne within a pericarp.
 Angiosperms, 107.
 Annual. Of only one year's duration. 44.
 Anther, 108.
 Antheridial tubes, 189.
 Antheridium, 176, 179, 203.
 Anterozoids, 176, 178, 179, 200, 206.
 Anthesis. Time of expansion of a flower.
 Apetalous. Without petals. 129.
 Apiculate. Ending in a short, pointed tip.
 Apothecium, 190.
 Arachnoid. Cobwebby; of slender entangled hairs.
 Archegonium, 201, 203, 206.
 Arcuate. Moderately curved.
 Areolate. Marked out into small spaces; reticulate.
 Aril, 152. Arilate, having an aril.
 Aristate. Having an awn, or slender, bristle-like termination. 94.
 Articulate. Jointed; having a node or joint.
 Ascent of sap, 233.
 Ascomycetes, 190.
 Ascus, 190, 191.
 Aspergillus, 192.
 Assimilation, 234; carbon, 72; (Exp. 11), 66.
 Assurgent. Ascending.
 Attenuate. Slenderly tapering; becoming very narrow.
 Auriculate. Having an ear-shaped appendage. 93.
 Awl-shaped. Narrowed upward from the base to a slender or rigid point.
 Awn. A bristle-shaped appendage.
 Axil, 29.
 Axile placentation, 105.
 Axillary. Situated in an axil. 29.
 Baccate. Berrylike, pulpy throughout.
 Bacteria, 160, 184; practical study, 256.
 Barbed. Furnished with rigid points or bristles, usually reflexed like the barb of a fishhook.
 Barbellate. Finely barbed.
 Bark, anatomy of, 225; falling of old layers, 226.
 Basidiomycetes, 163, 194.
 Basidium, 195.
 Bast fibers, 219.
 Batrachospermum, 180.
 Berry, 149.
 Bidentate. Two-toothed.
 Biennial. Of two years' duration. 45.
 Bifid. Two-cleft.
 Big Trees, 63.
 Bilabiate. Two-lipped.
 Bilocellate. Having two secondary cells.
 Biloculate. Two-celled.
 Bladderwort, 89.
 Blade, 73.
 Blue-green Algae, 170.
 Books of reference, 244, 255.
 Bract. A more or less modified leaf sub-

- tending a flower, or belonging to an inflorescence. 126, 140.
- Bracteate. Having bracts.
- Bracteolate. Having bractlets.
- Bractlets. Secondary bracts, as on a pedicel of a flower.
- Bread Mold, 160, 168.
- Brown Algæ, 158.
- Bryophytes, 198.
- Buds, accessory, 29; adventitious, 33; axillary, 29; comparative vigor, 26; discussion introducing study of, 247; dormant condition, 30; general structure, 23; growing, 27; laboratory studies, 23; latent, 32; mixed, 30; naked, 31; nondevelopment, 25, 32; protection, 27, 28, 31; time taken to unfold, 248; unfolding, 25; winter, 29.
- Bulb. 60.
- Bulbiferous. Bearing bulbs.
- Bulblets, 58.
- Caduceous. Falling off early.
- Calcarate. Produced into, or having, a spur.
- Calcium oxalate, 217.
- Callus. A hard protuberance, or callosity.
- Calyculate. Having bracts around calyx, imitating an outer calyx.
- Calyptra, 203.
- Calyx, 100, 110.
- Cambium, 222; of cork, 225.
- Campanulate. Bell-shaped; cup-shaped; with a broad base. 132.
- Campylotropous (ovule or seed). So curved as to bring apex and base nearly together. 138.
- Canaliculate. Longitudinally channeled.
- Canescent. Hoary, with gray pubescence.
- Capitate. Shaped like a head; collected into a head or dense cluster.
- Capsule. A dry, dehiscent fruit composed of more than one carpel. 151.
- Carbon assimilation, 234.
- Carbon dioxide, source of, 234.
- Carinate. Having a keel or a projecting longitudinal medial line on the lower surface.
- Carpel. A simple pistil, or one member of a compound pistil. 104.
- Carpogonium, 181.
- Carpospore, 182.
- Caruncle, 152.
- Carunculate. Having a caruncle.
- Caryopsis. A grain, as of grasses; a seed-like fruit with a thin pericarp adnate to the contained seed. 150.
- Catkin. An ament. 141.
- Candate. Having a slender taillike appendage.
- Caudex. The persistent base of an otherwise annual herbaceous stem.
- Caulescent. Having a manifest stem.
- Caulicle, 17.
- Cauline. Belonging to the stem.
- Cell, 212; changes in shape, 218; of ovary, 105; of stamens, 136; typical, 173.
- Cell fusion, 220.
- Cell sap, 216.
- Cellular structure of plants, 116.
- Cellulose, 218.
- Cell wall, 217.
- Cespitose. Growing in tufts; forming mats or turf.
- Chaff. A small, thin scale or bract, becoming dry and membranous.
- Chaffy. Having or resembling chaff.
- Chaloza, 137, 153.
- Chlorophyll, 23, 72.
- Chlorophyll granules, 215.
- Chloroplastids, 215.
- Chromatophore, 173.
- Cilium, 172.
- Ciliate. Marginally fringed with hairs.
- Ciliolate. Minutely ciliate.
- Cinereous. Ash color.
- Circinate. Coiled from the top downward, as the young frond of a fern.
- Circumscissile. Dehiscing by a regular transverse circular line of division.
- Clavaria, 195.
- Clavate. Club-shaped; gradually thickened upward.
- Claw, 132.
- Cleistogamous. Fertilized in the bud, without the opening of the flower. 119.
- Cleft. Cut about to the middle. 95.
- Climbers, 58.
- Club Moss, 167.
- Coalescence. The union of parts or organs of the same kind. 114.
- Cochleate. Spiral like a snail shell.
- Collenchyma, 219.
- Columella. The persistent axis of some capsules, spore cases, etc.
- Coma. A tuft of hairs. 152.
- Comose. Furnished with a *coma*.
- Commisssure. The surface by which one carpel joins another, as in the Umbelliferae.
- Complete (flower), 128.
- Components of plant body, 231.
- Compound. Composed of two or more similar parts united into one whole. Compound leaf; one divided into separate leaflets. 82, 96.
- Compressed. Flattened laterally.
- Conceptacle, 179.
- Conduction of sap in leaf, 69.
- Conduplicate. Folded together lengthwise.
- Confluent. Running into each other; blended into one.
- Coniferous. Cone bearing.
- Coniferous flower, 102.
- Conjugation, 172, 182.
- Connate. United congenitally.
- Connective. The portion of a stamen which connects the two cells of the anther. 108.
- Convivent. Coming into contact; converging.
- Convolute. Rolled up longitudinally.
- Cordate. Heart-shaped, with the point upward. 93.
- Coriaceous. Leathery in texture.
- Cork, 225.

- Corm.** The enlarged fleshy base of a stem, bulblike, but solid. 60.
- Corolla.** The inner perianth, of distinct or connate petals. 100, 110.
- Coroniform.** Shaped like a crown.
- Corrugate.** Wrinkled or in folds.
- Corticium,** 195.
- Corymb.** A flat-topped or convex open flower cluster, in the stricter use of the word, equivalent to a contracted raceme, and progressing in its flowering from the margin inward. 140.
- Corymbose.** In corymbs, or corymblike.
- Costate.** Ribbed; having one or more longitudinal ribs or nerves.
- Cotyledons.** The foliar portion or first leaves (one, two, or more) of the embryo as found in the seed. 17.
- Cotyledons,** sleep of, 75.
- Crateriform.** Having the form of a shallow bowl.
- Creepers,** 57.
- Crenate.** Dentate with the teeth much rounded. 95.
- Crenulate.** Finely crenate.
- Cristate.** Bearing an elevated appendage resembling a crest.
- Cross-fertilization,** 118; agencies for, 120.
- Crossing,** effect of, 127.
- Crown.** An inner appendage to a petal, or to the throat of a corolla. 132.
- Crustaceous.** Of hard and brittle texture.
- Cryptogams,** 13; laboratory studies, 157; (ch. xvi.), 168; relationship to phanerogams, 211.
- Cucullate.** Hooded or hood-shaped; cowlid.
- Culm.** The peculiar stem of sedges and grasses.
- Cuneate.** Wedge-shaped; triangular, with the acute angle downward. 93.
- Cupules,** 200.
- Cuspidate.** Tipped with a *cusp*, or sharp and rigid point. 94.
- Cuticle,** 227.
- Cutleria,** 178.
- Cyme.** A usually broad and flattish determinate inflorescence, *i.e.* with its central or terminal flowers blooming earliest. 142.
- Cymose.** Bearing cymes, or cymelike.
- Cytoplasm.** General mass of the protoplasmic cell, aside from the nucleus. 214.
- Deciduous.** Not persistent; not evergreen.
- Decomound.** More than once compound or divided. 98.
- Decumbent.** Reclining, but with the summit ascending.
- Decurrent (leaf).** Extending down the stem below the insertion.
- Decussate.** Alternating in pairs at right angles. 91.
- Definite.** Of a constant number, not exceeding twenty.
- Deflexed.** Bent or turned abruptly downward.
- Dehiscent, Dehiscence,** 151. Opening regularly by valves, slits, etc., as a capsule or anther. 151.
- Deliquescent trunks,** 83.
- Deltoid.** Shaped like the Greek letter Δ.
- Dentate.** Toothed, usually with the teeth directed outward. 82, 94.
- Denticulate.** Minutely dentate.
- Depressed.** Somewhat flattened from above.
- Determinate (inflorescence),** 139, 142.
- Diadelphous (stamens).** Combined in two sets. 135.
- Diandrous.** Having two stamens. 135.
- Dicarpellary.** Composed of two carpels.
- Dichotomous.** Forking regularly by pairs.
- Dicotyledonous.** Having two cotyledons.
- Dicotyledons,** 17; fibrovascular bundles of, 222; plan of flower, 110; stem structure, 47; stem, anatomy of, 223.
- Didymous.** Twin; found in pairs.
- Didynamous (stamens).** In two pairs of unequal length. 135.
- Diffuse.** Widely or loosely spreading.
- Digestion,** 235; (Exp.), 250.
- Digitate.** Compound, with the members borne in a whorl at the apex of the support.
- Dimerous (flower).** Having all the parts in twos.
- Dimorphous.** Occurring in two forms. 123.
- Diœcious.** Unisexual, with the two kinds of flowers on separate plants. 119, 129.
- Discoid.** Resembling a disk. Discoid head, in Composite, one without ray flowers.
- Disk.** A development of the receptacle at or around the base of the pistil. In Composite, the tubular flowers of the head as distinct from the ray.
- Dissected.** Cut or divided into numerous segments. 79.
- Dissemination,** 145, 153; agents of, 153; by animals, 155; by ejection, 156; by water, 155; by wind, 153.
- Dissepiment.** A partition in an ovary or fruit.
- Distichous.** In two vertical ranks.
- Distinct.** Separate; not united; evident.
- Divaricate.** Widely divergent.
- Divided.** Lobed to the base. 96.
- Dodder,** 41.
- Dormant condition,** seeds, 19.
- Dorsal.** Upon or relating to the back or outer surface of an organ.
- Drawing,** 242.
- Drupaceous.** Resembling or of the nature of a drupe.
- Drupe.** A fleshy or pulpy fruit with the inner portion of the pericarp (1-celled and 1-seeded, or sometimes several-celled) hard or stony. 149.
- Drupelet.** A diminutive drupe.
- Echinate.** Beset with prickles.
- Ecology.** That part of botany which treats of plants in their relations to their sur-

- roundings. Of buds, 83; of flowers, 118, 127; of fruits, 153.
 Ectocarpus, 158, 178.
 Effuse. Very loosely spreading.
 Egg cell, 176, 178, 179, 181, 189, 201.
 Elater, 210.
 Elements composing plants, 231.
 Emarginate. Having a shallow notch at the extremity. 94.
 Embryo, 7, 16; food for, 19; of conifers, 12; origin of, 118.
 Embryo sac, 118, 211.
 Endocarp. The inner layer of a pericarp. 149.
 Endogens, 223.
 Endosperm, 18.
 Entire. Without toothings or divisions.
 Enzymes, ferments, 236.
 Ephemeral. Lasting only for one day.
 Epidermis, 226, 227.
 Epigynous. Growing on the summit of the ovary or apparently so. 130, 134.
 Epipetalous. Upon the petals. 134.
 Epiphytes, 16; roots of, 39, 40.
 Equisetum, 167, 210.
 Erode. As if gnawed.
 Exalbuminous. Without albumen. 18.
 Excurrent. Running out, as a nerve of a leaf projecting beyond the margin. Excurrent trunks, 33.
 Exfoliating. Cleaving off in thin layers.
 Exocarp. The outer of two layers of pericarp. 149.
 Exogenous. Growing by annular layers near the surface; belonging to the Exogens. 223.
 Experiments, manual of, 243.
 Exserted. Projecting beyond an envelope, as stamens from a corolla.
 Extrorse. Facing outward. 136.
 Falcate. Scythe-shaped; curved and flat, tapering gradually.
 Farinaceous. Containing starch; starchlike.
 Farinose. Covered with a meal-like powder.
 Fascicle. A close bundle or cluster. 143.
 Fastigiate (branches). Erect and near together.
 Fat, in seeds, 19.
 Fermentation by Yeasts, 186.
 Ferments, 236.
 Fern (laboratory study), 165.
 Ferns, 204.
 Ferruginous. Rust color.
 Fertile. Capable of producing fruit, or productive, as a flower having a pistil, or an anther with pollen.
 Fertilization, in *Vaucheria*, 176; of the ovule, 118.
 Fibrillose. Furnished or abounding with fine fibers.
 Fibrous. Composed of or resembling fibers. Fibrous tissue: a tissue formed of elongated thick-walled cells.
 Fibro-vascular. Composed of woody fibers and ducts. 221.
 Filament. The part of a stamen which supports the anther; any threadlike body. 108.
 Filamentous. Composed of threads.
 Filiferous. Thread bearing.
 Filiform. Thread shaped; long, slender, and terete.
 Fimbriate. Fringed.
 Fimbriate. Having a minute fringe.
 Fistular. Hollow and cylindrical.
 Flaccid. Without rigidity; lax and weak.
 Flexuous. Zigzag; bending alternately in opposite directions.
 Floccose. Clothed with locks of soft hair or wool.
 Floret, 126.
 Flower (ch. xii.), 103; arrangement of organs, 101; coniferous, 102; ecology, 118; general morphology, 103; laboratory studies, 99; terminology, 123; winter study, 252.
 Foliateous. Leaflike in texture or appearance.
 Follicle. A fruit consisting of a single carpel, dehiscing by the ventral suture. 150.
 Follicular. Like a follicle.
 Food, for buds, 32; of young plant, 8; stored in seed, 18; translocation, 236; supply (exp. study), 13.
 Foramen, 137.
 Forests, seeds in soil of, 19.
 Formaline, 242.
 Fornicate. Arched over, as the corona of some Boraginaceae, closing the throat.
 Free. Not adnate to other organs.
 Frond. The leaf of Ferns and some other Cryptogams.
 Fruit, ecology of, 153; laboratory studies, 144; nature of, 147; origin, 144.
 Fruits, aggregate, 148; drupaceous, 148; in relation to dissemination, 145; kinds, 147; multiple, 148; self-burying, 154; stone, 148.
 Fugacious. Falling or fading very early.
 Fungi, 183; Sac Fungi, 190.
 Funicle. The free stalk of an ovule or seed. 137.
 Funnel-form, 132.
 Fuscous. Grayish brown.
 Fusiform. Spindle-shaped; swollen in the middle and narrowing toward each end.
 Galea. A hooded or helmet-shaped portion of a perianth, as the upper sepal of *Aconitum*, and the upper lip of some bilabiate corollas.
 Galeate. Helmet-shaped; having a galea.
 Gamete, 176, 179, 183, 207.
 Gametophyte, 207.
 Gamopetalous. Having the petals of the corolla more or less united. 111, 131.
 Gamophyllous. Composed of coalescent leaves, sepals, or petals.
 Gemma, 200.
 Gemmiparous. Producing gemmæ.
 Geniculate. Bent abruptly, like a knee.
 Geotropism (Exp. 5), 11, 49, 240.

- Germination**, 9; conditions, 19; heat of (Exp. 3), 10; influence of temperature, 11; of Horse-chestnut, 22; time required, 247.
- Gibbous**. Protuberant or swollen on one side.
- Glabrate**. Somewhat glabrous, or becoming glabrous.
- Glabrous**. Smooth; not rough, pubescent, or hairy.
- Gland**. A secreting surface or structure; any protuberance or appendage having the appearance of such a structure.
- Glandular**. Bearing glands or of the nature of a gland.
- Glaucous**. Covered or whitened with a bloom.
- Glochidiate**. Barbed at the tip.
- Glomerate**. Compactly clustered.
- Glomerule**. - A cymose head. 143.
- Glumaceous**. Furnished with or resembling glumes.
- Glume**. One of the chaffy bracts of the inflorescence of Grasses.
- Granular**. Composed of small grains.
- Grit cells**, 220.
- Growth and reproduction**, 174; annual, 33; conditions, 239; fluctuations, 239; grand period, 239; of stems, 52; phases, 238; of root (Exp.), 35.
- Guard cells**, 228.
- Guttation** (Exp.), 35, 249.
- Gynosperruous**. Bearing naked seeds, without an ovary.
- Gynnosperms** (*Coniferae*), 102; pistils of, 106.
- Gynandrous**. Having the stamens borne upon the pistil, as in *Orchidaceae*. 134.
- Gynobase**. An enlargement or prolongation of the receptacle bearing the ovary.
- Gynœcium**, 109.
- Habit**. The general appearance of a plant.
- Halophytes**, 65.
- Hastate**. Like an arrow head, but with the basal lobes pointing outward nearly at right angles, 93.
- Heliotropism**, 240; (Exp.), 49, 68.
- Herb**. A plant with no persistent woody stem above ground.
- Herbaceous**. Having the characters of an herb; leaflike in color and texture.
- Herbaria**, 253.
- Heterocyst**, 170.
- Heterogamous**. Bearing two kinds of flowers.
- Hilum**. The scar or point of attachment of the seed. 137, 153.
- Hirsute**. Pubescent with rather coarse or stiff hairs.
- Hispid**. Beseet with rigid or bristly hairs or with bristles.
- Hispidulous**. Minutely hispid.
- Homogamous**. Bearing but one kind of flowers.
- Hormogonia**, 171.
- Horsetail** (*Equisetum*), 167.
- Hyaline**. Transparent or translucent.
- Hybrid**. A crossbreed of two species.
- Hydnum**, 195.
- Hydrophytes**, 65.
- Hydrotropism** (Exp.), 35, 240, 249.
- Hymenium**, 191, 195.
- Hypha**, 183.
- Hypogynous**. Situated on the receptacle beneath the ovary and free from it and from the calyx; having the petals and stamens so situated. 130, 134.
- Imbricate**. Overlapping, either vertically or spirally, where the lower piece covers the base of the next higher, or laterally, as in the aestivation of a calyx or corolla, where at least one piece must be wholly external and one internal. 139.
- Immersed**. Growing wholly under water; wholly covered by the involucreal leaves, as sometimes the capsule in *Hepaticæ*.
- Imperfect** (flower), 128.
- Incised**. Cut sharply and irregularly, more or less deeply. 95.
- Included**. Not at all protruded from the surrounding envelope.
- Incomplete** (flowers), 129.
- Incubous** (leaf). Having the tip or upper margin overlapping the lower margin of the leaf above.
- Incumbent** (cotyledons). Lying with the back of one against the radicle.
- Indefinite** (stamens). Inconstant in number or very numerous.
- Indehiscent**. Not opening by valves, etc.; remaining persistently closed. 148.
- Indigenous**. Native and original to the country.
- Induplicate**. Valvate with margins projecting inwards. 138.
- Indurated**. Hardened.
- Indusium**, 205.
- Inequilateral**. Unequal-sided.
- Inferior**. Lower or below; outer or anterior. Inferior ovary: one that is adnate to the calyx, 130.
- Inflated**. Hollow and distended.
- Inflorescence**. The flowering part of a plant, and especially the mode of its arrangement. 101, 139.
- Innate** (anther), 135.
- Insectivorous** plants, 86.
- Inserted**. Attached to or growing out of.
- Integuments** (teguments), 137.
- Intercrossing**, agencies, 120.
- Internode**. The portion of a stem between two nodes.
- Intramarginal**. Within and near the margin.
- Introrse**. Turned inward or toward the axis. 136.
- Involucrel**. A secondary involucre, as that of an umbellet in *Umbelliferae*, 142.
- Involucellate**. Having an involucrel.
- Involucreal**. Belonging to an involucre.
- Involucrate**. Having an involucre.

- Involucre.** A circle or collection of bracts surrounding a flower cluster or head, or a single flower.
- Involute.** Rolled inward. 138.
- Iodine,** in test for starch, 9; preparation, 246.
- Irregular** (flower). Showing inequality in the size, form, or union of its similar parts. 129.
- Irritability,** 240.
- Keel.** A central dorsal ridge, like the keel of a boat; the two anterior united petals of a papilionaceous flower. 133.
- Kidney-shaped.** Crescentic with the ends broad and rounded; reniform.
- Labiate.** Lipped; belonging to the Labiatae. 133.
- Laboratory outfit,** 241, 255.
- Lacerate.** Irregularly cleft as if torn.
- Laciniate.** Slashed; cut into narrow pointed lobes.
- Lamella.** A thin flat plate or laterally flattened ridge. 194.
- Lanceolate.** Shaped like a lance head, broadest above the base and narrowed to the apex. 92.
- Lateral.** Belonging to or borne on the side.
- Latex tubes,** 220.
- Leaf,** 71; activities of (Exps.), 66; anatomy, 266; assimilation in (Exp. 11), 66, 72; conduction in (Exp. 20), 69; form and qualities, 72; heliotropism (Exp. 17), 68; laboratory studies, 66; office, 71; parts, 73; respiration (Exp. 12), 66; sleep movements (Exp. 18), 68; special uses, 70; stability (Exp. 21), 69; structure, 69; tendril, of *Cobaea*, 84; venation, 70.
- Leaflet.** A single division of a compound leaf.
- Leaves,** aquatic, 79, 80; arrangement, 89; bladeless, 76; climbing, 83; compound, 70, 82, 96; disposition in relation to light, 74; division, 96; duration, 89; equal illumination, 81; for storage, 83; insectivorous, 86; lobing, 96; metamorphosed, 70; netted veined, 78; palmately veined, 78; parallel veined, 77; pinnately veined, 78; shapes, 78; shedding of, 89; special conformation, 83; special uses, 83; spinelike, 83; terms used in description, 92.
- Legume.** The fruit of the Leguminosæ, formed of a simple pistil and usually dehiscent by both sutures. 150.
- Leguminous.** Pertaining to a legume or to the Leguminosæ.
- Lepidote.** Beset with small scurfy scales.
- Liber,** 225.
- Lichens,** 163, 196.
- Ligulate.** Furnished with a ligule. 133.
- Ligule.** A strap-shaped corolla, as in the ray flowers of Compositæ; a thin scarious projection from the summit of the sheath in Grasses.
- Limb.** The expanded portion of a gamo-
- petalous corolla, above the throat; the expanded portion of any petal, or of a leaf. 131.
- Linear.** Long and narrow, with parallel margins.
- Lip.** Each of the upper and lower divisions of a bilabiate corolla or calyx; the peculiar upper petal in Orchids.
- Liverworts,** 164, 198.
- Lobe.** Any segment of an organ, especially if rounded. 96.
- Loculicidal.** Dehiscent into the cavity of a cell through the dorsal suture. 151.
- Loment.** A legume constricted, and at length breaking, between the seeds. 150.
- Longevity** of trees, 63.
- Lunate.** Of the shape of a half moon or crescent.
- Lycopodium,** 167, 209.
- Lyrate.** Pinnatifid with a large and rounded terminal lobe, and the lower lobes small.
- Macrosporangium,** 208.
- Macrospore,** 208.
- Marcescent.** Withering, but persistent.
- Marchantia,** 164, 198.
- Material,** illustrative, 242, 252.
- Medullary rays,** 224.
- Membranaceous, Membranous.** Thin and rather soft and more or less translucent.
- Meniscoid.** Concavo-convex.
- Mericaarp.** One of the achenelike carpels of Umbelliferae.
- Merous.** In composition, having parts; as, 2-merous, having two parts of each kind.
- Mesophytes,** 65.
- Micropyle.** The point upon the seed at which was the orifice of the ovule. 153.
- Microscopes,** compound, 242, 255; dealers in, 241; simple, 241.
- Microsphaera,** 162, 191.
- Microsporangium,** 208.
- Microspore,** 208.
- Midrib.** The central or main rib of a leaf.
- Mildews,** powdery, 191.
- Mistletoe,** 41.
- Monadelphous** (stamens). United by their filaments into a tube or column. 134.
- Monandrous,** 135.
- Moniliform.** Resembling a string of beads; cylindrical with contractions at intervals.
- Monocotyledonous.** Having but one cotyledon.
- Monocotyledons,** 17; fibrovascular bundles of, 222; floral plan, 110; stem structure, 47, 223.
- Monœcious.** With stamens and pistils in separate flowers on the same plant. 119, 129.
- Morphology,** 14.
- Mosses,** 202.
- Movements,** 239; due to change of turgidity, 240; induced, 240; spontaneous, 240.
- Mucilaginous.** Slimy; containing mucilage.
- Mucro.** A short and small, abrupt tip.

- Mucronate.** Tipped with a mucro. 94.
Multifid. Cleft into many lobes or segments.
Mummy cases, seeds from, 19.
Muricate. Rough, with short, hard points.
Muriculate. Very finely muricate.
Mycelium, 183.
- Naked.** Bare; without the usual covering or appendages. 129.
Nectar glands, 125.
Nectar, protection of, 125.
Nectary. Any place or organ where nectar is secreted. 125.
Nectariferous. Producing nectar.
Nemalion, 159.
Nerve. A simple or unbranched vein or slender rib. 78.
Node. The place upon a stem which normally bears a leaf or whorl of leaves.
Nodose. Knotty or knobby.
Nostoc, 157, 170.
Notebooks, 241.
Nucellus, 137.
Nucleus, 116, 173, 214.
Nut. A hard, indehiscent, 1-celled, and 1-seeded fruit, though usually resulting from a compound ovary. 150.
Nutlet. A diminutive nut.
Nutrient salts absorbed, 232.
- Obcompressed.** Compressed dorsiventrally instead of laterally.
Obconically. Inversely conical, having the attachment at the apex.
Oboeate. Inverted heart-shaped, 94.
Ob lanceolate. Lanceolate, with the broadest part toward the apex, 92.
Oblique. Unequal-sided or slanting.
Oblong. Considerably longer than broad, and with nearly parallel sides. 92.
Obovate. Inverted ovate. 93.
Obovoid. Having the form of an inverted egg.
Obsolete. Not evident; rudimentary.
Obtuse. Blunt or rounded at the end. 94.
Ocrea. A legging-shaped or tubular stipule.
Ocreate. Having sheathing stipules.
Ochroleucous. Yellowish white.
Official. Of the shops; used in medicine or the arts.
Offsets, 58.
Oil in seeds, 9.
Oögonium, 176, 179, 189.
Oöspore, 176, 179, 189.
Oösporic reproduction, 182.
Opaque. Dull; not smooth and shining.
Operculate. Furnished with a lid.
Operculum. A lid; the upper portion of a circumscissile capsule. 203.
Orbicular. Circular. 92.
Orchids, roots of, 40.
Orthotropous (ovule or seed). Erect, with the orifice or micropyle at the apex. 137.
Oscillatoria, 170, 256.
- Osmosis,** 230.
Oval, 92.
Ovary. The part of the pistil that contains the ovules. 104.
Ovate. Egg-shaped; having an outline like that of an egg, with the broader end downward. 92.
Ovoid. A solid with an oval outline.
Ovule, 136; fertilization of, 118.
Ovules, 103; study of, 99.
Ovuliferous. Bearing ovules.
Oxidation, source of vital heat, 20.
Oxygen, in germination (Exp. 1), 10, 19; liberated, 235; required by cells, 237; taken up by embryo, 20.
- Palate.** A rounded projection of the lower lip of a personate corolla, closing the throat.
Paleaceous. Chaffy.
Palet. The upper thin chaffy or hyaline bract which, with the glume, incloses the flower in Grasses.
Palisade cells, 227.
Palmate (leaf). Radiately lobed or divided. 78.
Palmately. In a palmate manner.
Panicle. A loose, irregularly compound inflorescence with pedicellate flowers. 142, 143.
Panicled, Paniculate. Borne in a panicle; resembling a panicle. 142, 143.
Papilionaceous (corolla). Having a standard, wings, and keel, as in the peculiar corolla of many Leguminosæ. 132.
Papillose. Bearing minute nipple-shaped projections.
Pappus. The modified calyx limb in Compositæ, forming a crown of very various character at the summit of the achene. 149.
Parasitic. Growing on and deriving nourishment from another plant. 16, 41.
Parenchyma, spongy, 227.
Parietal. Borne on or pertaining to the wall or inner surface of a capsule. 105.
Parted. Cleft nearly but not quite to the base. 95.
Partial. Of secondary rank.
Pectinate. Pinnatifid with narrow, closely set segments; comblike.
Pedate. Palmately divided or parted, with the lateral segments 2-cleft.
Pedicel. The support of a single flower. 140.
Pedicellate. Borne on a pedicel.
Peduncle. A primary flowerstalk, supporting either a cluster or a solitary flower. 140.
Pedunculate. Borne upon a peduncle.
Peltate. Shield-formed and attached to the support by the lower surface. 80, 93.
Penicillium, 192.
Pentadelphous. Of 10 stamens. 185.
Perennial. Lasting year after year. 45.
Perfect (flower). Having both pistil and stamens. 128.
Perfoliate (leaf). Having the stem apparently passing through it.

- Perianth.** The floral envelope, consisting of the calyx and corolla (when present), whatever their form. 100, 110.
- Pericarp.** The matured ovary. 147.
- Perigynium.** The inflated sac which incloses the ovary in *Carex*.
- Perigynous.** Adnate to the perianth, and therefore around the ovary and not at its base. 130, 134.
- Persistent.** Long-continuous, as a calyx upon the fruit, leaves through winter, etc.
- Personate (corolla).** Bilabiate, and the throat closed by a prominent palate. 133.
- Petal.** A division of the corolla. 110.
- Petaloid.** Colored and resembling a petal.
- Petiolate.** Having a petiole.
- Petiole,** the footstalk of a leaf, 73; movements of, 75; sleep movements, 75; uses, 74.
- Petiolule,** 75.
- Peziza,** 162, 190.
- Phænogamous.** Having flowers with stamens and pistils and producing seeds. 13.
- Phloëm,** 222.
- Photosynthesis (Exp. 11),** 66, 72.
- Photosynthetic assimilation,** 235.
- Phyllocladum,** 63.
- Phyllodium.** A somewhat dilated petiole having the form of and serving as a leaf-blade. 76.
- Phyllotaxy,** 89.
- Physiology (ch. xviii.),** 229.
- Pileus,** 194.
- Pilose.** Hairy, especially with soft hairs.
- Pinna (pl. Pinnæ).** One of the primary divisions of a pinnate or compoundly pinnate frond or leaf.
- Pinnate (leaf).** Compound, with the leaflets arranged on each side of a common petiole. 78, 97.
- Pinnatifid.** Pinnately cleft. 96.
- Pinnule.** A secondary pinna; one of the pinnately disposed divisions of a pinna.
- Pistil,** 99, 104.
- Pistillate.** Provided with pistils, and, in its more proper sense, without stamens. 129.
- Pitcher Plants,** 87.
- Pitted.** Marked with small depressions or pits.
- Placenta,** 104.
- Placentation, types of,** 105.
- Plasmolysis (§ 350),** 153, 256.
- Pleurococcus,** 157, 171.
- Plicate.** Folded into plaits, usually lengthwise.
- Plumose.** Having fine hairs on each side, like the plume of a feather, as the pappus-bristles of Thistles.
- Plumule.** The bud or growing point of the embryo. 18.
- Pod** Any dry and dehiscent fruit.
- Pollen,** 100; grain, 116, 212; growth of, 117; of Pines, 120; tube, 117.
- Pollination by insects,** 121; by water, 120; by wind, 120.
- Polliniferous.** Bearing pollen.
- Pollinium (pl. Pollinia).** A mass of waxy pollen or of coherent pollen grains, as in *Asclepias* and *Orchids*. 136.
- Pollinoid,** 131.
- Polyadelphous.** Having many stamens. 135.
- Polycotyledonous embryo,** 17.
- Polygamous.** Having flowers, some of them perfect, some staminate or pistillate only. 129.
- Polypetalous.** Having separate petals. 111, 131.
- Polyporus,** 196.
- Polysiphonia,** 159.
- Pome.** A kind of fleshy fruit, of which the apple is the type. 149.
- Porose.** Pierced with small holes or pores.
- Posterior.** In an axillary flower, on the side nearest to the axis of inflorescence.
- Præmorse.** Appearing as if bitten off.
- Preserving material,** 242, 255.
- Prickle.** A small spine or more or less slender sharp outgrowth from the bark or rind.
- Procumbent.** Lying on the ground.
- Proliferous.** Producing offshoots.
- Propagation, by gemmæ,** 200; vegetative (by stems), 58.
- Prostrate.** Lying flat upon the ground.
- Proteid matter, in seeds,** 19; test for, 246.
- Protein granules,** 216.
- Proterandry,** 119.
- Proterogynous.** Having the stigma ripe for the pollen before the maturity of the anthers of the same flower. 119.
- Prothallium,** 205, 208, 209.
- Protonema,** 204.
- Protoplasm,** 116, 173, 213, 214.
- Pseudaxillary.** Terminal, but becoming apparently axillary by the growth of a lateral branch.
- Pseudo-costate.** False ribbed, as when a marginal vein or rib is formed by the confluence of the true veins.
- Pteridophytes,** 204.
- Puberulent.** Minutely pubescent.
- Pubescent.** Covered with hairs, especially if short, soft, and downy.
- Pulvinus,** 75; action of, 240.
- Punctate.** Dotted with depressions or with translucent internal glands or colored dots.
- Puncticulate.** Minutely punctate.
- Pungent.** Terminating in a rigid sharp point; acrid.
- Putamen.** The shell of a nut; the bony part of a stone fruit.
- Quadrato.** Nearly square in form.
- Raceme.** A simple inflorescence of pediceled flowers upon a common, more or less elongated axis.
- Racemose.** In racemes, or resembling a raceme.
- Radiate.** Spreading from or arranged around a common center; bearing ray flowers.

- Radical.** Belonging to or proceeding from the root or base of the stem near the ground.
- Radicle.** The initial root of the embryo. Less properly, the stem of the embryo; below the cotyledons (caulicle). 20.
- Rameal.** Belonging to a branch.
- Ramification.** Branching.
- Raphe,** 153.
- Ray.** The branch of an umbel; the marginal flowers of an inflorescence when distinct from the disk.
- Receptacle.** The more or less expanded or produced portion of an axis which bears the organs of a flower (the *torus*), or the collected flowers of a head. 112.
- Recurved.** Curved downward or backward.
- Red Algae,** 159.
- Reduplicate,** 138.
- Reflexed.** Abruptly bent or turned downward.
- Regular.** Uniform in shape or structure. 125.
- Reniform.** Kidney-shaped. 93.
- Repend.** With a slightly uneven and somewhat sinuate margin. 95.
- Reproduction,** 174; asexual, 183; carposporic, 182; oösporic, 182; sexual, 183; zygosporic, 182.
- Resiniferous.** Producing resin.
- Respiration** (Exp. 2), 10, 236; in leaves, (Exp. 12), 66; in germination, 20.
- Resting periods,** 238; in buds, 30; seeds, 19.
- Reticulate.** In the form of network; net-veined. 77.
- Retrorse.** Directed back or downward.
- Retuse.** With a shallow notch at a rounded apex. 94.
- Revolute.** Rolled backward from the margins or apex.
- Rhachis.** The axis of a spike or of a compound leaf. 70.
- Rhizome.** Any prostrate or subterranean stem, usually rooting at the nodes and becoming erect at the apex. 50, 59.
- Rhizopus,** 160, 186.
- Rhombic, Rhomboidal.** Somewhat lozenge-shaped; obliquely four-sided.
- Rib.** A primary or prominent vein of a leaf. 77.
- Ringent.** Gaping, as the mouth of an open bilabiate corolla. 138.
- Rockweed,** 158, 178.
- Root, anatomy,** 229; conduction (Exp. 7), 85; geotropism, 11; gross anatomy, 84; growing point, 39; laboratory studies, 34; primary, 36; origin, 36.
- Root cap,** 39.
- Root hairs,** 22; action of, 38.
- Root pressure,** 233; (Exp.), 35; (Exp.), 249.
- Roots,** absorption, 37; adventitious, 37; aerial, 39; as holdfasts, 42; climbing, 35, 42; duration of, 44; for storage, 43; functions, 37; growth (Exp.), 249; origin of new, 229; parasitic, 40; storage, 35.
- Rootstock.** Same as Rhizome. 59.
- Rostrate.** Having a beak or spur.
- Rosulate.** In the form of a rosette.
- Rotate** (corolla). Wheel-shaped; flat and circular in outline. 131.
- Rotund.** Rounded in outline.
- Rudiment.** A very partially developed organ; a vestige.
- Rudimentary.** But slightly developed.
- Rufous.** Reddish brown.
- Rugose.** Wrinkled.
- Runcinate.** Sharply incised, with the segments directed backward.
- Runner.** A filiform or very slender stolon. 58.
- Rusts,** 192.
- Saccate.** Sac-shaped.
- Sac, embryo,** 118; pollen, 108; fungi, 190.
- Sagittate.** Shaped like an arrowhead, the basal lobes directed downward. 93.
- Silver-shaped** (corolla). Having a slender tube abruptly expanded into a flat limb. 131.
- Samara.** An indehiscent, winged fruit. 150.
- Sap, ascent of** (Exp. 8), 49, 233.
- Saprolegniaceæ,** 188.
- Saprophytes,** 39.
- Scabrous.** Rough to the touch.
- Scape.** A peduncle rising from the ground, naked or without proper foliage.
- Scapose.** Bearing or resembling a scape.
- Scarious.** Thin, dry, and membranaceous, not green.
- Sclerotic cells,** 220.
- Scorpioid** (inflorescence). Circinately coiled while in the bud. 143.
- Seed,** 152; appendages, 155; ecology, 153; origin, 15; processes leading to formation of, 116; study of, 7, 145.
- Seed coats, how removed by seedling,** 22.
- Seedlings, development,** 12, 20.
- Seed plants,** 14.
- Seed rudiments** (ovules), 15.
- Seeds, dispersal,** 153; ejected, 155; from mummy cases, 19; in forest soil, 19; resting state, 19; store of food, 19; vitality, 19.
- Segment.** One of the parts of a leaf or other like organ that is cleft or divided, 96.
- Selaginella,** 166, 207.
- Self-fertilization,** 118; prevented, 119.
- Sensitive Plant** (Exp. 19), 68.
- Sepal.** A division of a calyx. 110.
- Septicidal** (capsule). Dehiscing through the partitions and between the cells. 151.
- Septifragal.** The valves breaking from the septa in dehiscence. 151.
- Septum.** Any kind of partition.
- Sequoias,** 63.
- Serrate.** Having teeth pointing forward. 94.
- Serrulate.** Finely serrate.
- Sessile.** Without footstalk of any kind.
- Setaceous.** Bristlelike.
- Setose.** Beset with bristles.

- Setulose.** Having minute bristles.
Sexual reproduction. 138.
Sheath. A tubular envelope, as the lower part of the leaf in Grasses.
Sheathing. Inclosing as by a sheath.
Shoot, 14; metamorphosed (§§ 87-99), 58.
Shrub. A woody perennial, smaller than a tree.
Sieve tubes, 238.
Silicle. A short silique.
Silique. The peculiar pod of Crucifere.
Silky. Covered with close-pressed, soft, and straight pubescence.
Simple. Of one piece; not compound.
Sinuate. With the outline of the margin strongly wavy. 95.
Sinus. The cleft or recess between two lobes. 80.
"Sleep of Plants," 76.
Sleep movements, 75; of leaf (Exp. 18), 68.
Smooth. Without roughness or pubescence.
Sorus (pl. Sori). A heap or cluster, applied to the fruit dots of Ferns. 205.
Spadix. A spike with a fleshy axis. 126, 141.
Spathe. A large bract or pair of bracts inclosing an inflorescence. 126.
Spatulate. Gradually narrowed downward from a rounded summit. 93.
Spermatophytes, 14.
Spicate. Arranged in or resembling a spike.
Spiciform. Spikelike.
Spike. A form of simple inflorescence with the flowers sessile or nearly so upon a more or less elongated common axis. 141.
Spikelet. A small or secondary spike.
Spine. A sharp woody or rigid outgrowth from the stem.
Spinose. Spinelike, or having spines.
Spirogyra, 157, 173.
Spongy parenchyma, 227.
Sporangium. A spore case. 205.
Spores, 181, 182, 187, 191, 201, 205.
Sporidia, 194.
Sporocarp. The fruit cases of certain Cryptogams containing sporangia or spores.
Sporogonium, 201.
Sporophylls, 212.
Sporophyte, 207.
Spur. A hollow saclike or tubular extension of some part of a blossom, usually nectariferous.
Squamula. A reduced scale, as the hypogynous scales in Grasses.
Squarrose. Having spreading and projecting processes, such as the tips of involucreal scales.
Squarrulose. Diminutively squarrose.
Stability of plant body, 230.
Stamen. One of the pollen-bearing or fertilizing organs of the flower. 108.
Stamens, study of, 100.
Staminate (flower). Possessing stamens and no pistil. 129.
Staminodium. A sterile stamen, or any structure without anther corresponding to a stamen.
Standard. The upper dilated petal of a papilionaceous corolla.
Starch, 216; formation (Exp. 11), 66; in seeds, 19; observation, in laboratory, 250; test, 9.
Stellate, Stelliform. Star-shaped.
Stem, 51; anatomy, 223; ascent of sap (Exp. 8), 49; characteristic features, 46; endogenous, 223; exogenous, 223; geotropism (Exp. 9), 49; growth in, 48; heliotropism, 49 (note); internal structure, 46; laboratory studies, 45.
"Stemless" plants, 56.
Stems, as foliage, 61; creeping, 57; for propagation, 58; growth of, 52; twining, 53.
Sterile. Unproductive, as a flower without pistil, or stamen without an anther.
Stigma, 104, 107.
Stigmatic. Belonging to or characteristic of the stigma.
Stimulus, 240.
Stipe. The stalklike support of a pistil; the leaf stalk of a Fern; the stalk of a Toadstool. 194.
Stipitate. Having a stipe.
Stipular. Belonging to stipules.
Stipulate. Having stipules.
Stipules, 73; as thorns, 73; of Acacias, 73; of the Pea, 69.
Stolon. A runner, or any basal branch that is disposed to root. 58.
Stoliferous. Producing stolons.
Stomates, 199, 228; action, 233.
Storage, 236; in leaves, 70.
Striate. Marked with fine longitudinal lines or ridges.
Strict. Very straight and upright.
Strigose. Beset with appressed sharp straight and stiff hairs.
Strobile. An inflorescence marked by imbricated bracts or scales, as in the Hop and the Pine cone.
Strophiole. An appendage at the hilum of certain seeds.
Style, 104.
Stylopodium. A disklike expansion at the base of a style, as in Umbellifere.
Sub-. A Latin prefix, usually signifying somewhat or slightly.
Subulate. Awl-shaped.
Succulent. Juicy, fleshy.
Suffrutescent. Slightly or obscurely shrubby.
Suffruticose. Very low and woody; diminutively shrubby.
Sugar, in seeds, 19.
Sulcate. Grooved or furrowed.
Sundew, 86.
Superior (ovary). Free from the calyx, 130.
Suspended (ovule). Hanging from the apex of the cell.
Suture. A line of dehiscence.
Syconium, 151.

- Symbiosis, 197.
 Symmetry, deviations from, through light adjustment (§ 118), 74.
 Sympodium, 143.
 Syngenesions, 135.
 Synonym. A superseded or unused name.
 Systematic botany, 253.
- Teguments, 137.
 Teleutospore, 194.
 Temperature, influence on germination, 11.
 Tendrils, 54; sensitiveness, 55.
 Tension of tissues, 230.
 Terete. Cylindrical.
 Terminal. At or belonging to the apex.
 Ternate. In threes. 98.
 Testa, 152; outgrowths of, 145.
 Tetradyamous. Having four long and two shorter stamens. 135.
 Tetraspore, 181.
 Tetragonal. Four-angled.
 Text-books, 244, 255.
 Thallophtes, 169.
 Thallus. In Cryptogams, a cellular expansion taking the place of stem and foliage. 169.
 Throat. The orifice of a gamopetalous corolla.
 Thyrse. A contracted or ovate, and usually compact, panicle. 143.
 Thyrsoïd. Resembling a thyrse.
 Tissues, 221.
 Tissue tension, 230.
 Topics, supplementary, 12, 33, 35.
 Tomentose. Densely pubescent, with matted wool.
 Torose. Cylindrical, with contractions at intervals.
 Torulose. Diminutive of Torose.
 Torus. The receptacle of a flower.
 Transfer of plant food, 236.
 Transfer of water in plant, 232.
 Translocation of organic substances (transfer), 233, 236.
 Transpiration (Exps. 13, 14, 15, 16), 66, 67.
 Trees, Big, of California, 63; longevity of, 63.
 Triandrous. Having three stamens. 135.
 Trichogyne, 181.
 Trichomes, 23, 229.
 Trifoliate. Having three leaflets. 98.
 Trigonous. Three-angled.
 Trimorphous. Occurring under three forms.
 Triquetrous. Having three salient angles, the sides concave or channeled.
 Truncate. Ending abruptly, as if cut off transversely. 94.
 Tuber. A thickened and short subterranean branch, having numerous buds or eyes. 50, 59.
 Tubercle. A small tuber or tuberlike body.
 Tuberiferous. Bearing tubers.
 Tuberous. Having the character of a tuber; tuberlike in appearance.
 Tumid. Swollen.
 Tunicated. Having concentric coats, as an onion.
- Turbinate. Top-shaped; inversely conical.
 Turgidity (§ 108), 73, 230; changes of, 240.
 Twiners, 53.
- Ulothrix, 172.
 Umbel. An inflorescence in which a cluster of peduncles or pedicels spring from the same point. 140.
 Umbellate. In or like an umbel.
 Umbonate. Bearing a stout projection in the center; bossed.
 Undulate. With a wavy surface; repand. 95.
 Ungiculate. Contracted at base into a claw.
 Unifoliate, 98.
 Unisexual. Of one sex, either staminate or pistillate only. 128.
 Urceolate. Hollow and cylindrical or ovoid, and contracted at or below the mouth, like an urn.
 Uredospore, 193.
 Utricle. A small, bladdery, 1-seeded fruit; any small, bladderlike body.
- Vacuoles, 215.
 Valvate. Opening by valves, as a capsule; in aestivation, meeting by the edges without overlapping. 138.
 Valve. One of the pieces into which a capsule splits. 151.
 Vascular. Furnished with vessels or ducts.
 Vaucheria, 158, 175.
 Vegetative propagation, 58, 200.
 Veinlets, 77.
 Veins. Threads of fibro-vascular tissue in a leaf or other organ, especially those which branch (as distinguished from nerves). 77.
 Venation, 70; of leaf, 76.
 Ventral. Belonging to the anterior or inner face of an organ; the opposite of dorsal.
 Ventral suture, 114.
 Venus's Flytrap, 88.
 Vernal. The arrangement of leaves in the bud.
 Verrucose. Covered with wartlike elevations.
 Versatile (anther). Attached near the middle, and turning freely on its support. 135.
 Verticillate. Disposed in a whorl. 90.
 Vesicle. A small bladder or an air cavity.
 Vesicular, Vesiculose. Composed of or covered with vesicles.
 Villous. Bearing long and soft hairs.
 Virgate. Wand-shaped; slender, straight, and erect.
 Vitality of seeds, 19.
- Water, in germination, 20.
 Water Mold, 161, 188.
 Whorl. An arrangement of leaves, etc., in a circle round the stem, 90.
 Wing. Any membranous or thin expansion

bordering or surrounding an organ; the
lateral petal of a papilionaceous corolla.
Wood , annual layers, 224; structure of, 48,
219.
Woolly . Clothed with long tortuous or
matted hairs.
Xerophytes , 65.
Xylene , 222. | Yeast , 160.
Yeasts , 185.

Zoösporangia , 178.
Zoösporangium , 189.
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